Geologic Report for the Gulf of Alaska Planning Area

OCS Report
MMS 92-0065

U.S. Department of the Interior
Minerals Management Service
Alaska OCS Region

Front Cover:

Unloading oil barrels at the Chilcat Oil Company Refinery at Katalla, Alaska. Petroleum was produced from the field from 1901 to 1932. This picture was probably taken around 1911 when Katalla oil was transported and sold in barrels to the Copper River railroad project. The refinery also supplied fuel to the fishing fleet. The light, paraffinic oil was reportedly so clean that it did not stain wooden barrels.

Back Cover:

Cable tool rig drilling in the Katalla Oil Field, Gulf of Alaska. The walking beam that raised and dropped the bit extends through the wooden wall protecting the derrick floor.

Credits:

The historical photographs on the covers and on pages 144, 153, and 181 are from the Barrett Willoughby Collection and are reprinted with the permission of the Alaska and Polar Regions Department of the Elmer E. Rasmuson Library at the University of Alaska Fairbanks. The photograph of Alaska's first oil well (page 229) is used by permission of the Cordova Historical Society of Cordova, Alaska. Florance Barrett Willoughby was a noted Alaskan author who wrote novels, short stories, biographies, travel books, and magazine articles. Her father, Martin Barrett, was captain of a coastal trading schooner. One of her historical/romance novels, Spawn of the North, *was made into a movie in 1937. Her book on Ben Eilson, the pioneer Alaskan aviator, was published in 1959, a year after her death.*

The photographs may have been taken by Florance Willoughby, by her father, by her husband, W. T. Prosser, a mining engineer who wrote several papers on the petroleum industry at Katalla, by O. L. Willoughby, an oil well driller who may have been related to her stepfather, or by the Sitka photographer, E. W. Merrill, who was the subject of one of her books. The photographs may also have been taken by R. W. Moss, a photographer noted for his superb studies of Gulf of Alaska Indians. Mr. Moss worked in both Katalla and Cordova as a draftsman for The Copper River and Northwestern Railroad, and may have worked for Clark Davis, manager of the Alaska Petroleum and Coal Company. He spent several days at the Chilcat oil camp in September 1908. The photograph of the first well was probably taken by Einar Evans (1902).

The masthead of "The Katalla Herald," published from 1907 to 1909, proclaimed Katalla to be "the coming metropolis of Alaska, where the rails meet the sails" (p. 154, 230, 246, 301 and 302). Abundant fish, timber, coal, copper, and gold, and the promise of significant accumulations of oil made such claims quite plausible. F. J. A. Strong, the editor and a tireless and flamboyant promoter, was later appointed Territorial Governor of Alaska by President Woodrow Wilson. "The Katalla Herald" is available on microfilm from the University of Alaska Archives, as are "Alaska's Magazine" and "Alaska-Yukon Magazine," additional sources of the historical clippings used in the collages (p. 2, 44, 62, 182, 188, 271, and 274).

The history of the Gulf of Alaska area is discussed in The Copper Spike *by Lone E. Janson (1975) and* The Alaska Journal—a 1981 Collection, *Virginia McKinney, editor. John F. C. Johnson of the Chugach Alaska Corporation provided a great deal of historical data concerning Thomas George White.*

The pen and ink illustrations on pages 4, 244–245, and 272 were drawn from slides by Jean Thomas of the U.S. Minerals Management Service. The composite drawing (p. 142–143) of the Katalla Oil Field at Katalla Slough is based on photographs provided by the Cordova Historical Society of Cordova, Alaska, and the Elmer E. Rasmuson Library, University of Alaska Fairbanks. The log cabin, tents, derrick, and sailboat (left page) are from the earliest period of development; the oil storage tank and barge are from a later period. The Katalla field produced from 1901 to 1932. Production at the Chilcat Oil Company Refinery ceased after the refinery was destroyed by fire. Petroleum exploration, onshore and offshore, continues in the area today.

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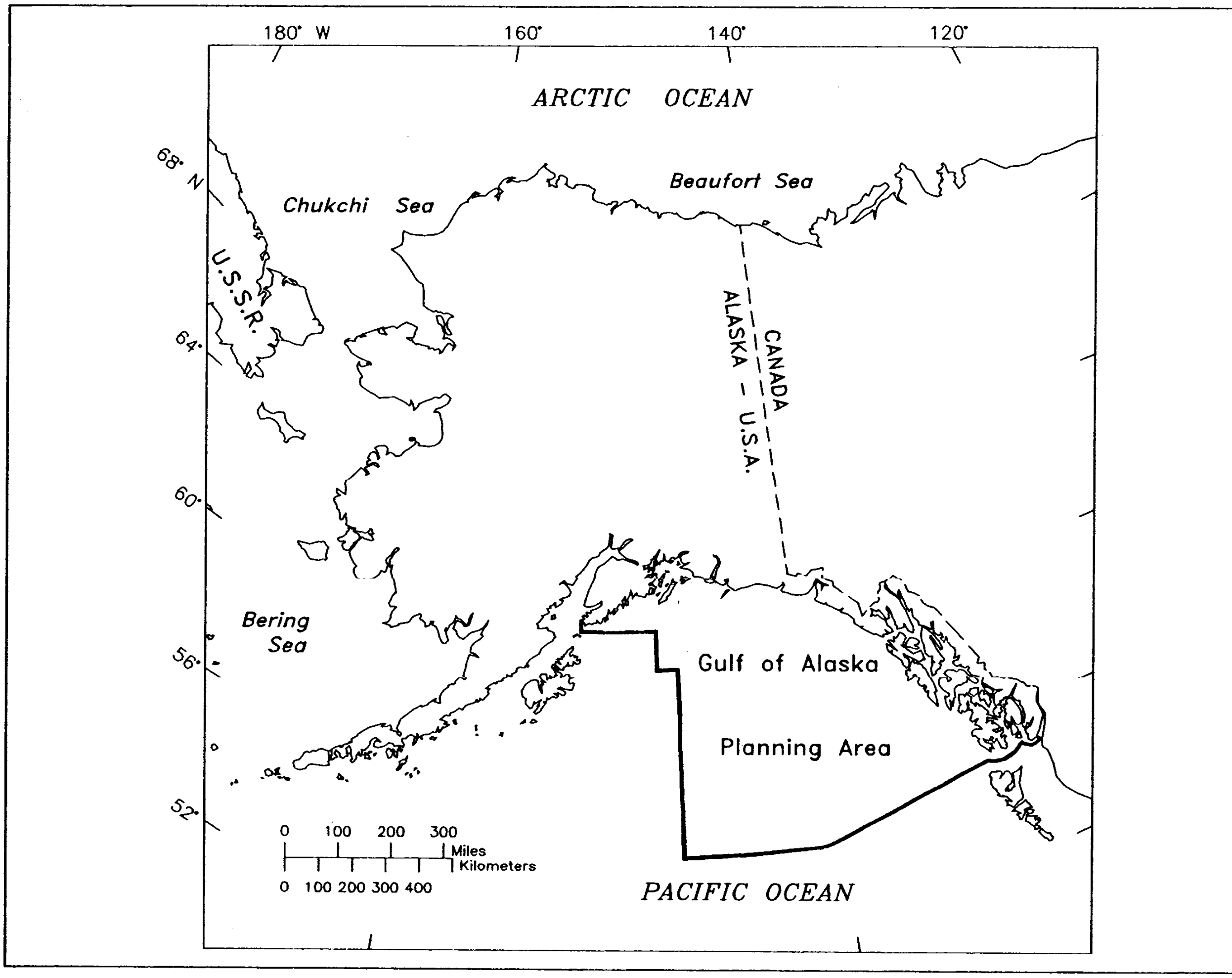
Photographic credits are located inside the front cover.

Introduction

This report is a summary of the regional geology, geologic history, petroleum potential, and environmental characteristics of the Gulf of Alaska Planning Area (fig. 1). The interpretations are based on offshore seismic reflection lines, subsurface data obtained from onshore and offshore wells, dredge samples, shallow core holes, and geologic investigations of outcrops onshore. The primary emphasis, however, is on 13 wells drilled offshore between 1975 and 1983.

Despite the lack of exploration success thus far, industry interest in the Gulf of Alaska area as a potential petroleum province remains high. A proposed offshore lease sale (Sale 158) is scheduled for 1995 and another in the Middleton Island area may be added to the next 5-year lease sale schedule.

Figure 1. Location of the Gulf of Alaska Planning Area. Figure 68 shows the planning area in more detail. Figures 67–69 show lease sale areas and proposed lease sale areas.



KATALLA HERALD

EXPECTS TO GET GUSHER

The new oil well of the Alaska Petroleum & Coal company is now down 1600 feet in an oil shale, and general manager Clark Davis says he expects to have a gusher in another week. The indications are exceedingly favorable. Between 1200 and 1300 feet a stratum of oil sand was encountered. It was so hard, in fact that very slow progress was made in getting through it. Then oil shale was struck at 1300 feet and the drilling now is much easier and the well is being sunk at a rapid rate.

The Pacific Coal and Oil Co's well is producing about 40 barrels a day. The product is being used by the Katalla company as fuel for steam shovels and other purposes. This well was closed for three years, and it is said that the output could be materially increased by "shooting" it so that the accumulation of parafine wax could be got rid of.

BIG FLOW FINE OIL

Mirror Slough Will Be a Busy Place

Out at Mirror slough the timbers are ready for the erection of the Alaska Coal-Oil company's rig on the Barrett-Carless-Sinclair property. The machinery is on the steamer Lindsay and will be shipped from Cordova to Mirror slough.

Col. Barrett, who came in from the slough the other day, says that ... has been dug in the bedr... seepage on the propert... two and a half barrels a... procured, and there is amp... believe that this section is o... substantial oil developments,

In this connection it may ... that Clarence Cunningham a... have organized in Seattle, a ... which will at once begin drillin... at Martin river. The incorpor... called the Alaska Commercial O... pany, and a dispatch says tha... company has been organized fo... purpose of shipping crude ... talla. The dispatch ... pany owns ...

WANT BIG EXHIBITS

Of The Coal And Oil Of Katalla

...dge Britton is in receipt of a let... from J. C. McBride, Alaska-Yukon... Exposition commissioner for Al... relative to securing good coal and... exhibits from this secti... Mr. Mc... says: ... are very ... ntity ...

OIL DRILLING AT BERING LAKE

...ng for oil at Bering lake, which ...g prosecuted by the Anglo-...can Oil Company, of which Capt. ... Rathbone is manager, is pro...ing satisfactorily, according to a ...ement made by the latter, who was ...own Wednesday. The hole is now ...vn 1450 feet. The formation is hard ...d the oil indications are considered ...tirely favorable. The work of drill...ng was suspended a portion of this week in order to put down casing.

Surveyor Hubboll is surveying coal lands for the Pacific Oil & Coal Company, and he is daily expecting ... veyor Watson from Valdez to assist him.

ALASKA, WHERE THE RAILS MEET THE SAILS

...er they ... Bertha. ... company, ... he is con...

OIL IS THE LEADER

OIL WELL IS DOWN 1600 FEET

...he Anglo-American Coal & Oil Com... of which Capt. Rathbone is gen... manager, is making good prog... sinking for oil on Bering lake. ...s been struck in abundance, for ...of nearly 1100 feet; salt water ...nd at 1400 feet, and oil shale ...ing through the salt water. ... is now down some 1600 feet, Rathbone says that he will ... to a depth of 3000 feet, un... ruck at a lesser depth. He ... boring operations all win... ...w hole will probably be ...hree-quarters of a mile ...nt on ... higher ridge ...apt. Rathbone expresses ...nfidence in the Bering

THE NEW PENNSYLVANIA — THE NEW MONTANA

Katalla Townsite

COMING METROPOLIS

...minal of Two Railroads and in Pre... Most Rapidly Growing City on the ...qual in Extent and Quantity to Penn... a few miles in the Interior. Oil of ...rade abounds. The vast Deposits of ...ley, the Most Extensive in the World, ...alla.

...ED BUSINESS INVESTMENT OPPORTUNITY

...SALE ONLY BY THE OWNERS

ALASKA ...EUM ...OMPA...

1700 feet is only 30 degrees. ...fore figures that at 2200 fee... will disappear and beneath ... found the immense oil dep... which he is confident th... abounds.

The Pacific Coal & Oil ... well in the same section is ... twenty-five or thirty barr... which is being used by th... Company as fuel for one of ... shovels. The oil found there ... crevice which, when struc... years ago at a depth of ... spouted 100 feet or more int... taking tools, piping, etc. wi... wells gather parafine wax, ... are "shot" from time to tin... ing is accomplished by nin... glycerine in the bore and th... ing it. By this means the ... rock is shattered, loosenin...

Several Rigs Will Soon Be at Work

What with projected railroad con...ruction, coal development and drill...g for oil, Katalla promises to be the ...stributing center for a quite busy and ...tensive section, this season. ...ave been so many disappoint... ...road building to the ...onment, that ...

KATALLA EXHIBITS

Of Coal And Oil a... Exposition

...Katalla will h... ...and oil ...

WILL PIPE OIL TO KANAK ISLAND

A. G. McClarty of Vancouver, B. C., who was here a short time ago exam...nds sold through Wm. Cheney ...orthern Oil company, expects ...he oil—when it is struck—to ...n Kanak island from whence ...e taken to its destination in ...eamers. Mr. McClarty, who ... the people he represents ...ll kinds of money, including ...immediately after his arrival ...posed to build a breakwater ...onto. After a few days spent ...tigation however, he decided ...ipe line and Kanak were more ...and much less costly.

...cClarty says his company will ...illing for oil early this spring.

Will Drill For Oil

C. F. Sinclair, who is in town Seattle after an absence of s... months, has completed the organi... of a company for the purpose of d... for oil on property at Mirror s... in which he is interested. Mr. Si... will probably secure the Cunni... oil rig now at Cave point. Mr. ...clair however says that he will n... gin work until he is in position to at least three or four holes, and he hopes to do, beginning this

Future of Katalla Assured

No Thinking Man Can Get Away From the Fact That

Katalla Will Be the Greatest Town In Alaska

Katalla is the termini of two great railroad systems now building to the coal fields and the rich copper fields of the great Copper river. Already we have a flourishing town of $250,000 taxable property. The First Bank of Katalla has a paid up capital stock of $25,000.

Lots For Sale on Easy Terms

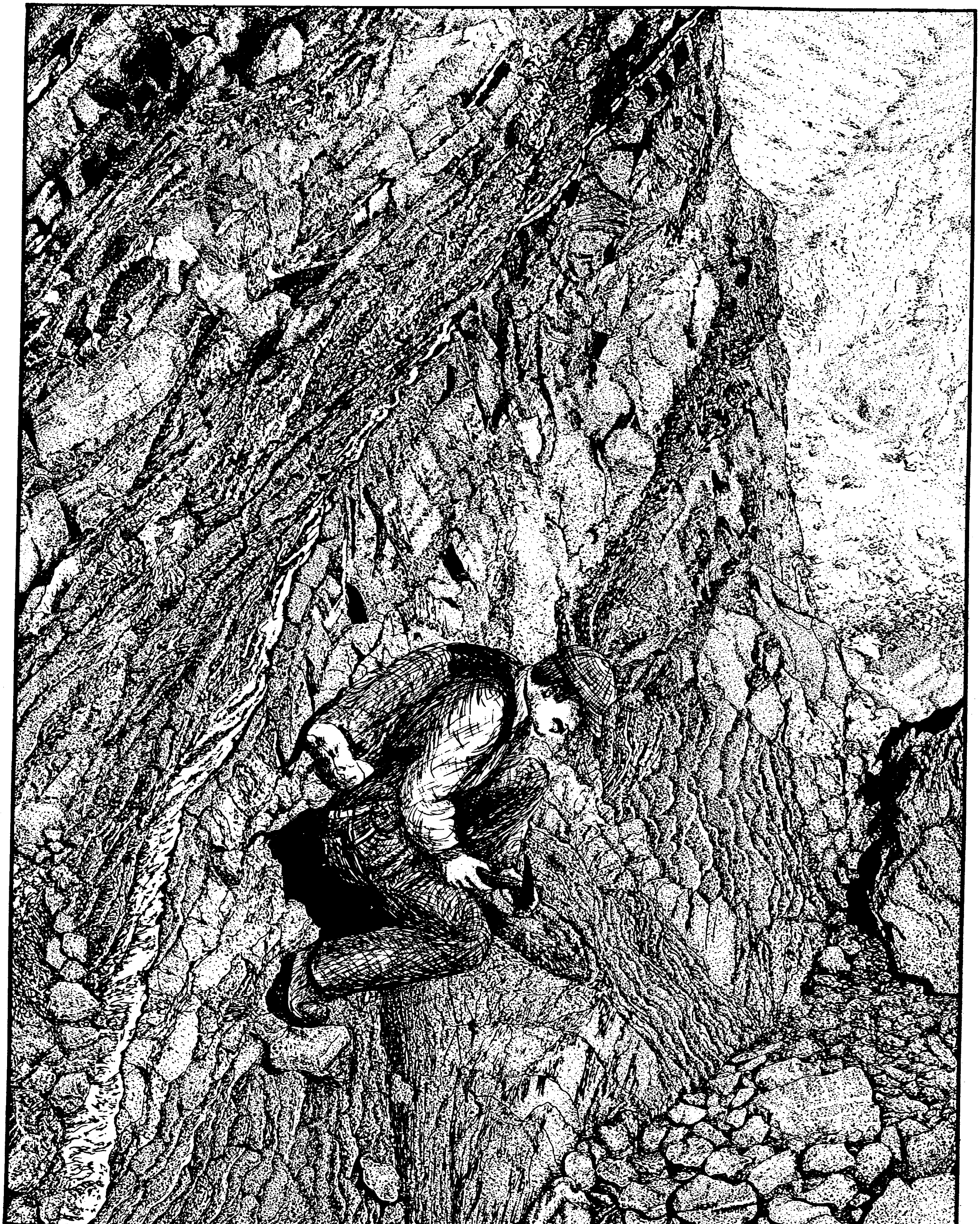
Alaska Petroleum & Coal Company,

SOLE AGENTS WRITE US

...plications For Patents

...e Cunningham and associates ...n begin the publication of ...ons for patents to eighteen ...f land in the Stillwater region, ...g about 1,400 acres. This ...n mineral, and was located ... provisions of the soldiers' ... homestead entry law.

Part I: Regional Geology



1. Framework Geology

Introduction

The Gulf of Alaska Planning Area includes an 800-mile segment of the offshore continental margin from the Amatuli Trough southwest of Montague Island on the west, to Dixon Entrance at the U.S.-Canada border to the southeast (fig. 2). Within this region, the continental shelf ranges from less than 15 miles in width adjacent to Baranof Island to greater than 60 miles near Middleton Island. Seaward of the shelf margin, the planning area includes a portion of the bathyal Pacific basin.

The present geologic setting of the northern Gulf of Alaska involves three types of tectonic regimes: (1) an area of convergence west of Kayak Island where the Pacific plate is subducting beneath continental crust of the North American plate at the Aleutian megathrust, (2) translation along southeast Alaska where the Pacific plate is being transported northward with respect to the North American plate, and (3) a transitional margin from Kayak Island to Cross Sound, intermediate between the zones of convergence and transform (fig. 2).

Geologic Setting

The geologic setting of the northern Gulf of Alaska continental margin and the adjacent onshore area of southern Alaska is the result of a complex history of late Mesozoic and Cenozoic crustal plate interactions. South of the Denali fault, the Alaska continental margin is composed of amalgamated allochthonous tectonostratigraphic terranes (fig. 3). The principal terranes consist of, from north to south, the (1) Wrangellia and Peninsular terranes, (2) Alexander terrane, (3) Chugach terrane, (4) Ghost Rocks terrane, (5) Prince William terrane, and (6) the recently defined Yakutat terrane.

The Wrangellia, Peninsular, and Alexander terranes are situated north of the Border Ranges fault and are composed of variably metamorphosed rocks of Mesozoic and older age (fig. 3). Strata within these terranes were intruded by Paleozoic and younger plutonic rocks (Jones and others, 1986). These terranes, termed "microplates" by Plafker (1987), are made up predominantly of older oceanic plateaus and arcs that were accreted to the continent prior to the Cenozoic to become the backstop against which younger terranes were accreted (Bruns, 1988).

Opposite page. Minerals Management Service geologist sampling steeply dipping sedimentary rocks, Gulf of Alaska.

The Chugach terrane in southern Alaska is bounded by the Border Ranges fault to the north and the Resurrection and Contact fault systems to the south, and is represented by an arcuate belt of accretionary rocks comprising three distinct assemblages (Plafker and others, 1977; Plafker, 1987): (1) a coherent volcaniclastic flysch assemblage of Late Cretaceous age, (2) a Late(?) Jurassic to Early Cretaceous melange assemblage containing volcanic, metasedimentary, and plutonic rocks, and (3) minor Early(?) Jurassic or older blueschist-greenschist facies metamorphic rock. The Chugach terrane has been highly folded and faulted and forms the core of the rugged Chugach-St. Elias Mountain Range.

The Ghost Rocks terrane comprises a narrow sliver of rocks situated between the Chugach and Prince William terranes and extending southwestward from the Resurrection Peninsula area of the Kenai Peninsula (fig. 3). The Ghost Rocks terrane is composed of extrusive and intrusive rocks, deep-water oceanic sediments, and highly disrupted melange (Byrne, 1982, 1984; Plafker, 1987). These rocks represent a Cretaceous to Paleocene subduction complex that originated at a more southerly latitude and was accreted to the continental margin by about 62 Ma (early Paleocene) (Byrne, 1984; Plafker and others, 1989b).

The Prince William terrane lies seaward of the Ghost Rocks and Chugach terranes, between the Contact fault system and the Aleutian subduction zone (fig. 3). To the northeast, it is bounded by the Kayak zone and its onshore extension. The Prince William terrane consists of a basement complex composed of the Orca Group and an overlying offshore sequence of Cenozoic clastic sedimentary strata. The Orca Group is a deformed and

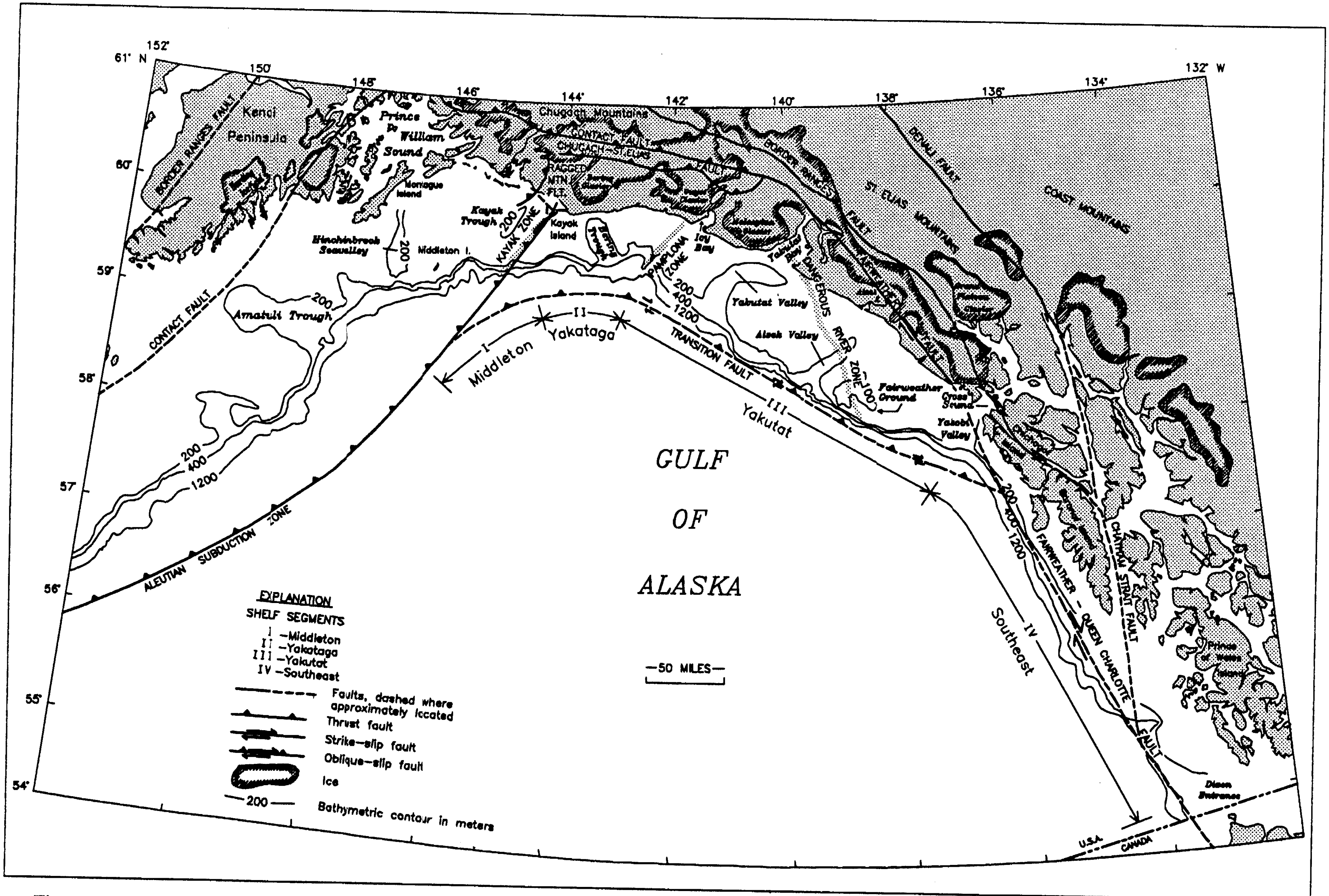


Figure 2. Geologic framework of the northern Gulf of Alaska region, including major faults, selected physiographic and bathymetric features, and regional subdivisions of the continental margin. The bathymetry is generalized from Chase and others (1970), Atwood and others (1981), Seeman (1982), and Carlson and others (1985), Hood and Zimmerman (1986).

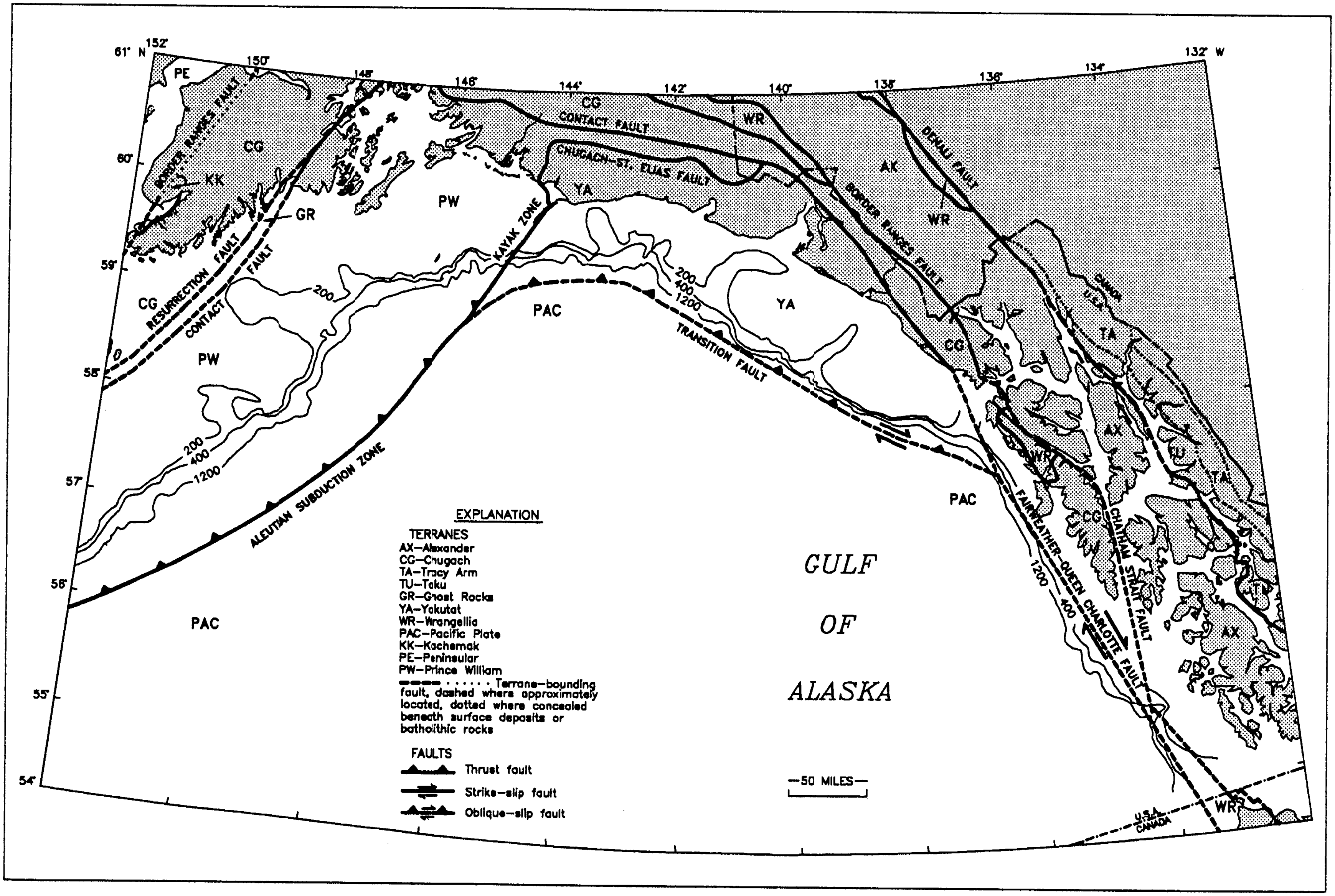


Figure 3. Tectonostratigraphic terranes and terrane boundaries in the northern Gulf of Alaska region. The terranes and boundaries are adapted from Jones and others (1986) and Monger and Berg (1987).

metamorphosed late Paleocene to middle Eocene deep-sea fan complex that is interbedded with oceanic volcanic rocks and pelagic sediments (Winkler, 1976; Winkler and Plafker, 1981; Dumoulin, 1987).

The Yakutat terrane, the most recently arrived allochthonous terrane, is situated seaward of the Chugach-St. Elias and Fairweather fault systems (fig. 3). It is bounded to the west by the Kayak zone and its onshore extension, and on the south by the Transition fault system. The Yakutat terrane is believed to be presently moving north with the Pacific plate and is colliding with and subducting beneath southern Alaska (Rogers, 1977; Plafker and others, 1978a; Bruns, 1983a, b, 1985b; Plafker, 1987). Basement rocks of the Yakutat terrane consist of upper Mesozoic flysch and melange east of the Dangerous River zone, a probable Paleogene shelf edge (Bruns, 1985b). West of the Dangerous River zone, the basement is composed of early Eocene and possible Paleocene oceanic crust. Rocks overlying the basement are predominantly Paleocene(?) through Quaternary clastic sedimentary strata.

Structural Segments of the Gulf of Alaska Continental Margin

For discussion purposes, the continental margin within the Gulf of Alaska Planning Area is subdivided into four segments along fundamental geologic and tectonic boundaries (fig. 2). These segments are, from west to east, the Middleton, Yakataga, Yakutat, and Southeast structural segments of the continental margin.

Middleton Segment

The Middleton segment of the Gulf of Alaska continental margin reflects convergence of the Pacific plate and the overlying Yakutat terrane with the eastern end of the Prince William terrane (figs. 2 and 3). The Middleton segment is bordered on the east by the Kayak zone, on the south by the Aleutian megathrust, and merges with strata of the Kodiak planning area to the west.

The Kayak zone, the boundary between the Middleton and Yakataga segments of the continental margin, denotes a major zone of convergence and structural shortening (Bruns, 1979, 1982b). To the east, the leading edge of the Yakutat terrane is colliding with the Prince William terrane and inboard terranes of southern Alaska. Vertical displacement of Cenozoic strata on adjacent sides of the Kayak zone is estimated to be greater than 3.5 miles (Bruns, 1985b).

The Middleton continental shelf shows evidence of extensive Pleistocene glaciation. South of Montague Island, the Hinchinbrook Seavalley exhibits steep-sided walls and a U-shaped cross section, reflecting seaward scouring and erosion by a major glacial lobe (Atwood and others, 1981) (fig. 2). The Kayak Trough, located adjacent to the west coast of Kayak Island, provides additional evidence for large-scale Pleistocene glaciation on the continental shelf. However, neither the Hinchinbrook or Kayak Seavalleys have associated canyons seaward of the shelf break, suggesting that the deposition of glacial sediments was primarily limited to the continental shelf.

At Middleton Island, approximately 3,900 feet of early Pleistocene and possibly latest Pliocene glaciomarine strata are exposed on a structural high near the shelf edge (Plafker and Addicott, 1976; Mankinen and Plafker, 1987). Middleton Island has undergone significant faulting, tilting, and uplift during the late Pleistocene, and reflects the effects of compressional tectonics on this segment of the continental margin. The presence of uplifted marine terraces (Plafker and Rubin, 1978) and the uplift of the island during the 1964 Alaska earthquake (Plafker, 1969) indicate that tectonic deformation continues to the present.

Yakataga Segment

The Yakataga segment of the continental margin, situated between the Kayak zone and the Pamplona zone, is the more structurally complex portion of the Yakutat terrane (fig. 2). Strata are deformed by northeast-trending folds and associated thrust faults. This deformation is part of a larger zone of tectonically controlled folding and thrusting extending from the Fairweather fault in the vicinity of Yakutat Bay to the southern end of the Kayak zone proximal to the Aleutian subduction zone.

The eastern boundary of the Yakataga shelf segment, the Pamplona zone, marks the boundary between structurally deformed Cenozoic strata to the west and rocks of the Yakutat segment to the east. Folds and faults of the Pamplona zone reflect the easternmost limit of deformation and structural shortening as the Yakutat terrane collides with inboard terranes of southern Alaska. Folded strata within this zone disrupt the seafloor and are expressed as a prominent bathymetric high. To the northeast, the Pamplona zone extends onshore to the Samovar Hills area (Plafker, 1987).

The continental shelf between the Kayak zone and Icy Bay dips gently seaward, with an average gradient of 0.3 degrees (Atwood and others, 1981). A single bathymetric feature, the Bering Trough, transects this portion of the shelf margin. This broad, U-shaped trough begins about 3 miles seaward of the Bering Glacier and extends to the continental shelf break 35 miles to the south. Meltwater streams draining the Bering Glacier are presently transporting glacial flour into the trough, which has accumulated a veneer of Holocene glaciomarine sediment (Carlson and others, 1982).

Yakutat Segment

The Yakutat segment of the northern Gulf of Alaska continental margin, extending from the Pamplona zone eastward to Cross Sound, encompasses the eastern, predominantly undeformed portion of the Yakutat terrane (fig. 2). This portion of the Yakutat terrane, termed the "Yakutat block" by Rogers (1977) and Plafker and others (1978d), falls within the eastern half of the tectonic transition zone. The Yakutat block is bounded by the Chugach-St. Elias and Fairweather-Queen Charlotte fault systems to the north and east, the Transition fault system to the south, and thrust faults and folds of the outer Pamplona zone to the west (fig. 2).

The southern boundary of the Yakutat block, the Transition fault system, separates Mesozoic and younger rocks of the Yakutat terrane from the Oligocene age oceanic crust of the Pacific plate (Naugler and Wageman, 1973; Schwab and others, 1980; Plafker, 1987). The Transition fault is proposed to have been an active tectonic boundary largely prior to Pliocene time, and was probably created by transform tectonism (Bruns, 1983a). Fairweather Ground, a shelf-edge high along the southeastern margin of the Yakutat block, may have been uplifted during Pliocene and Quaternary time in response to minor compressive stress along the adjacent segment of the Transition fault system (Bruns, 1985b) (fig. 2).

Onshore, between Icy Bay and Cross Sound, rugged, glaciated mountains reflect tectonic convergence between the leading edge of the Yakutat terrane and previously accreted terranes. Piedmont glaciation during Pleistocene time resulted in the formation of two large U-shaped valleys that extend seaward across the continental shelf to the shelf edge (Carlson and others, 1982) (fig. 2). The largest of these glacially carved valleys, the Yakutat Valley, extends offshore from Yakutat Bay for a distance of 87 miles. To the east, the smaller, narrower Alsek Valley begins seaward of the Alsek River and extends southwestward to the shelf break.

Southeast Segment

The Southeast segment of the Alaska continental margin extends from Cross Sound southeastward 300 miles to Dixon Entrance in the eastern Gulf of Alaska. This segment of the continental margin is located adjacent to and within the late Cenozoic transform zone between the Pacific and North American lithospheric plates. The rate of movement along this transform boundary, the Fairweather-Queen Charlotte fault system, is estimated to be approximately 6 cm/yr at the present time (Minster and Jordan, 1978).

Southeast Alaska Islands and the adjacent continental mainland are underlain by an assemblage of lithologically diverse tectonostratigraphic terranes that have been displaced along major Cenozoic transform zones (fig. 3). Included in this assemblage are the Chugach, Alexander, Wrangellia, Taku, Tracy Arm, and adjacent Yakutat terranes (Monger and Berg, 1987). Rocks composing these terranes are dominantly Paleozoic and Mesozoic in age. The geology and tectonostratigraphy of rocks underlying the offshore continental margin of southeast Alaska must be inferred predominantly from nearby exposed onshore geology. Basement strata underlying the shelf may be correlative with rocks of the displaced terranes exposed on the adjacent onshore margin (Bruns and Carlson, 1987). West of Chichagof and Baranof Islands, the basement probably consists of Chugach terrane rocks. South of the Chatham Strait fault, the Alexander terrane likely composes the basement under the inner shelf, and Wrangellian strata are inferred to underlie the outer shelf.

The continental shelf between Cross Sound and Dixon Entrance is from 15 to 30 miles wide. North of the entrance to Chatham Strait and south of Yakobi Valley, a glacially carved seavalley located seaward of Cross Sound, the shelf is essentially flat with a dip of 0.2° to 0.4° toward the shelf break. Between the southern tip of Baranof Island and Dixon Entrance, the undulating shelf topography is incised by a deep seavalley and displays numerous linear fault scarps (see chapter 4).

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2. Geologic History

Introduction

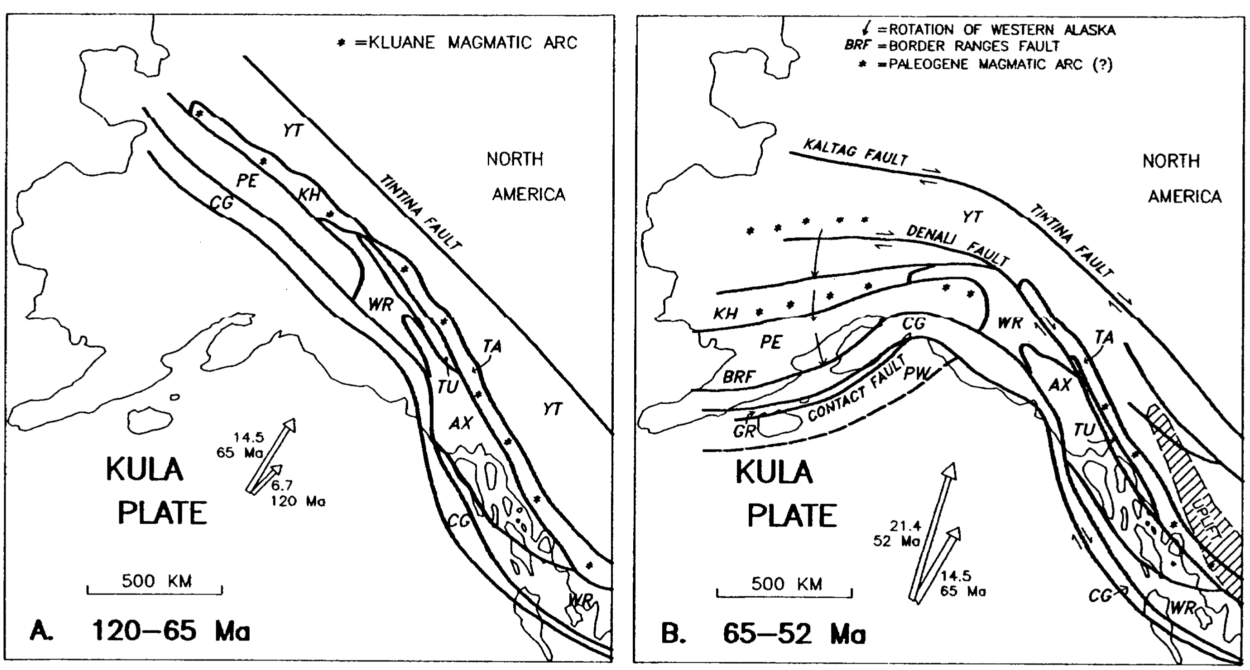
Southern Alaska and the Canadian Cordillera are composed of allochthonous tectonostratigraphic terranes that arrived at their present positions along the continental margin of North America during the Mesozoic and Tertiary (Jones and others, 1978; Coney and others, 1980; Jones and others, 1986; among others). Various courses of travel and arrival times have been proposed for these exotic terranes based on paleomagnetic, structural, petrologic, biogeographic, and plate movement studies. Since accretion, the terranes have been altered by structural deformation, volcanism, plutonism, and regional and local metamorphism. An understanding of the geology and history of the terranes underlying the Gulf of Alaska continental margin is necessary for a thorough assessment of the hydrocarbon potential of the area.

The following geologic model for the late Mesozoic and Cenozoic evolution of southcentral and southeastern Alaska is based in part on studies by Bruns (1983a, 1985b), Nye (1983), Plafker (1987), Plafker and others (1989b), and Wallace and others (1989) (figs. 4 and 5).

Mid-Cretaceous through Late Cretaceous (120-65 Ma)

By mid-Cretaceous time, rocks composing the Wrangellia, Alexander, Peninsular, and Taku terranes,

Figure 4. Inferred geologic evolution of southcentral and southeastern Alaska, 120-65 Ma (A), and 65-52 Ma (B). The tectonic setting and evolution were modified from Plafker and others (1989b). The tectonostratigraphic terranes shown are YT, Yukon-Tanana; TA, Tracy Arm; TU, Taku; AX, Alexander; WR, Wrangellia; PE, Peninsular; KH, Kahiltna; CG, Chugach; GR, Ghost Rocks: and PW, Prince William. Terrane boundaries and divisions are adopted from Jones and others (1987), Monger and Berg (1987), and Plafker (1987). Relative plate motions and rates are from Engebretson and others (1985). The time scale is from Harland and others (1990). The coastline of Alaska is displayed for reference purposes only and does not imply the actual location of the terranes with respect to the present-day coastline of North America for the time period represented. The rates of plate movement are expressed in centimeters per year (cm/yr).



and part of the Chugach terrane were amalgamated into a composite "superterrane" located south of the North American continental margin (Hillhouse and Gromme, 1984; Plafker and others, 1989a, 1989b; Wallace and others, 1989). A reorganization of oceanic plates in the northwest Pacific basin occurred during Aptian to Campanian time, resulting in the fragmentation of the Farallon plate and the formation of the Kula plate at about 85 Ma (Engebretson and others, 1985). The movement of the Kula plate displaced the composite superterrane northeastward and resulted in the docking of this terrane against the North American continent during Late Cretaceous time (fig. 4, part A). This docking is documented by extensive coeval magmatism (Kluane Arc) and metamorphism along the suture between the superterrane and inboard terranes in southern Alaska and British Columbia (Plafker and others, 1989b). Arc-derived volcanogenic sediments, possibly in part from the Kluane Arc, were deposited in deep water seaward of the continental margin during Campanian to Maastrichtian time (83-65 Ma). Subsequent accretion of these deep-water trench sediments to the continental margin is recorded in strata of the Valdez Group and its correlatives (Little and Naeser, 1989), which comprise the outboard, younger component of the Chugach terrane.

Paleocene to late early Eocene (65-52 Ma)

The early Paleogene along the northern and eastern Gulf of Alaska continental margin was marked by rapid northeastward underthrusting of the Kula plate beneath North America (Engebretson and others, 1985) (fig. 4, part B). A consequence of this rapid underthrusting was extreme uplift and erosion of the Coast Mountains of British Columbia (Hollister, 1979). In western Alaska, two adjacent magmatic belts developed, possibly in response to oblique underthrusting of the margin by the Kula plate (Moll and Patton, 1982; Plafker and others, 1989b). The Ghost Rocks terrane, a Cretaceous to Paleocene subduction complex consisting of volcanics, intrusives, and mélange (Byrne, 1982), was accreted to the southern margin of the Chugach terrane by 62 Ma (Moore and others, 1983). Paleomagnetic studies suggest that rocks of the Ghost Rocks terrane were transported northward up to 25° from their site of origin (Moore and others, 1983; Plumley and others, 1983). Outboard of the Ghost Rocks and Chugach terranes, the Prince William terrane was formed during the late Paleocene to middle Eocene by progressive accretion of deep-sea fan sediments and interbedded volcanics (Orca Group) (Winkler, 1976; Plafker and others, 1985). Studies by Winkler and Plafker (1981) indicate that accretion of basement rocks of the Prince William terrane was completed by about 51 Ma.

Western Alaska experienced counterclockwise rotation beginning in early Eocene time (fig. 4, part B) (Moore and Connelly, 1977; Winkler and Plafker, 1981; Little and Naeser, 1989). The rotation resulted in the oroclinal bending of terranes in central and southern Alaska, and may have caused dextral strike-slip faulting on several major interior faults (Little and Naeser, 1989). The early to middle Eocene was a time of active transcurrent faulting on the Tintina, Kaltag, Denali, and possibly other inboard intracontinental faults (Lanphere, 1978; Fuchs, 1980; Gabrielse, 1985).

Late early to early middle Eocene (52-48 Ma)

The counterclockwise rotation of western Alaska continued through middle Eocene time (fig. 5, part A) and was accompanied by sustained strike-slip movement on major intracontinental faults (Lanphere, 1978; Plafker, 1987; Plafker and others, 1989b). Plafker (1987) suggested that up to 112 miles (180 km) of dextral offset occurred on the Chatham Strait fault during this period, which initiated the formation of the proto-Dangerous River zone along the outer continental margin. East of Kodiak Island, a major early Eocene (51±3 Ma) geothermal event resulted in extensive plutonism and high-temperature metamorphism of sediments of the Chugach and Prince William terranes (Winkler and Plafker, 1981; Winkler and others, 1981; Nelson and others, 1985; Plafker and others, 1985). This thermal episode may have been initiated by subduction of the Kula-Farallon ridge (Marshak and Karig, 1977; Helwig and Emmet, 1981; Moore and others, 1983). However, this does not agree with plate reconstruction models for the North Pacific basin by Engebretson and others (1984, 1985), which place the Kula-Farallon ridge farther to the south during the early Eocene, probably adjacent to Washington or British Columbia.

By the beginning of the middle Eocene, accretion of deep-marine sediments and associated oceanic volcanic rocks composing the basement complex of the Prince William terrane was essentially complete (Plafker and others, 1985). Early Paleogene clastic sediments were deposited locally as fans and turbidites in deep water

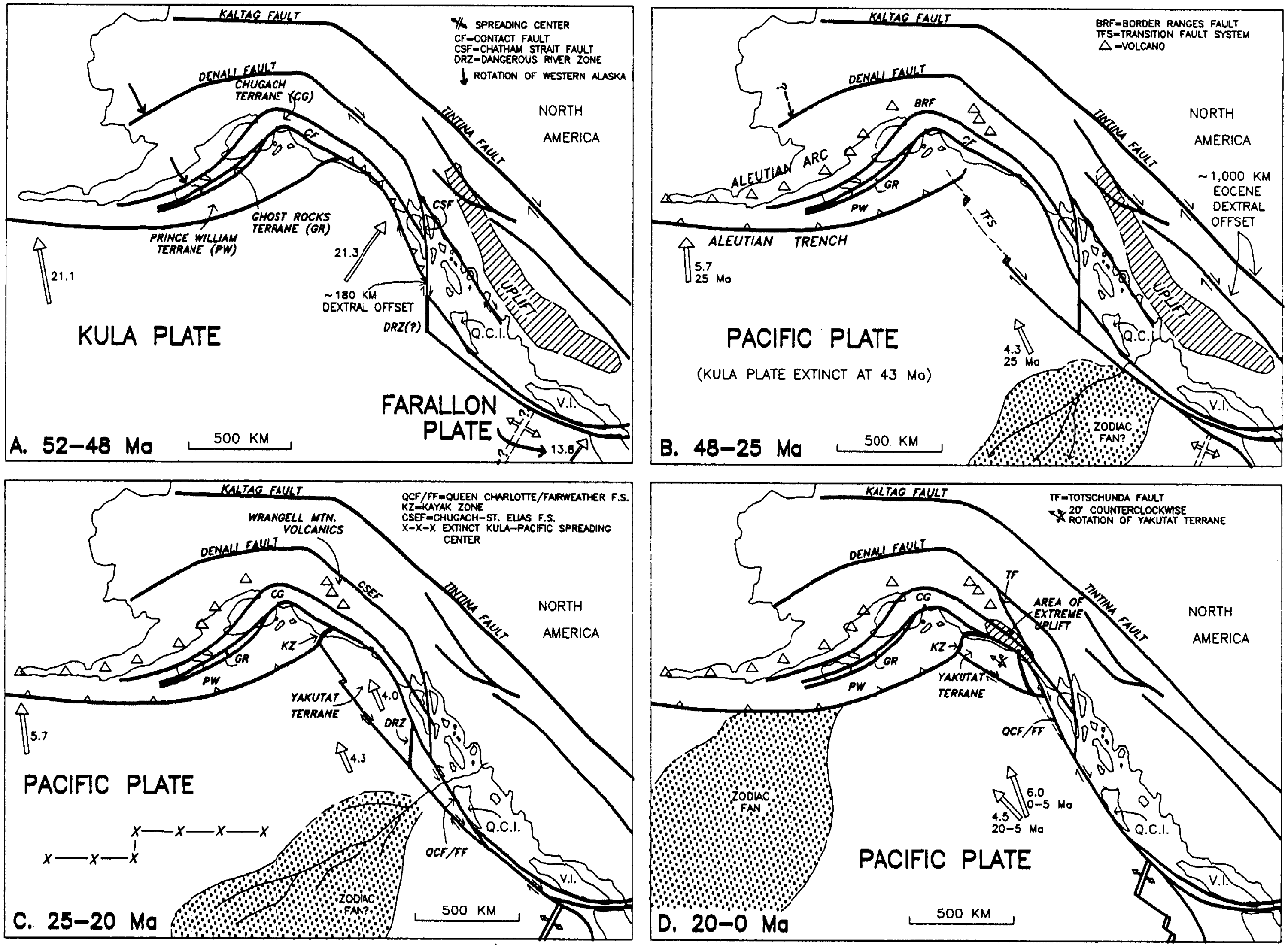


Figure 5. Inferred geologic evolution of southcentral and southeastern Alaska, 52-48 Ma (A), 43-25 Ma (B), 25-20 Ma (C), and 20-0 Ma (D). The tectonic setting and evolution were modified from Plafker (1987). Relative plate motions and rates are from Engebretson (1982). The time scale is from Harland and others (1990). The coastline of Alaska is displayed for reference purposes only and does not imply the actual location of the terranes with respect to the present-day coastline of North America for the time period represented. Abbreviations for geographic features include V.I., Vancouver Island; and Q.C.I., Queen Charlotte Islands. Rates of plate movement are expressed in cm/yr.

along the continental margin in the northern and eastern Gulf of Alaska.

Early middle Eocene to middle late Oligocene (48-25 Ma)

A major change in plate motion occurred in the north Pacific basin at 43 Ma when the Pacific-Kula spreading center ceased being active (Engebretson and others, 1985; Lonsdale, 1988). The direction of convergence between oceanic crust and adjacent onshore terranes shifted from predominantly northeastward to northwestward, in part reflecting seafloor spreading away from the Pacific-Farallon ridge (fig. 5, part B). The Transition fault, north of the Queen Charlotte fault system, developed as a ridge-trench transform system as a result of the change in plate motion in the eastern Gulf of Alaska from obliquely convergent to nearly parallel to the shelf margin (Plafker, 1987).

The Alaska Peninsula and Aleutian Arc were sites of andesitic volcanism beginning by middle Eocene time (Wallace and Engebretson, 1984; Wilson, 1985; Scholl and others, 1987) (fig. 5, part B). Magmatism escalated during the late Eocene and Oligocene, expanding to the adjacent Alaska Range (Wilson, 1985). This volcanic activity may have been initiated by the subduction of the Pacific plate beneath the western margin of the central Gulf of Alaska and the newly emplaced Aleutian Arc farther to the west (Wilson, 1985; Plafker, 1987; Plafker and others, 1989b). However, the kinematics, timing, and rates of displacement for tectonic plates in the northern Pacific basin remain uncertain, and individual studies have often reached contradictory conclusions (e.g., Grow and Atwater, 1970; Hayes and Pitman, 1970; DeLong and others, 1978; Byrne, 1979; Engebretson and others, 1984, 1985; Rea and Duncan, 1986; Lonsdale, 1988).

Minor oroclinal bending of southern Alaska during the middle to late Eocene and possibly into the early Oligocene is recorded by deformation of rocks of the Prince William terrane (Plafker and others, 1989b). The Tintina fault and associated transcurrent faults in eastern Alaska and British Columbia experienced a high degree of dextral offset during this time (Gabrielse, 1985). Along the Pacific margin of North America, the Zodiac deep-sea fan of middle Eocene to late(?) Oligocene age was deposited seaward of a plutonic and/or metamorphic provenance. The site of deposition may have been as far south as British Columbia (Stewart, 1976; Harbert, 1987) (fig. 5, part B). However, other proposed provenances for the Zodiac fan include (1) a northward drifting landmass that presently underlies the Alaska Peninsula and parts of southern Alaska (Stevenson and others, 1983), (2) the southern Alaska continental margin northward of the present location of the fan (Hamilton, 1973), and (3) rocks from the vicinity of present-day Washington State and British Columbia (von Huene and others, 1985).

East of Kodiak Island, Paleogene clastic sediments were deposited on the eastern Prince William terrane as deep-water fans and turbidites. Still further east, strata of middle Eocene to Oligocene age deposited on oceanic crust inboard of the Transition fault reflect a variety of depositional environments, including coastal plain, shelf, and deep-water marine.

Middle late Oligocene to middle early Miocene (25-20 Ma)

The Yakutat terrane probably broke away from the Pacific continental margin of North America during the late Oligocene by dextral offset on the Fairweather-Queen Charlotte transform system (Plafker, 1983; Bruns, 1985b; Richter and others, 1990) (fig. 5, part C). The Yakutat terrane may have originated adjacent to southeasternmost Alaska and British Columbia (Nye, 1983; Plafker, 1983, 1987; and Plafker and others, 1989b), a location that is supported by petrographic studies of Yakutat terrane Paleogene sandstones, which appear to have been derived from the igneous and high-grade metamorphic rocks of the Coast Range plutonic complex of British Columbia (Hollister, 1979; Plafker and others, 1980; Chisholm, 1985). A British Columbia and southeastern Alaska origin is also compatible with paleomagnetic data from the OCS Y-0211 Yakutat No. 1 well (Van Alstine and others, 1985), which indicate a $13^{\circ} \pm 3^{\circ}$ post-early Eocene northward displacement of the Yakutat terrane. However, this requires a significant Paleogene dextral offset on intracontinental transcurrent faults within Canada ($8^{\circ} \pm 3^{\circ}$ of northward displacement), with a resulting northward component of displacement on the Fairweather-Queen Charlotte fault system of approximately 5° (Plafker, 1987).

Other tectonic evolution models place the origin of the Yakutat terrane as far south as California (Bruns, 1983a; Keller and others, 1984). These models agree with preliminary microfaunal data from deep-sea core and dredge samples from the Gulf of Alaska and western U.S. continental margin, which indicate 30° of northward migration of the terrane over the last 50 m.y. (Keller and others, 1984). However, a California origin for the Yakutat terrane is not consistent with the $13^{\circ} \pm 3^{\circ}$ of displacement indicated by paleomagnetic data. A second disadvantage of the distant origin model for the Yakutat terrane is that it requires the terrane to have migrated past a variety of source areas. This is not supported by petrologic studies of Paleogene sandstones, which, as previously discussed, suggest a single plutonic and metamorphic source terrane.

The discrepancy between the microfaunal data and the paleomagnetic and petrologic data could be a result of (1) the preliminary understanding of Paleogene microfossils as paleolatitude indicators (especially at high latitudes) in the north Pacific, (2) the poorly preserved nature of Eocene planktonic foraminifera from onshore California (Poore and others, 1977) to which the Yakutat species were compared (Keller and others, 1984), and (3) possible northward extensions of warmer zones along the Pacific margin during the early Eocene (Wolfe and McCoy, 1984). Studies of Eocene molluscan, microfaunal, and paleobotanical assemblages in the Puget Sound area of Washington by Wolfe and McCoy (1984) suggest that the Yakutat terrane was located at a latitude north of Puget Sound during the Eocene.

Collision and oblique underthrusting of the northern portion of the Yakutat terrane beneath the North American plate during the late Oligocene and early Miocene was marked by arc volcanism in the Wrangell Mountains (Richter and others, 1990). Lavas from this event exhibit medium-K, calc-alkaline bulk compositions, typical of continental volcanic arcs situated adjacent to convergent plate margins (Skulski and others, 1991). The frequency of Wrangell Mountain volcanic activity was apparently low during the late Oligocene and early Miocene, possibly because of the oblique, low angle of convergence between the Yakutat terrane and the North American plate and the consequent low relative down-dip velocity of the subducting crust (Richter and others, 1990).

Late Oligocene through early Miocene sedimentation on the Yakutat terrane in the eastern Gulf of Alaska consisted largely of fine-grained clastic sediments deposited in a deep-water marine environment during a period of regional marine transgression (see chapter 5). Depocenters and upwelling current systems shifted progressively shoreward, causing basinward sediment starvation and local development of restricted, organic-rich sediments. To the east of Kodiak Island on the Prince William terrane, deep-water clastic sedimentation, typically in the form of turbidites or fan complexes, continued through the early Miocene.

Middle early Miocene to Present (20-0 Ma)

From approximately 20 Ma to 5 Ma, northwestward movement of the Pacific plate relative to the continental margin of North America was almost equally accommodated by dextral offset and oblique subduction on the Transition fault outboard of the Yakutat terrane, and by dextral displacement on faults within the Queen Charlotte-Fairweather transform system (Plafker, 1987) (fig. 5, part D). The Yakutat terrane continued to be transported northward, although at a slower rate than the adjacent Pacific plate, with underthrusting of the continental margin along the northern, leading edge of the terrane.

The collision and subduction of the Yakutat terrane beneath the North American continent initiated rapid uplift of the Chugach and St. Elias mountain ranges in the northeastern Gulf of Alaska. This uplift is inferred to have increased regional precipitation, initiated alpine glaciation, and resulted in local climatic cooling (Marincovich, Jr., 1990). Subsequent glaciomarine sedimentation, in part a consequence of episodic climatic cooling and regional glaciation of North America, resulted in the deposition of the Yakataga Formation of middle Miocene to Holocene age in continental margin basins on the adjacent Yakutat and eastern Prince William terranes. The deposition of the Yakataga Formation was characterized by very high sedimentation rates, creating a fairly complete sedimentary record of Cenozoic glaciation in the northern Gulf of Alaska.

The Yakutat terrane began rotating counterclockwise in the late Miocene(?) (Bruns, 1985b), possibly in response to subduction-related tectonic processes along the northern, leading edge of the terrane. Plafker (1987) calculated the magnitude of rotation to be about 20° on the basis of the present trend of the Dangerous River zone with respect to the Chatham Strait fault. This is in agreement with paleomagnetic data from the OCS Y-0211 No. 1 well, which indicate that early to middle Eocene and Oligocene sedimentary rocks from the Yakutat terrane have been rotated up to 20° (Van Alstine and others, 1985).

Seaward of the Yakutat terrane, the Transition fault remained active as an oblique subduction margin that separated Pacific oceanic crust from Cretaceous and Tertiary strata of the Yakutat terrane until at least early Pliocene time (Bruns, 1985b). Since about 5 Ma, the Transition fault has been either inactive (Bruns, 1985b), or a site of only minor relative displacement. Along the base of the Yakutat continental slope, the fault is overlain by undeformed Pliocene and Quaternary sediments. Evidence of an accretionary wedge is lacking. Nevertheless, observed seismicity from the Transition fault zone suggests that some dextral oblique slip is presently occurring (Page, 1975; Perez and Jacob, 1980). On the basis of observed seismicity and relative plate motions, the magnitude of oblique convergence is estimated to be about 0.4 cm/yr (Lahr and Plafker, 1980; Plafker and Jacob, 1986).

Northward displacement of the Yakutat terrane with the Pacific plate since 5 Ma has largely been accommodated by subduction along the northern and western leading edges of the terrane (Wrangell Wadati-Benioff zone and Kayak zone, respectively) by crustal shortening and thickening within the block (Bruns, 1985b), and by mountain-building processes (von Huene and others, 1979; Perez and Jacob, 1980; Hudson and Plafker, 1983). In southeast Alaska and British Columbia, the Fairweather-Queen Charlotte transform system is presently accommodating differential motion between the Pacific and North American lithospheric plates.

3. Seismic Stratigraphy

Introduction

The seismic and stratigraphic framework of the Gulf of Alaska Planning Area was developed by the interpretation of a database of both public and private multichannel seismic-reflection profiles (fig. 6), and the integration of these data with other types of geophysical and geologic data. For ease of discussion, the planning area is subdivided into four segments along geologically distinctive boundaries according to the scheme of Plafker and others (1978a). These are, from west to east, the Middleton, Yakataga, Yakutat, and Southeast segments of the continental margin. Previous studies that have helped define the regional seismic framework of the offshore northern Gulf of Alaska continental margin include Plafker and others (1975, 1980), Rogers (1977), von Huene and others (1979), Bruns (1979, 1982a, 1982b, 1983b, 1985b), Bruns and Schwab (1983), Bruns and Carlson (1987), and Plafker (1987).

Middleton Segment

Shelf Stratigraphy

Seismic-reflection profiles across the offshore Middleton shelf and slope provide insight into the stratigraphic framework, structure, and depositional history of the western convergent-margin segment of the Gulf of Alaska geologic province (plate 1 and fig. 7). Key seismic horizons selected on the basis of regional chronostratigraphic and structural significance were tentatively identified by correlation to the Tenneco Middleton Island No. 1 well and to surface exposures on Middleton Island, Kayak Island, and onshore areas adjacent to the shelf segment. Time-depth conversion of seismic-reflection data was accomplished by constructing a single depth curve from averaged stacking velocities by use of the Dix equation (Dix, 1955) (fig. 8).

Seismic Horizons

Six seismic horizons, designated from youngest to oldest M1 through M6, were identified and correlated across the Middleton platform (plate 1).

Horizon M1, present only in the eastern portion of the basin, unconformably underlies the youngest sequence of strata recognized on the shelf (lines MI-1, MI-2). Stratigraphic projection of horizon M1 with respect to early(?) Pleistocene strata in the Tenneco Middleton Island No. 1 well and to early Pleistocene marine sediments of the Yakataga Formation on Middleton Island (Plafker and Addicott, 1976) indicates that the time of development of the unconformity significantly postdates the early Pleistocene. Strata overlying horizon M1 display continuous, high-amplitude reflections that display onlap against pre-M1 sediments. Where present, post-M1 strata delineate areas of probable Holocene and latest(?) Pleistocene subsidence. Differential subsidence associated with recent movement along the Pinnacle fault is evident on profile MI-1 (north end) where pre-M1 reflections exhibit a basinward divergent configuration.

Horizon M2 is mapped on a prominent basin-wide unconformity that projects stratigraphically above the early Pleistocene strata identified on Middleton Island and in the nearby Tenneco Middleton Island No. 1 well (plate 1). Based on this constraint, and its stratigraphic position below horizon M1, horizon M2 is tentatively assigned an age of middle to late Pleistocene. Reflections above horizon M2 display internal sigmoid progradational configurations adjacent to and inclined away from the Kayak zone (line MI-1, center; line MI-2, south end). This progradational seismic facies was developed in response to middle to late Pleistocene uplift and erosion along the Kayak zone, and probably consists of deltaic and prodeltaic clastic sediments deposited during basinward shifting of delta systems along the northwestern margin of the uplift.

Reflections within strata bounded by horizon M2 and the seafloor typically display some degree of thinning by internal convergence towards and onlap against major thrust zones (plate 1, lines MI-1 to MI-5). Below horizon M2, the sequences are generally consistent in thickness across thrust structures (line MI-2, sequences M2-M5, M5-M6). This relationship, confirmed by structural flattening to horizon M2 (Bruns, 1985b)

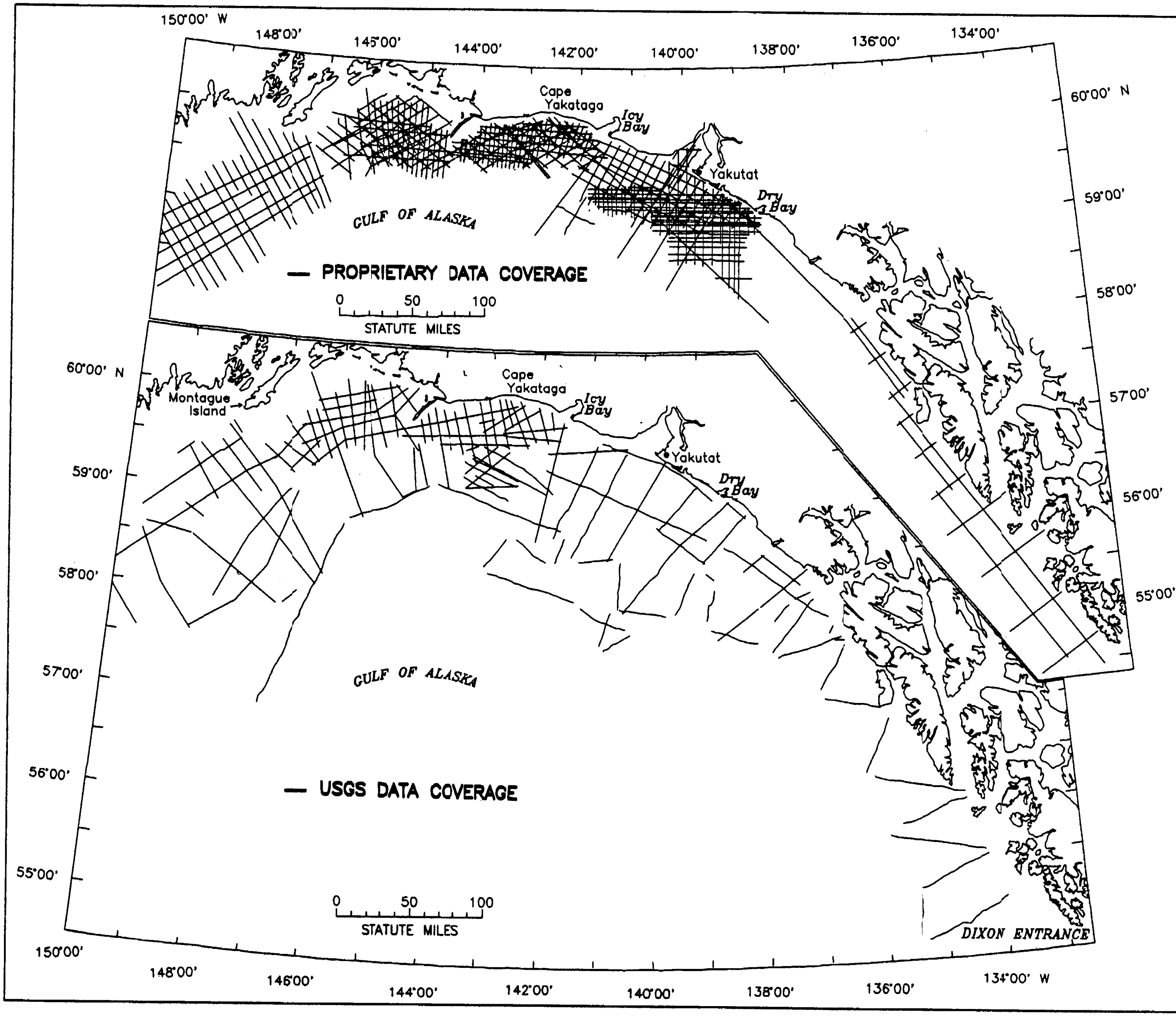


Figure 6. Data coverage map of proprietary and USGS multichannel seismic-reflection tracklines used in this study. We acknowledge and thank the following companies for allowing us to use their data: Digicon Geophysical Corporation, Geophysical Service Inc., ARCO Alaska Inc., Grant-Norpac, Amoco Production Company, Conoco Inc., Petroleum Information, and an anonymous donor.

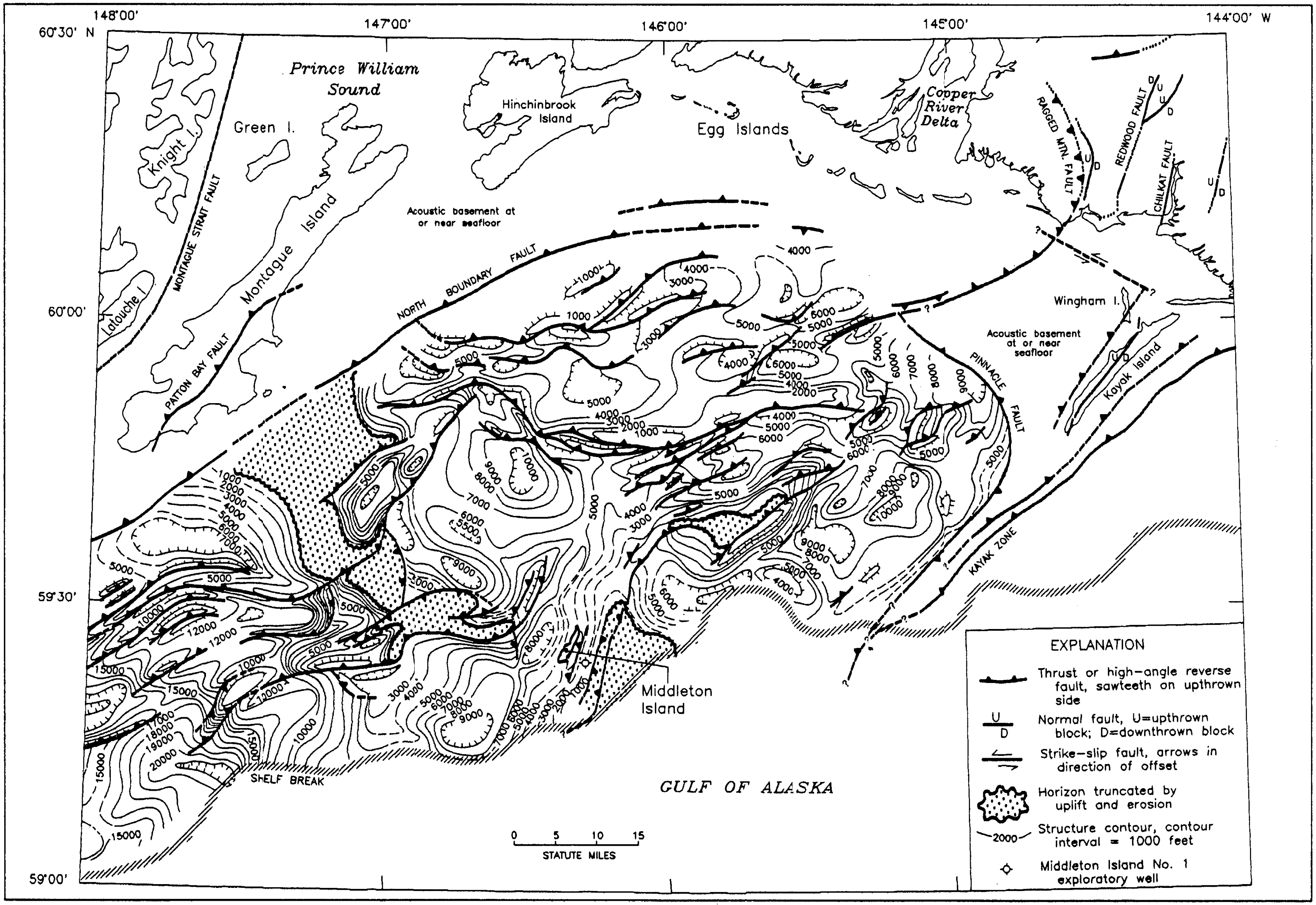


Figure 7. Structure contour map on horizon M6, a regional unconformity that in the vicinity of the Middleton Island No. 1 well represents the base of the late Miocene to Pleistocene glaciomarine Yakataga Formation. Strata immediately underlying horizon M6 consist of siltstone and shale that are tentatively correlated to the Sitkinak Formation on the Kodiak shelf. Onshore geology adapted from Plafker (1967, 1974) and Winkler and Plafker (1981).

indicates that the formation of unconformity M2 corresponds to the initiation of thrust faulting on the Middleton shelf during middle to late Pleistocene time.

Horizons M3, M4A, and M4B (plate 1) all represent local unconformities within the Yakataga Formation that are not traceable basinwide. The origin of unconformities M3 and M4A appears to be related to differential subsidence in the vicinity of the Southeastern thrust zone (line MI-1, center), although these unconformities clearly pre-date this thrust feature. Horizon M4B occurs within a seaward-thickening stratigraphic section along the outer shelf (line MI-5, south end) and probably formed in conjunction with an episode of rapid subsidence of the shelf margin. Horizons M3, M4A, and M4B are probably middle Pleistocene based on the estimated ages of the bounding sequences.

Horizon M5 is a largely conformable basin-wide surface separating moderately to semi-continuous reflections from underlying strata displaying poorly to moderately continuous reflections (plate 1, lines MI-1 to MI-5). Reflections overlying horizon M5 onlap the underlying surface in areas where post-M5 strata display basinward thickening, indicating that the deposition of post-M5 sequence strata was in part controlled by tectonic subsidence of underlying strata (line MI-3, center). A tentative correlation of horizon M5 to strata of the Yakataga Formation within the uppermost section of the Middleton Island No. 1 well yields an age of probable early Pleistocene.

The oldest mapped horizon on the Middleton shelf, horizon M6, represents a regional unconformity that, at the Middleton Island No. 1 well, separates early Miocene strata from overlying late Miocene glaciomarine sediments of the lower Yakataga Formation (Keller and others, 1984)(fig. 7). Reflection configurations change abruptly across horizon M6 (plate 1, all lines), with pre-M6 strata commonly exhibiting a chaotic reflection pattern that suggests the sequence has been significantly deformed. This is corroborated by a change in seismic-refraction velocities, which increase from 14,750 to 16,050 feet per second across the boundary (Bruns, 1985b). Strata

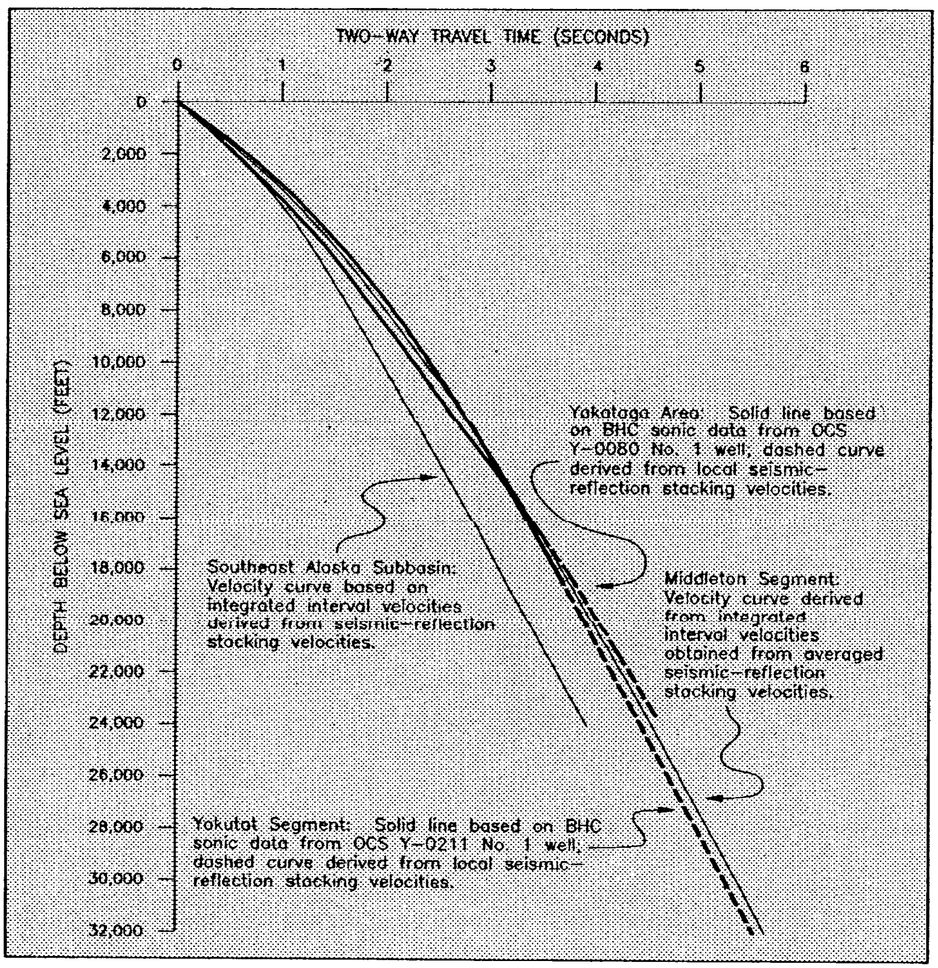


Figure 8. Time-depth relationships for the major geologic provinces within the Gulf of Alaska Planning Area. The time-depth curves were constructed using interval velocities derived both from seismic reflection stacking velocities (Dix, 1955) and from borehole-compensated sonic logs.

immediately underlying unconformity M6 in the Middleton Island No. 1 well consist predominantly of siltstone and shale that are tentatively correlated to rocks within the Sitkinak Formation on the Kodiak shelf.

Unconformities that appear chronologically and/or stratigraphically equivalent to horizon M6 are recognized on seismic profiles and in wells throughout the northern Gulf of Alaska. To the east, wells penetrating the fold-and-thrust regime of the Yakataga shelf encounter a late Miocene regional unconformity (Yakataga Segment, this chapter). Further east, in the ARCO OCS Y-0211 No. 1 well, late Miocene age rocks unconformably overlie early to middle Miocene strata (Yakutat Segment, this chapter). On the Kodiak shelf, southwest of the Middleton platform, three stratigraphic test wells that penetrated the Miocene section show evidence of a time-transgressive erosional surface underlying early or middle Miocene age rocks (Turner and others, 1987).

The formation of this regional Miocene unconformity is likely related to two separate events. East of the Kayak zone, beginning during the late Oligocene or early Miocene, rocks composing the Yakutat terrane were uplifted during collision and subduction of the terrane with the North American plate (Plafker, 1987; Plafker and others, 1989b). Nondeposition and subaerial erosion were subsequently responsible for formation of the unconformity across the Yakataga and Yakutat shelf margins. On the Prince William terrane, west of the Kayak zone, the mechanism responsible for development of the Miocene unconformity is unclear. Fisher and Holmes (1980) attributed the unconformity to uplift and erosion related to the growth of an anticlinal structure near the present Kodiak shelf break. Byrne (1986) proposed that vertical uplift of the Kodiak shelf began in late Eocene time in response to underplating of sediments along the Pacific-North American convergent shelf margin. The absence of Oligocene and early Miocene(?) strata in the offshore Kodiak COST wells suggests that regional uplift of the Kodiak area persisted through middle(?) Miocene time (Turner and others, 1987).

Slope and Base-of-Slope

Seismic horizons underlying the slope and base-of-slope adjacent to the Middleton shelf are visible on line 425 (fig. 9). Horizon M6, correlated at the Middleton Island No. 1 well with the base of the Yakataga Formation, underlies a sequence of relatively undeformed strata that extends across the upper and middle areas of the slope. Seismic profiles of the lower one-third of the slope display numerous diffractions, suggesting that the strata have undergone significant deformation. Dredge samples collected along the lower slope consist of siltstone and sandstone of probable Paleogene age, and poorly consolidated siltstone and mudstone of late Cenozoic age (Plafker and Bruns, 1982; Plafker, 1987).

Strata overlying oceanic basement at the base of the continental slope are relatively undeformed (fig. 9). Horizon A1, base of Pleistocene, and horizon A3, top of oceanic basalt (Bruns, 1985b), can be traced landward beneath disturbed strata of the lower slope. The undeformed configuration of base-of-slope reflections indicates that subduction of the Pacific plate at this site is occurring without underplating or other forms of sediment accretion that are normally associated with plate convergence along the Pacific-North American plate boundary to the west (chapter 4, this report).

Yakataga Segment

Shelf Stratigraphy

The stratigraphic framework of the offshore Yakataga shelf and shelf margin was developed from the interpretation of multichannel seismic-reflection data which were correlated to the Gulf of Alaska COST No. 1 well and 10 offshore exploratory wells. The correlation of seismic horizons and sequences was complicated by the structural complexity of this segment of the continental margin. Four regional seismic horizons, designated K1 to K4, were correlated in order to establish an areal and temporal stratigraphic and structural framework (plate 2; figs. 10, 11, and 12).

Velocity analysis of Yakataga shelf strata utilizing borehole-compensated (BHC) sonic data obtained from exploratory wells and interval velocities derived from seismic-reflection stacking velocities revealed that the relationship between interval velocity and depth is highly variable with respect to both the structural setting and the geologic age of the strata. Because of this, precise time-depth conversion of seismic-reflection data would require knowledge of the local velocities at all points. As this is impractical for a regional study, the somewhat less precise method of utilizing a single representative velocity function was applied. The single-function method appears to have provided satisfactory

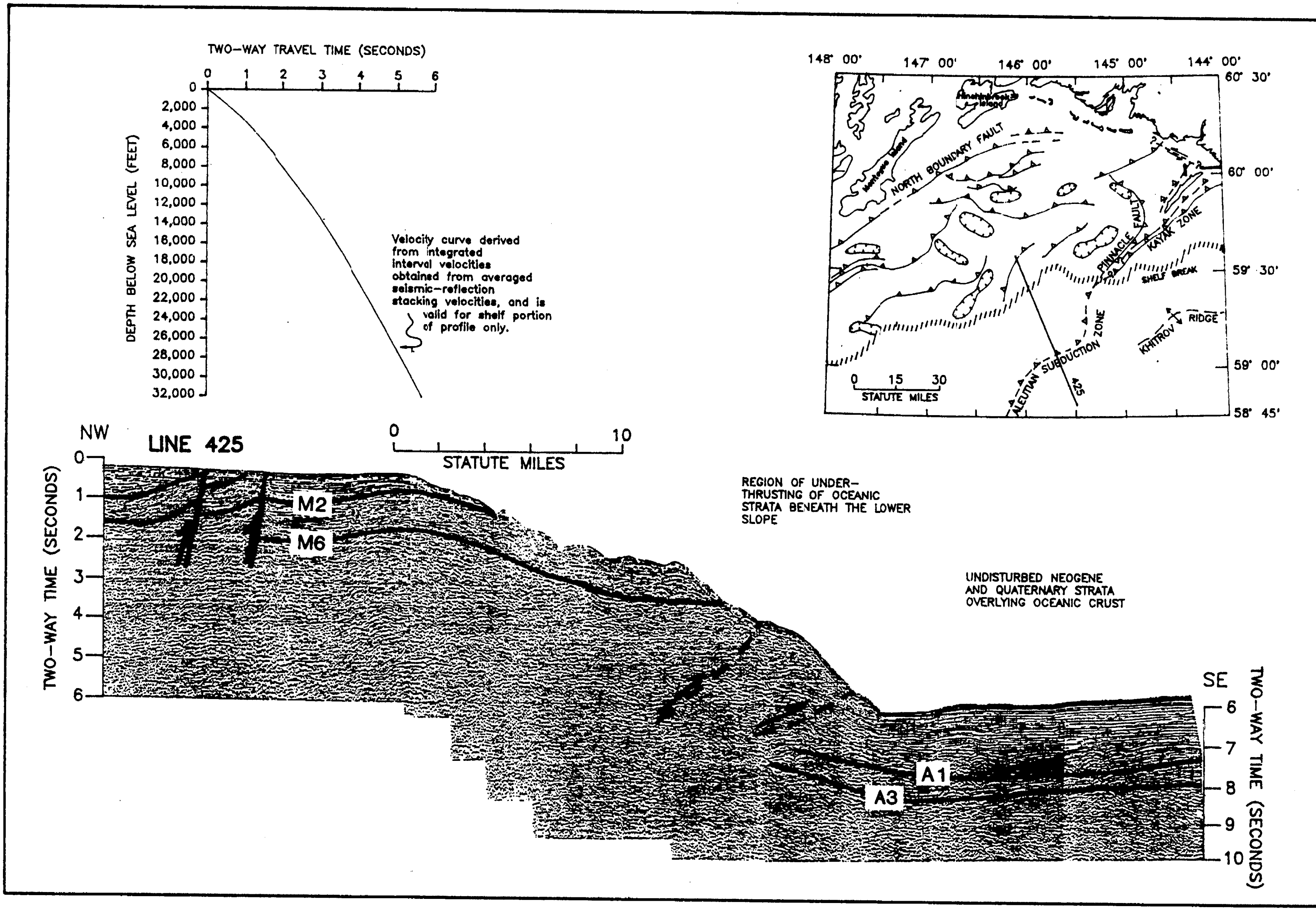


Figure 9. Seismic-reflection profile across the slope and base-of-slope adjacent to the Middleton shelf. Horizons shown represent (M2) a middle to late Pleistocene regional unconformity, (M6) base of late Miocene glaciomarine sediments, (A1) base of Pleistocene strata, and (A3) top of oceanic basalt. Interpretation of Line 425 modified from Bruns, 1985b.

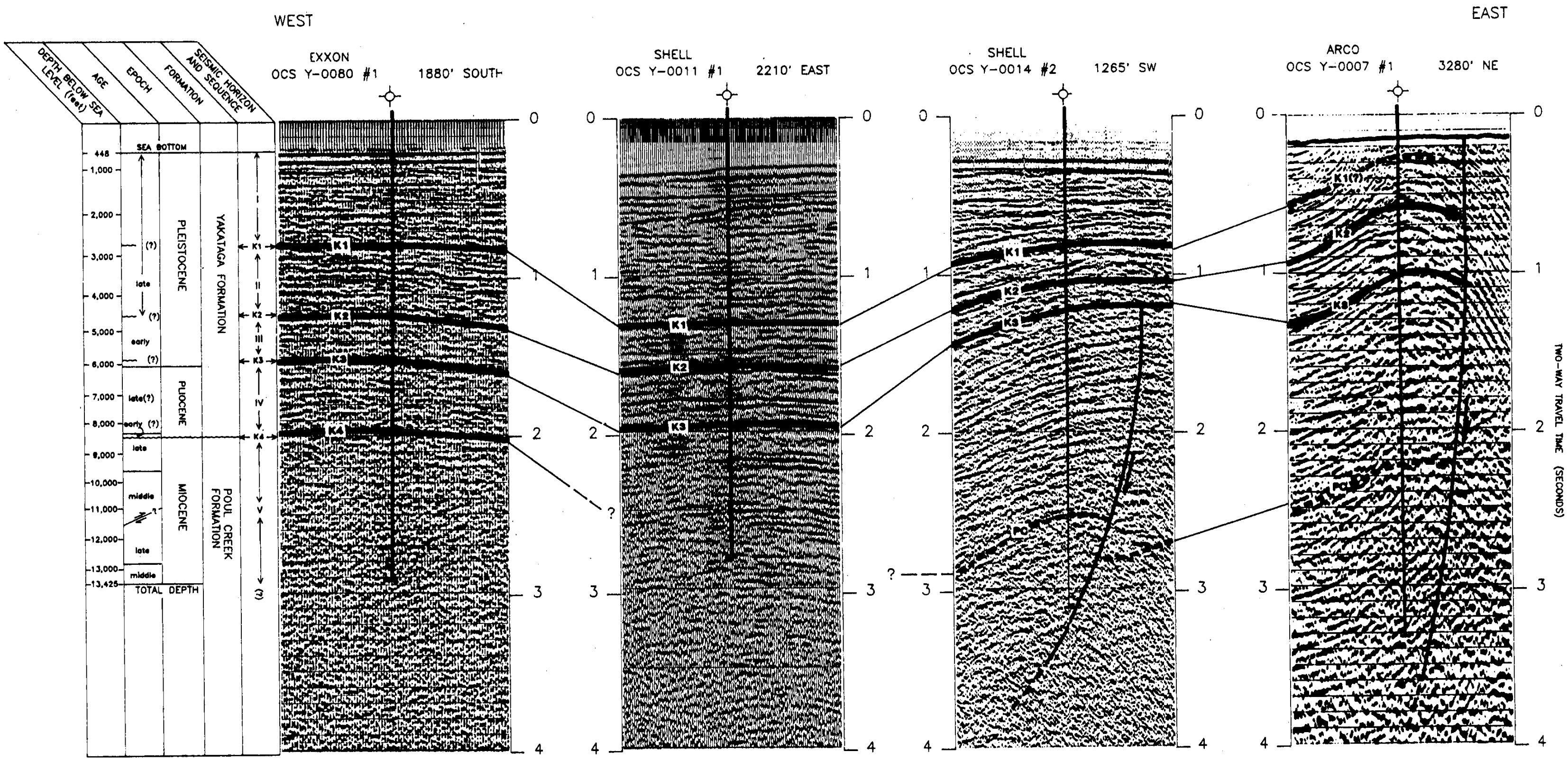


Figure 10. Correlation of seismic sequences and horizons from west to east across the Yakataga segment of the Gulf of Alaska continental shelf. The time-stratigraphic column on the left is based on preliminary paleontological analysis of the Exxon OCS Y-0080 No. 1 well and is valid only in the vicinity of this well. Horizon K4 represents an unconformity separating Miocene Poul Creek strata and late Pliocene Yakataga sediments at the OCS Y-0080 well. Correlation of horizon K4 to the east is hampered by limited seismic resolution due to a progressively thickening Pliocene and Pleistocene stratigraphic section. Horizon PC, the top of the Poul Creek Formation at the OCS Y-0014 No. 2 and OCS Y-0007 No. 1 wells, is picked on the basis of paleontologic and lithologic data. See figure 66 for well locations. Seismic profiles courtesy of, from left to right, Petroleum Information, Conoco, Inc., Amoco Production Company, and an anonymous donor.

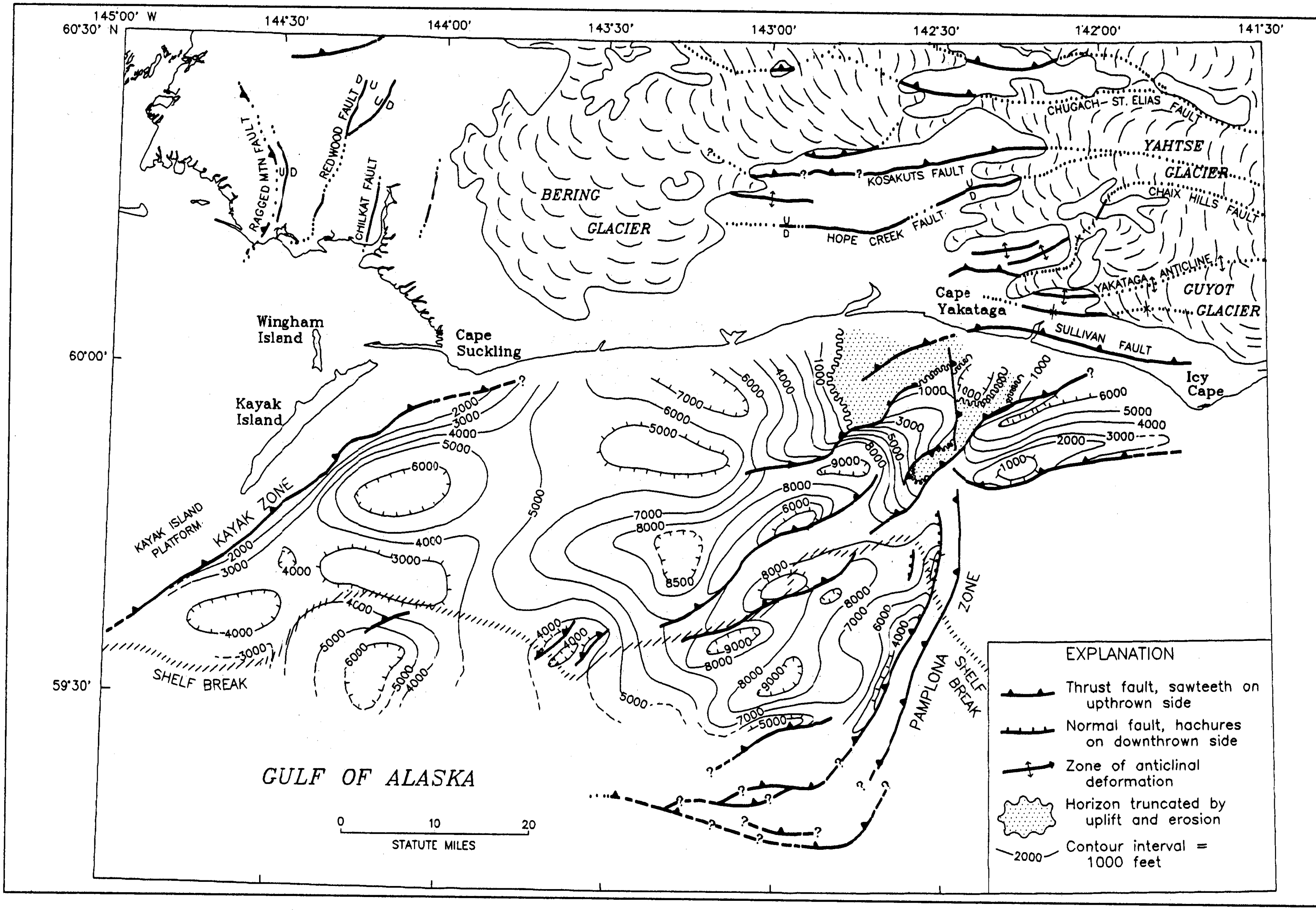


Figure 11. Structure contour map on horizon K1 within the upper Yakataga Formation, Yakataga shelf. Horizon K1 is a regional unconformity within late Pleistocene glaciomarine strata. Onshore faults are adapted from Winkler and Plafker (1981), Plafker (1967, 1974, and 1987), and Nelson and others (1985).

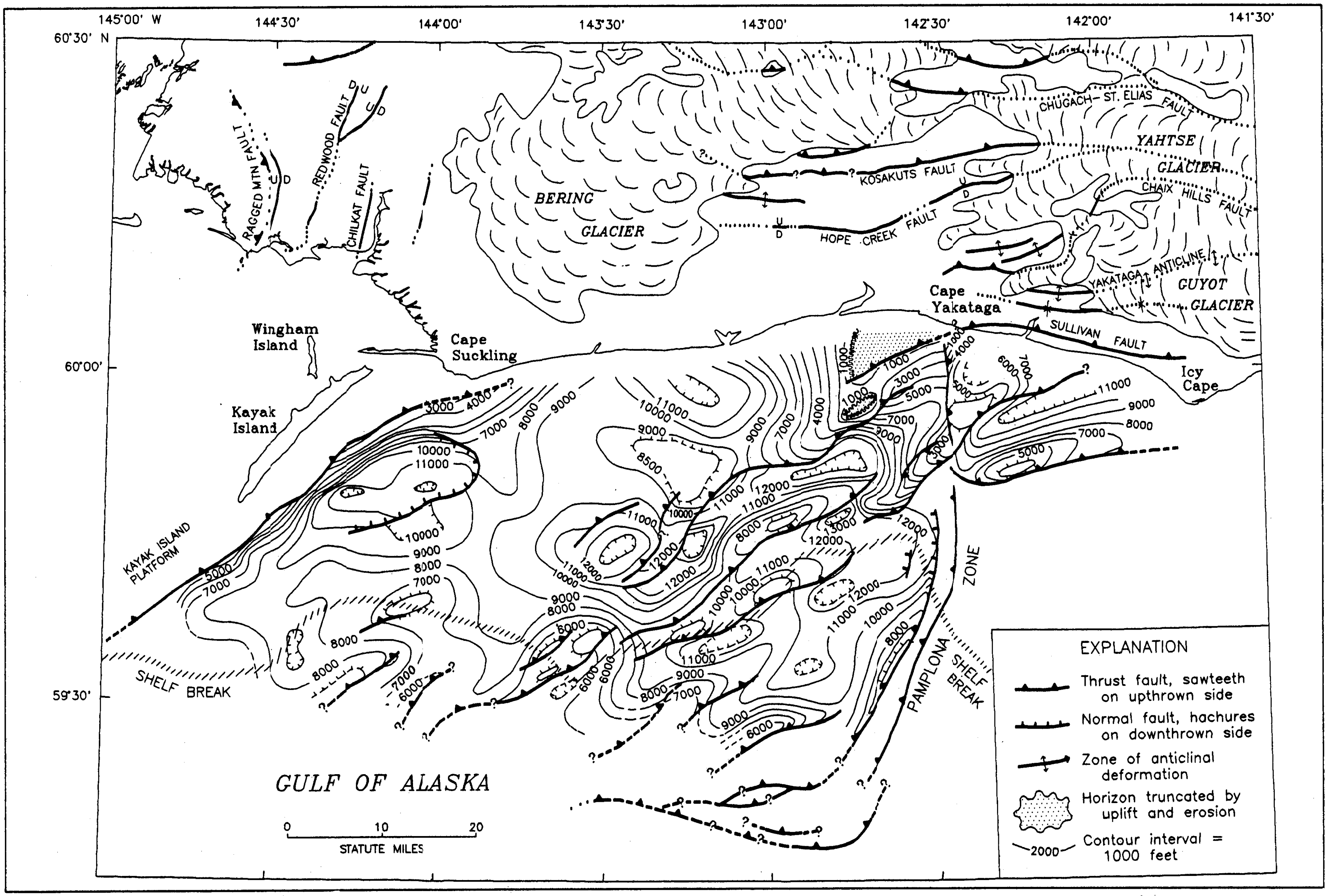


Figure 12. Structure contour map on horizon K3 within the lower Yakataga Formation, Yakataga shelf. Horizon K3 is a largely conformable contact separating early Pleistocene sequence III strata from underlying Pliocene and early Pleistocene strata of sequence IV. Onshore faults are adapted from Winkler and Plafker (1981), Plafker (1967, 1974, and 1987), and Nelson and others (1985).

results for purposes of regional structural analyses of the Yakataga shelf.

For this study, integrated BHC sonic data from the Exxon OCS Y-0080 No. 1 well were used to construct a representative velocity curve (fig. 8). The OCS Y-0080 No. 1 well is located in a less structurally deformed area of the Yakataga shelf, and provides a time-depth function that correlates closely with curves derived from seismic-reflection stacking velocities from less severely deformed areas of the platform. The use of a constant velocity function for time-depth conversion should not affect the stratigraphic or structural interpretation of the area. However, absolute depth values in more structurally complex areas, especially those that have undergone a large amount of uplift, may be in error up to approximately 10 percent.

Horizon K1

Horizon K1 represents a regional unconformity separating late Pleistocene sequences I and II strata of the Yakataga Formation (figs. 10 and 11, plate 2). Horizon K1 typically appears as a medium-amplitude, semi-continuous to continuous reflection. It is best recognized over structural highs, where overlying basal sequence I reflections terminate progressively updip at the horizon by onlap. West of Icy Bay, horizon K1 was uplifted over thrust-faulted anticlines and truncated at the seafloor.

Sequence I

On the western Yakataga shelf margin, sequence I is represented in the OCS Y-0080 No. 1 well by 2,300 feet of late Pleistocene glaciomarine sandstones, siltstones, shales, and conglomerates of the upper Yakataga Formation (fig. 10). Sequence I generally increases in thickness from west to east, where maximum thicknesses occur in structural lows situated on the downthrown side of high-angle reverse faults. Angularly discordant reflections at the upper boundary of the sequence, the seafloor, indicate widespread erosional truncation of upper sequence I strata (plate 2, all lines). A wide range of seismic facies and the presence of numerous local and sub-regional unconformities within sequence I suggest a complex depositional and structural history. A partial list of internal reflection patterns includes parallel, subparallel, divergent, and clinoform configurations. Divergent reflections and clinoform configurations indicate the progradation of sediments into rapidly subsiding or pre-existing structurally controlled depocenters. Mounded reflection configurations are locally observed on strike profiles, and are interpreted to represent deep-water fan/slope deposits. Basal reflections within sequence I commonly terminate by onlap against underlying structural highs.

Horizon K2

Horizon K2 is mapped on a prominent medium- to high-amplitude, generally continuous reflection that represents the lower boundary of sequence II (fig. 10 and plate 2). Reflections above and below horizon K2 are commonly concordant, although locally unconformable relationships are present. Onlap of overlying basal reflections can be noted adjacent to the Kayak Island platform (plate 2, line YG-3, NW end) and over isolated structural highs within the subbasin (line YG-4, center). Reflections directly beneath horizon K2 display little or no discordance, suggesting that the sequence boundary may represent a hiatus rather than an erosional surface.

Sequence II

Sequence II, bounded unconformably above by horizon K1 and below by horizon K2, is represented in the OCS Y-0080 No. 1 well by more than 1,750 feet of late Pleistocene glaciomarine clastic sediments (fig. 10 and plate 2). Reflections within sequence II are characterized by variable amplitude and moderate continuity. Internal reflection configurations are predominantly parallel to occasionally divergent.

A rather extensive mounded facies is displayed on oblique-strike profiles YG-1 and YG-2. This facies has been mapped as a broad mound with a depositional axis that strikes east-northeast. Reflections within this structure exhibit gently sigmoid to divergent patterns. Basal reflections downlap against horizon K2. The geometry and internal reflection configurations of this mounded facies are consistent with either a fan complex deposited on a subsiding deep-water shelf, or a slope or basinal fan or fan complex (Sangree and Widmier, 1977).

Horizon K3

Horizon K3 is a generally conformable contact between overlying early Pleistocene sequence III strata and the underlying Pliocene and early Pleistocene strata of sequence IV (figs. 10 and 12, plate 2). However, unconformable relationships are apparent locally, as can be seen on line YG-4 (center) and line YG-3 (NW end), where syndepositional faulting and subsidence have resulted in termination by onlap of overlying reflections against subbasin flanks. Reflections directly beneath horizon K3 are predominantly concordant with the sequence boundary.

Sequence III

In the OCS Y-0080 No. 1 well, sequence III corresponds to more than 1,300 feet of early Pleistocene shale and sandstone of the Yakataga Formation (fig. 10). Reflection characteristics within the sequence, including amplitude, frequency, and continuity, are all highly variable, suggesting that the seismic unit represents a range of depositional processes. On the western Yakataga shelf, sequence III reflections display poor continuity and medium- to low-amplitude, which are characteristic of laterally discontinuous lithofacies with low internal acoustic impedance contrasts (plate 2, lines YG-1, YG-2). Sequence III reflection continuity increases from west to east (lines YG-5, YG-6), which may indicate deposition in a progressively more uniform environment. Reflection configurations within sequence III are predominantly parallel to subparallel, except where local subsidence has resulted in increased sediment accumulation. At such locations (plate 2, line YG-4, center), the reflections diverge basinward as a result of contemporaneous fault movement and differential subsidence rates.

Horizon K4

Horizon K4 is a variable amplitude, semi-continuous reflection that, in the vicinity of the OCS Y-0080 No. 1 well, separates overlying sequence IV strata of the Yakataga Formation from underlying Miocene clastic sediments of the upper Poul Creek Formation (fig. 10 and plate 2). Horizon K4 cannot be traced east of the Bering Trough, where it is masked beneath a thickening overlying stratigraphic section. On the western Yakataga shelf, horizon K4 truncates underlying angular reflections (plate 2, lines YG-1, YG-2), indicating that the sequence boundary is at least in part erosional. Seaward of the shelf break, a prominent high-amplitude reflection is apparent beneath horizon K4 (plate 2, lines YG-1, YG-2, YG-4, horizon U). This local horizon, designated horizon U, is erosionally truncated updip at horizon K4 (lines YG-1, YG-2). Where present, horizon U may delineate the base of the Yakataga Formation, and horizon K4 may represent an intraformational unconformity.

Sequence IV

Sequence IV, bounded above by horizon K3 and unconformably below by horizon K4, is represented in the OCS Y-0080 No. 1 well by more than 2,500 feet of early(?) Pliocene to early Pleistocene shale, conglomerate, and sandstone of the lower Yakataga Formation (fig. 10 and plate 2). Reflections within sequence IV are generally semi-continuous and of variable amplitude. Reflection configurations within the unit are parallel to subparallel and, less commonly, divergent. Reflections at the base of sequence IV are generally concordant with the lower bounding horizon, although local onlap is apparent on the flanks of pre-existing structural highs. As previously noted, the base of sequence IV, horizon K4, cannot be identified with certainty east of the Bering Trough. Consequently, it is unclear whether the base of sequence IV corresponds to the base of the Yakataga Formation on the eastern Yakataga shelf, as depicted in figure 10 (OCS Y-0014 No. 2 and OCS Y-0007 No. 1 wells) or occurs here as a shallower, unconformable intraformational boundary. If the base of sequence IV on the eastern shelf is a horizon within the Yakataga Formation, as seismic correlation suggests (plate 2), then the basal Yakataga section is terminated by erosion and/or nondeposition from east to west.

Sequence V

In the OCS Y-0080 well, sequence V is represented by over 5,000 feet of middle to late Miocene age siltstone, shale, and rare sandstone of the Poul Creek Formation (fig. 10). The lower boundary of sequence V is not resolvable on available multichannel seismic-reflection profiles (plate 2), but on the basis of onshore sedimentary sequences, it is believed to correspond with the base of the Poul Creek Formation. Reflections within the sequence typically display poor continuity and variable amplitude, and are in part obscured by reflection multiples from shallower portions of the section. West of the Bering Trough, reflections in the upper part of the sequence exhibit angular discordance with the upper sequence boundary, indicating widespread truncation by erosion of upper sequence V strata (plate 2, lines YG-1 through YG-3). To the east, reflections are predominantly concordant with horizon K4. Identification of distinct seismic facies and associated depositional environments within sequence V is restricted by the resolution of available reflection profiles. However, paleontological and electric-log data suggest that the strata were deposited in a deep-marine basinal setting.

Sub-Sequence V Strata

The geologic nature of sedimentary strata underlying sequence V is inferred from marine seismic-refraction data. Studies by Bayer and others (1978) suggest that the continental shelf between Icy Bay and Kayak Island may be underlain by as much as 35,000 feet of probable Tertiary age sedimentary rock. Velocities within the lower portion of the sedimentary section (pre-sequence V) range from about 12,500 to 18,000 feet per second. The section is presumed to consist of strata equivalent to the Eocene and early Oligocene(?) Kulthieth and Stillwater Formations. Viewed in three dimensions, the pre-sequence V section resembles a wedge that thins toward the shelf margin. Southeast of Kayak Island, a 16,000-foot-thick interval of relatively high-velocity strata (15,500 to 18,000 feet per second) is present near the base of the section, and most likely represents Paleogene (Stillwater Formation or equivalent?) metasedimentary rock. This high-velocity unit is not present to the east (Bayer and others, 1978). The deepest layer resolved by the refraction study has a seismic velocity of approximately 23,000 feet per second, typical of the Paleogene oceanic basalt that composes acoustic basement beneath the eastern Gulf of Alaska.

Slope and Rise

The continental slope off the Yakataga shelf margin is underlain by complexly faulted and folded Yakataga Formation and older strata (fig. 13). Seismic horizons K1 through K4 can be traced from the shelf seaward onto the upper slope, where reflections appear to terminate against a highly thrust-faulted and anticlinally deformed zone. This zone underlies the central area of the slope and is most likely underlain by repeated down-faulted sections of the Yakataga Formation (sequences I-IV). Unfortunately, seismic correlation in this zone is hampered by the presence of numerous diffractions and, at depth, by the first seafloor multiple.

The base of the slope is marked by a bathymetric high, the Khitrov Ridge, a linear zone of relatively recent anticlinal deformation (fig. 13). Dredge sampling along the seaward slope of the Khitrov Ridge yielded siliciclastic and calcareous sediments of early Pliocene through Pleistocene age that are similar to the onshore Yakataga Formation (Plafker and Claypool, 1979; Plafker, 1987). Some of the samples collected from the Khitrov Ridge may be accreted trench deposits that have been rapidly lithified by forces associated with oblique subduction along the Pacific-North American plate boundary (Plafker and others, 1978d; Plafker, 1987).

Seaward of the Khitrov Ridge, 5,000 to 10,000 feet of relatively undeformed strata overlie Paleogene oceanic basalt adjacent to the base of the continental slope (fig. 13, lines 922, 928). Horizons within the base-of-slope section are identified from correlation of multichannel seismic-reflection data to Deep Sea Drilling Project (DSDP) hole 178 east of Kodiak Island (T. R. Bruns, unpublished data, 1978). Reflections within the upper Pleistocene sequence are typically flat lying and continuous, indicating areally uniform deposition. The underlying sequence (Oligocene(?) to Pliocene) exhibits varied reflection configurations, ranging from generally parallel to moderately chaotic. Reflections within the base-of-slope section terminate at the seaward base of the Khitrov Ridge (fig. 13, lines 922 and 928).

Yakutat Segment

Shelf and Slope

Seismic reflectors underlying the Yakutat segment of the continental shelf and slope were correlated to the ARCO OCS Y-0211 No. 1 well (Yakutat well) by the use of synthetic seismograms (fig. 14). Three seismic horizons, designated Y1 to Y3, were mapped over the area using a network of multichannel seismic-reflection profiles. Structure contour and isopach maps were prepared from the interpreted data (figs. 15 and 17 through 20). Seismic time was converted to depth using integrated borehole-compensated sonic data obtained from the well down to 3.5 seconds two-way time; below 3.5 seconds, an averaged time-depth curve was constructed from interval velocities derived from seismic-reflection stacking velocities by using the Dix equation (Dix, 1955)(fig. 8).

Horizon Y1

Horizon Y1 corresponds to a regional unconformity that, in the vicinity of the OCS Y-0211 well, separates the early Pliocene to Pleistocene age glaciomarine sediments of sequence I from underlying sequence II strata (figs. 14 and 15, plates 3A and 3B). Horizon Y1 is mapped on a medium- to high-amplitude, moderately continuous reflection. Seaward, horizon Y1 terminates at the shelf seafloor (plate 3A, lines YT-1, YT-2; plate 3B, lines 909, 911), or is truncated along the continental slope (plate 3A, lines YT-3, YT-4). South of Lituya Bay, at the eastern limit of the Yakutat shelf, horizon Y1 onlaps acoustic basement.

Sequence I

Sequence I, bounded by the seafloor and by horizon Y1, consists of medium- to high-amplitude reflections displaying poor to moderate continuity (plates 3A and 3B, all lines). These characteristics suggest laterally discontinuous and lithologically variable strata. Correlations of the Yakutat OCS Y-0211 well (fig. 14) to onshore wells and with dredge samples from the shelf margin (Plafker and others, 1980) suggest that sequence I strata are equivalent to the glaciomarine

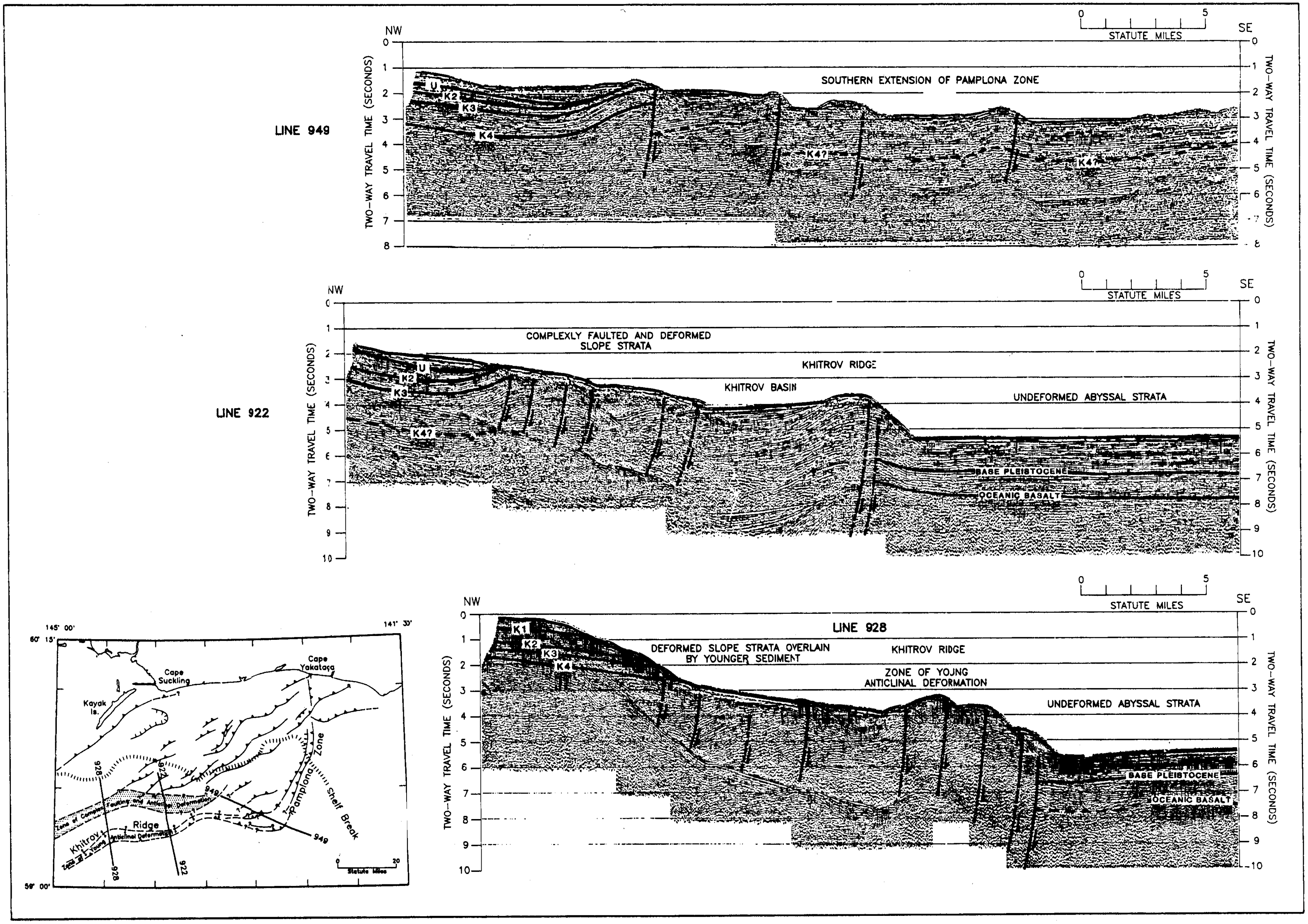


Figure 13. Interpreted multichannel seismic-reflection profiles across the slope and rise of the Yakataga segment of the Gulf of Alaska continental margin. Notice complexly faulted and deformed strata underlying the slope, and young anticlinal zone (Khitrov Ridge) marking the base of slope. Zones of anticlinal deformation and faulting, base of Pleistocene, and top of oceanic basalt in part modified from Bruns and Schwab (1983). Profiles are 24-fold data acquired in 1977 from the U.S. Geological Survey research vessel *S. P. Lee*.

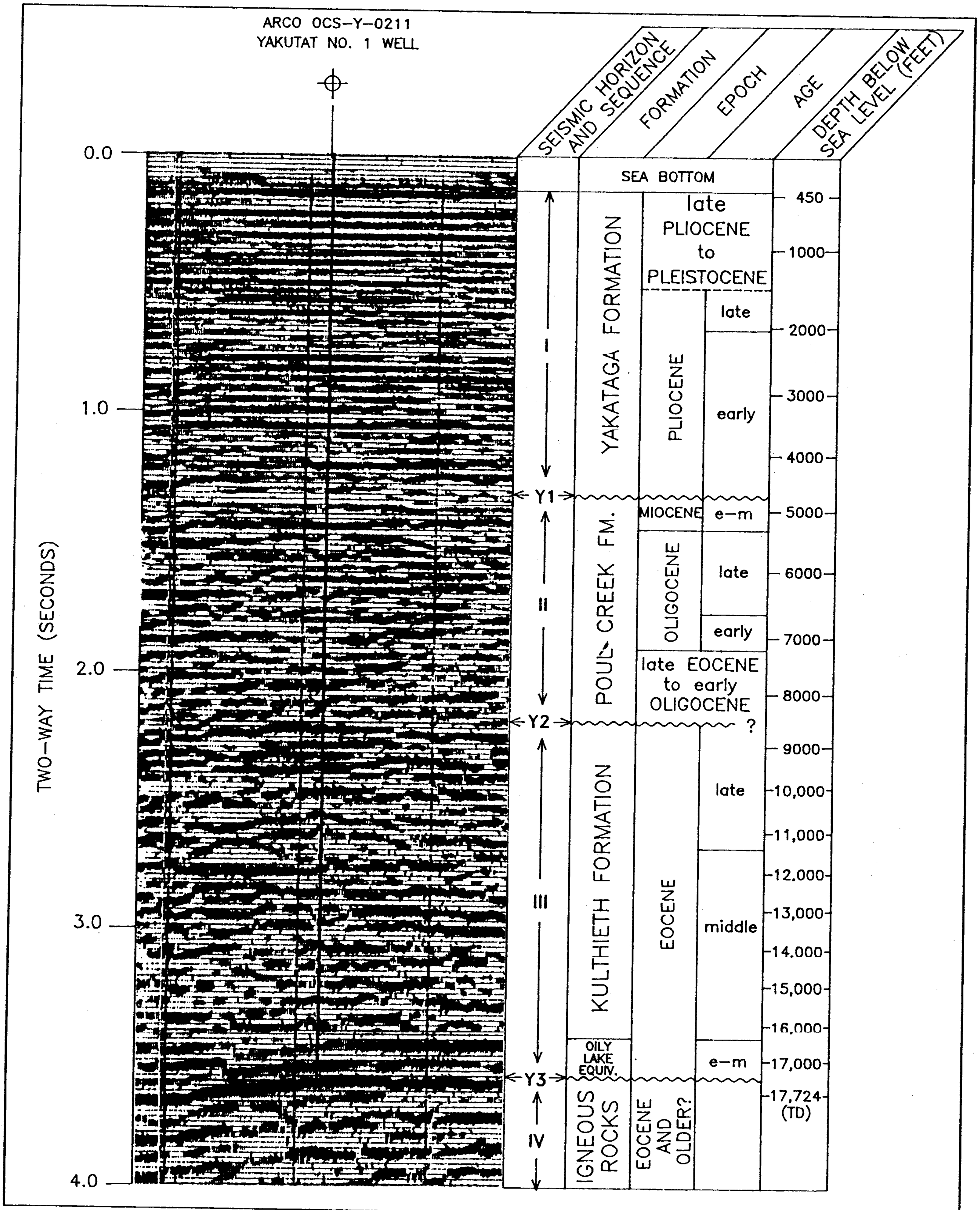


Figure 14. Seismic sequences and horizons, stratigraphic divisions, chronostratigraphy, and multichannel seismic-reflection profile of the OCS Y-0211 No. 1 well, Yakutat segment of the Gulf of Alaska. The depth scale was calibrated to the seismic profile by use of a synthetic seismogram. The seismic-reflection profile is courtesy of ARCO Alaska, Inc.

sediments of the Yakataga Formation. Strata within sequence I thin seaward away from the coastal margin (plate 3A, YT-1 through YT-4; plate 3B, lines 909, 911), and from the Pamplona zone southeastward to Fairweather Ground (plate 3B, line YT-5). This thinning is accomplished primarily by onlap against the lower boundary, and to a lesser extent by internal convergence of reflectors. At the seafloor, progressively older strata are exposed from north to south, away from the present-day coastline. Strata at the seafloor appear to have been terminated primarily by erosion.

Numerous local unconformities are present within sequence I (plate 3B, line 909, NE end at 1 second). These are expressed by seaward onlap of younger strata against underlying sediments. The unconformities appear to have developed in response to episodic Neogene uplift along the outer shelf, and in conjunction with contemporaneous regional subsidence inland adjacent and parallel to the coast between Yakutat Bay and Cross Sound (plate 3A, YT-1 and YT-2, NE ends; plate 3B, lines 909, 911).

A well-developed channel system is present in the middle to upper section of sequence I (fig. 16). The channels are steep walled and have an average apparent width of 1 to 1.5 miles. Individual channels range in depth from less than 500 feet to approximately 1,000 feet. Channel lengths cannot be determined from the present seismic coverage grid. The acoustic signature from within the channel fill is typically discontinuous to chaotic, and in some instances transparent, suggesting variable lithology and degree of stratification. The interval velocity of the channel fill is occasionally lower than that of adjacent sediment, resulting in pull-downs in underlying reflections (fig. 16, line A, south end, lower channel).

Many of the channels underlie two locally unconformable horizons. These horizons are interpreted to represent erosional surfaces formed during Pliocene and Pleistocene sea level lowstands. During the lowstands, glacial and glacial-fluvial processes eroded the channels in underlying glaciomarine sediments. Analogous channels of glacial-fluvial origin have been recognized in the Yakataga Formation onshore in the southern Alaska Coast Range (Armentrout and others, 1979; Armentrout, 1983b) and on Middleton Island (Plafker and Addicott, 1976; Eyles, 1987).

Horizon Y2

Horizon Y2 represents an unconformity or its correlative conformity and separates the late Eocene to middle Miocene clastic sediments of sequence II from the underlying Eocene sequence III strata (figs. 14 and 17, plates 3A and 3B). Horizon Y2 appears as a highly variable reflection throughout the Yakutat shelf. In some areas it is a prominent high-amplitude reflection, whereas in other areas it is difficult to distinguish from surrounding conformable reflections, or is masked by multiples. Horizon Y2 can most easily be recognized just south of the OCS Y-0211 well location, where discordant basal sequence II strata terminate by onlap (plate 3A, line YT-2, SW end). Horizon Y2 shallows from northwest to southeast across the Yakutat shelf, and is truncated by erosion at the seafloor northwest of the Fairweather Ground uplift (fig. 17).

Sequence II

Sequence II, bounded unconformably by horizons Y1 and Y2, is characterized by low- to medium-amplitude, moderately continuous to occasionally discontinuous reflections (plates 3A and 3B, all lines; fig. 18). Sequence II reflections are frequently obscured by multiples generated within the overlying section (plate 3A, line YT-1, right of center). Reflections at the top of the sequence are generally concordant with horizon Y1. Within sequence II, the reflections are parallel to subparallel, suggesting uniform deposition in a stable platform setting. Basal reflections are typically concordant with horizon Y2, although in areas of local subsidence (plate 3A, line YT-2, left of center) or structural uplift (plate 3A, line YT-1, YT-2, SW ends) the reflections display prominent onlap.

Based on correlations with the OCS Y-0211 well and with dredge samples collected from the shelf margin (Plafker and others, 1980), sequence II strata are equivalent to the Poul Creek Formation of late Eocene to middle Miocene age.

Horizon Y3

Horizon Y3 is a prominent high-amplitude reflection that delineates the top of acoustic basement (plates 3A and 3B, all lines; fig. 19). At the OCS Y-0211 well, horizon Y3 unconformably separates Paleogene clastics from underlying igneous intrusive rocks (fig. 14). On the Yakutat shelf west of the Dangerous River zone, horizon Y3 is believed to represent the top of an equivalent igneous unit. East of the Dangerous River zone, where acoustic basement consists of metamorphosed sediments of the Yakutat Group (Bruns, 1982a), horizon Y3 represents the unconformity

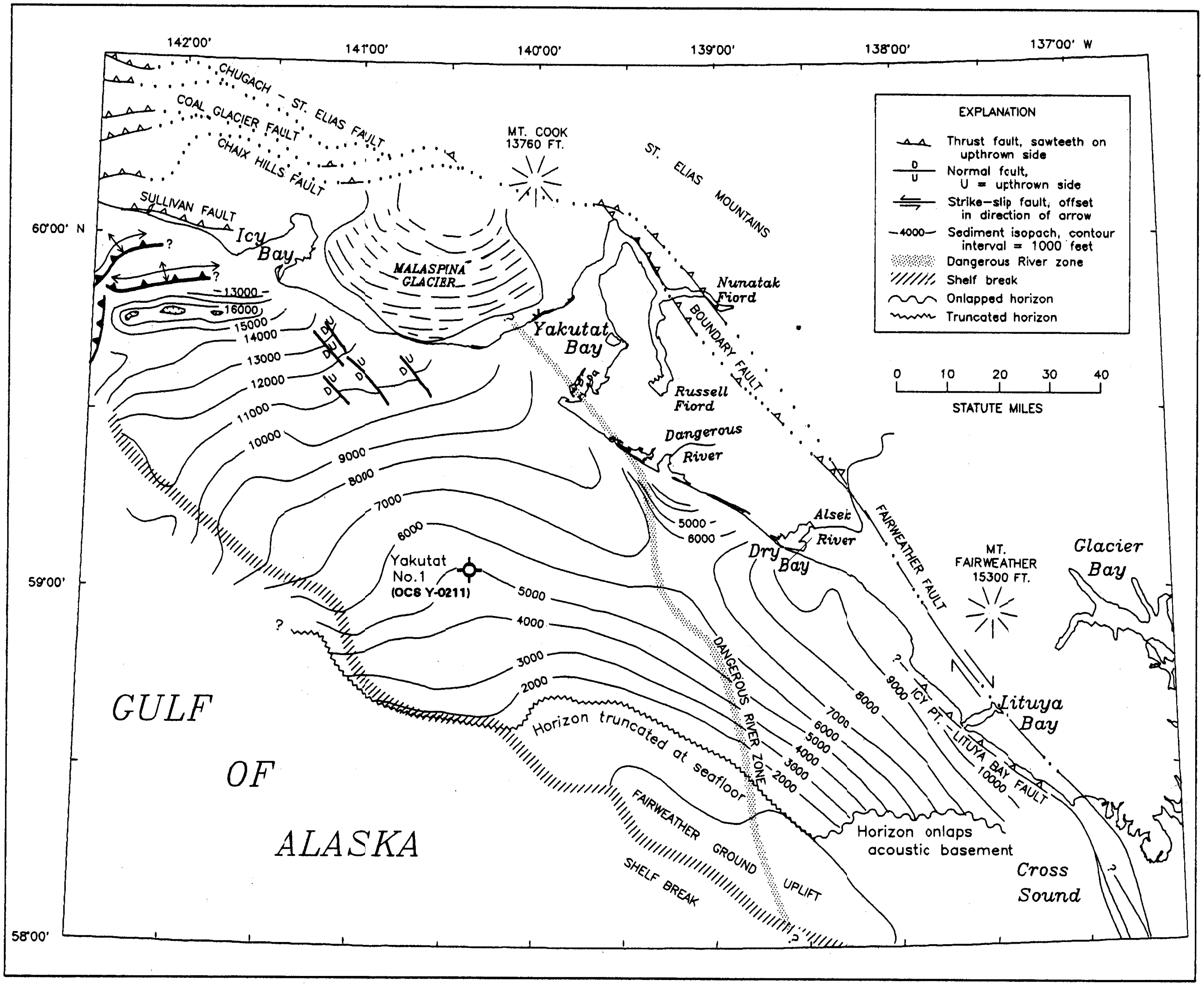


Figure 15. Structure contour map of seismic horizon Y1 on the Yakutat segment of the Gulf of Alaska continental shelf. Horizon Y1 is mapped on an unconformity which separates early Pliocene through Pleistocene glacio-marine sediments of the Yakataga Formation from underlying Poul Creek strata of late Eocene to middle Miocene age.

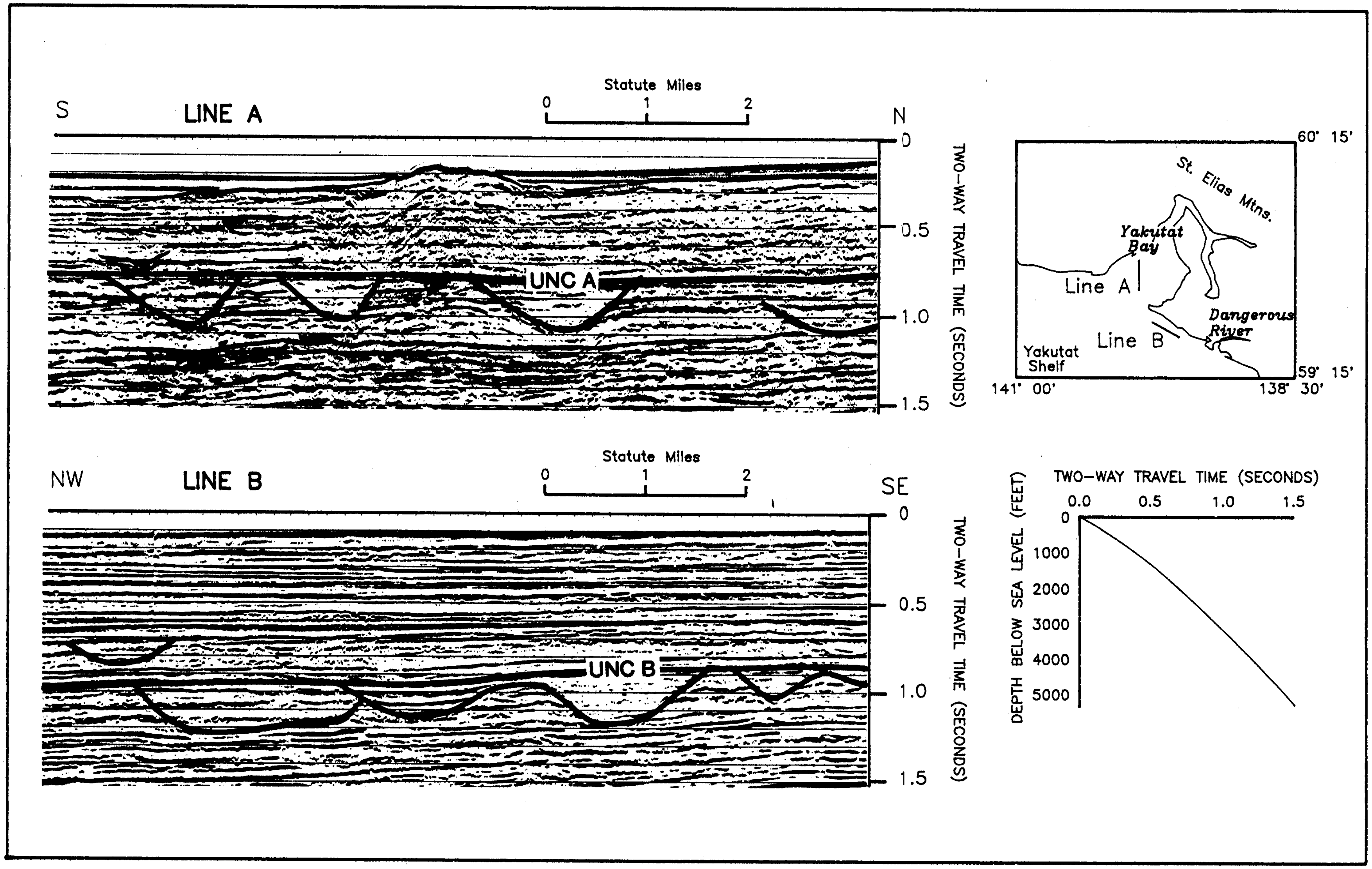


Figure 16. Pliocene and Pleistocene glacial and glacial-fluvial channels within the Yakataga Formation (Sequence I) in the vicinity of Yakutat Bay. Notice unconformities A (Pleistocene) and B (Pliocene?), which reflect low sea-level stands. Multichannel seismic-reflection data are courtesy of an anonymous donor.

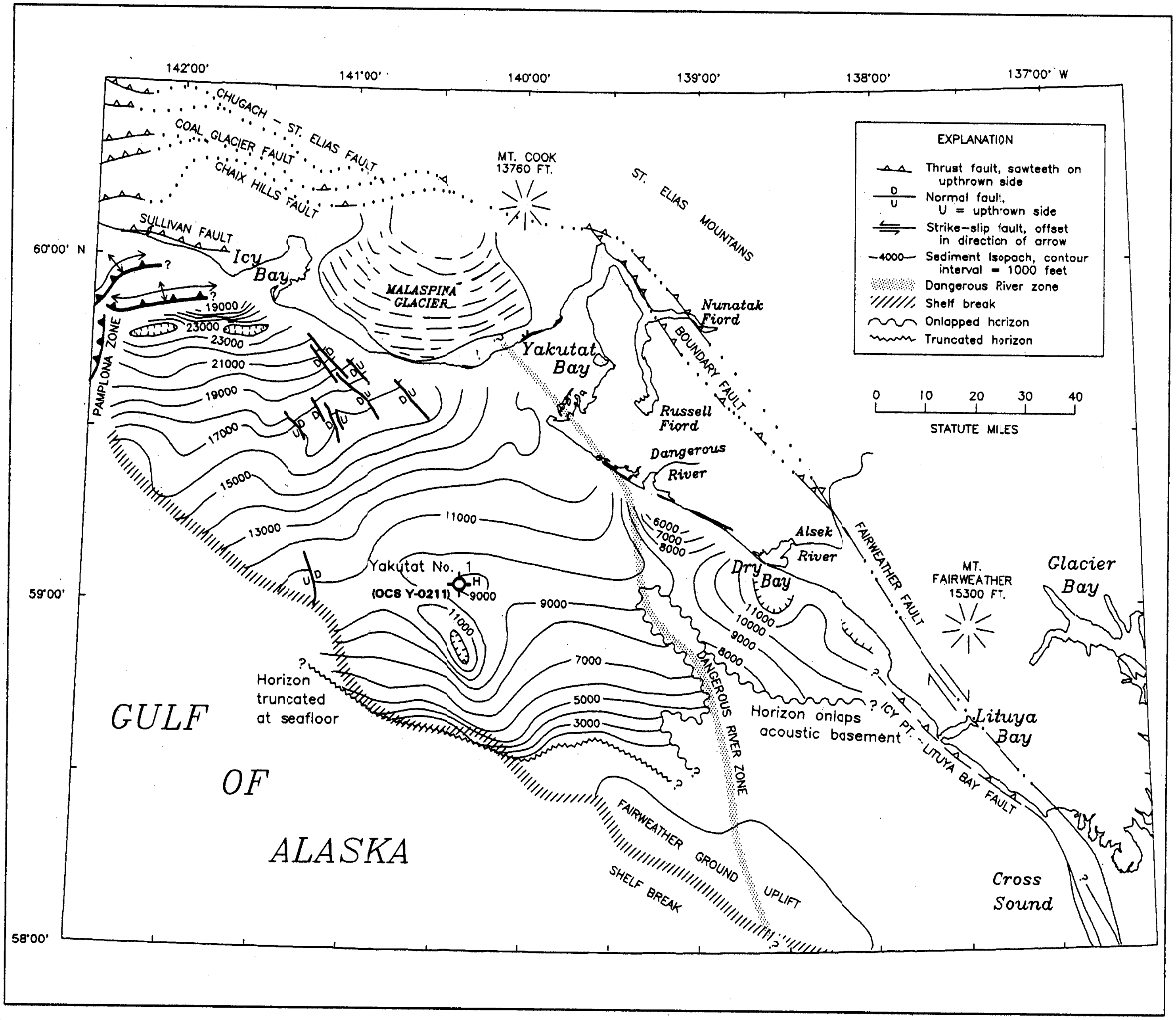


Figure 17. Structure contour map of seismic horizon Y2 on the Yakutat segment of the Gulf of Alaska continental shelf. Horizon Y2 separates late Eocene through middle Miocene age clastics from underlying Eocene strata of seismic sequence III.

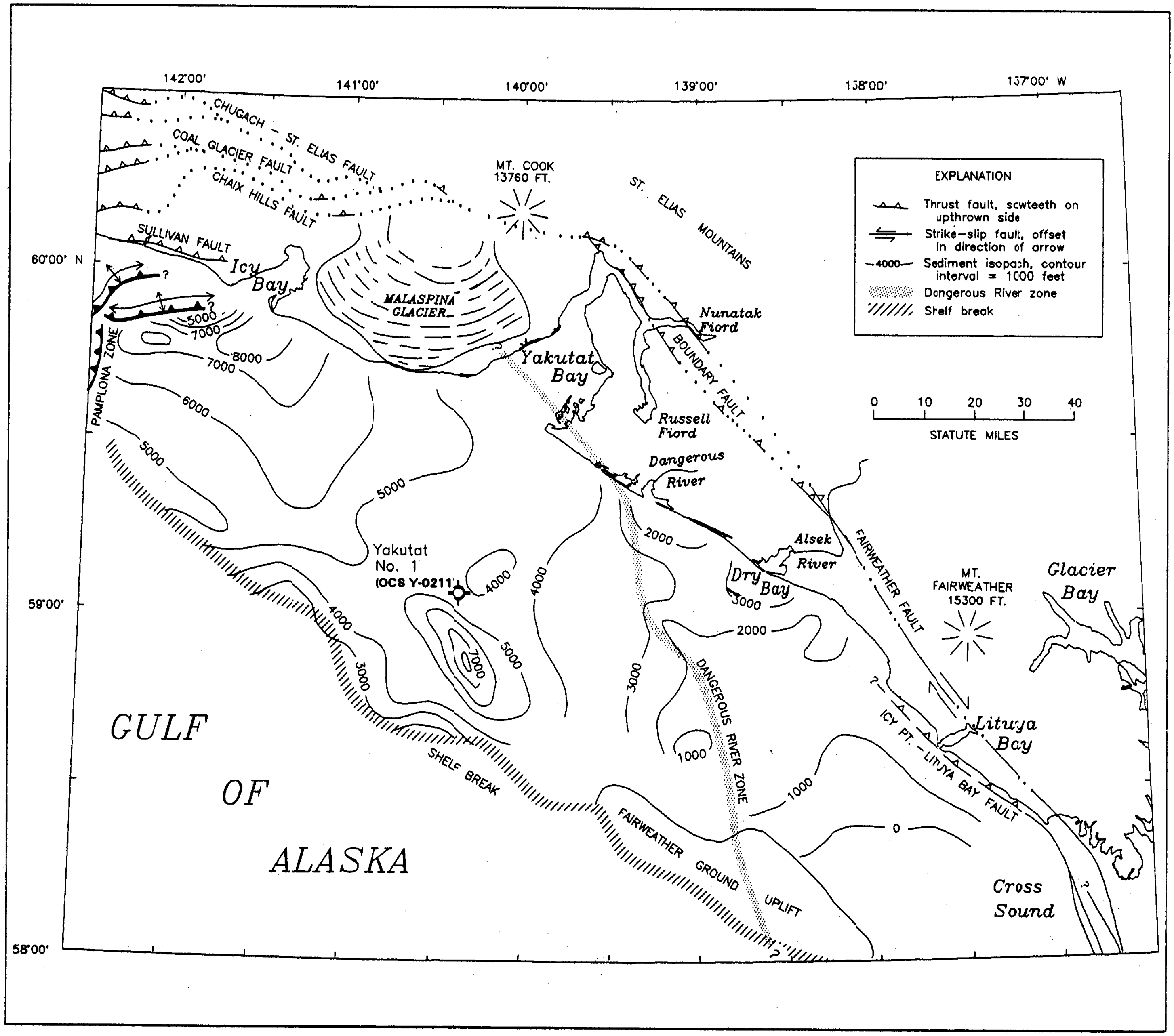


Figure 18. Isopach map of seismic sequence II on the Yakutat segment of the Gulf of Alaska continental shelf. Sequence II strata are equivalent to the onshore Poul Creek Formation of late Eocene to middle Miocene age.

separating the basement from overlying early Paleogene strata. Along the northern margin of the Fairweather Ground uplift (fig. 19), horizon Y3 is truncated at the seafloor by a combination of faulting and erosion. West of this uplift, horizon Y3 is terminated on or at the base of the slope.

Sequence III

At the OCS Y-0211 No. 1 well, sequence III is composed of late early to late Eocene deltaic marine clastic sediments (fig. 14). Sequence III strata are limited primarily to the west subbasin, west of the Dangerous River zone, except for a thin inlier section south of Dry Bay (fig. 20). Reflections within this sequence display poor to moderate continuity, and locally the section appears almost reflection free (plate 3B, line YT-5, SE end), which may indicate either a lithologically homogenous section or poor acoustic response. In other areas, reflections appear relatively strong (plate 3B, line YT-5, NW end), although some of these high-amplitude events appear to be multiples of earlier reflections. Reflections near the upper boundary of sequence III commonly display concordance or, less frequently, toplap with horizon Y2. Within the sequence reflections are generally parallel, although locally oblique progradational patterns occur (plate 3A, line YT-3, center). At the base of sequence III, reflections terminate by onlap and, less often, apparent downlap onto horizon Y3 (acoustic basement). This combination of reflection patterns and terminations indicates that sequence III strata were deposited by both progradational processes and more uniform sedimentary processes in a subsiding shelf or basinal setting. However, because of the poor seismic response and predominance of multiples within sequence III, interpretations based solely on seismic characteristics are tentative.

Sequence IV

Sequence IV corresponds to acoustic basement beneath the Yakutat continental margin (fig. 14). As previously stated, east of the Dangerous River zone the basement consists of moderately to complexly deformed and metamorphosed sediments of the Mesozoic Yakutat Group. West of the Dangerous River zone, igneous rocks unconformably underlie the Tertiary clastic section. Sequence IV reflections are typically disordered. Local high-amplitude reflections occurring below acoustic basement are not interpreted to be primary reflections (e.g., plate 3A, line YT-4, near shelf break).

Base-of-Slope

A relatively thick sedimentary section overlies acoustic basement at the base of the continental slope seaward of the Transition fault zone (plate 3B, lines 909, 967, SW ends) (fig. 21). Three seismic horizons within this sequence have been correlated using a multichannel seismic-reflection data network tied to DSDP hole 178, located east of Kodiak Island (Bruns, 1983b). Horizon A, the youngest of the mapped reflections, appears to represent basal Pleistocene. Horizon B correlates approximately to the base of Pliocene strata. Horizon C, the deepest reflection, is characterized by variable amplitude, discontinuous, and frequently hyperbolic reflections generated from the sediment-oceanic basalt interface.

In the vicinity of the slope margin, reflections from Pleistocene and younger strata overlying horizon A are typically parallel to subparallel and continuous, although locally they appear wavy and/or mounded. Bruns (1983b) attributes the wavy and/or mounded facies to deposition in a turbidite fan with buried channels and levees. The underlying sequence, bounded by horizons A and B, displays reflections of moderate amplitude and continuity. Reflections within this Pliocene unit are predominantly parallel to subparallel, indicating fairly uniform sedimentation in a stable basinal setting. The lowermost sequence, consisting of pre-Pliocene strata overlying acoustic basement, is variable in appearance. Reflection-free zones within this sequence suggest areas of nonstratification or lithologic homogeneity (plate 3B, line 967, SW end).

Southeast Segment

Shelf Platform

The offshore stratigraphy of southeast Alaska is not well known. Because there is little or no geological data from this area, the stratigraphic framework of the region is based heavily upon geophysical studies.

Acoustic basement underlying the southeast Alaska continental shelf is likely composed of well indurated, compositionally diverse Paleozoic and Mesozoic rocks that are stratigraphically equivalent to sedimentary, metamorphic, and igneous rocks exposed on nearby islands and the adjacent mainland. Refraction velocities obtained from the basement sequence in shallow intrabasinal shelf areas are relatively fast, generally greater than 16,400 feet per second (Bruns and Carlson, 1987), and are indicative of a highly indurated rock.

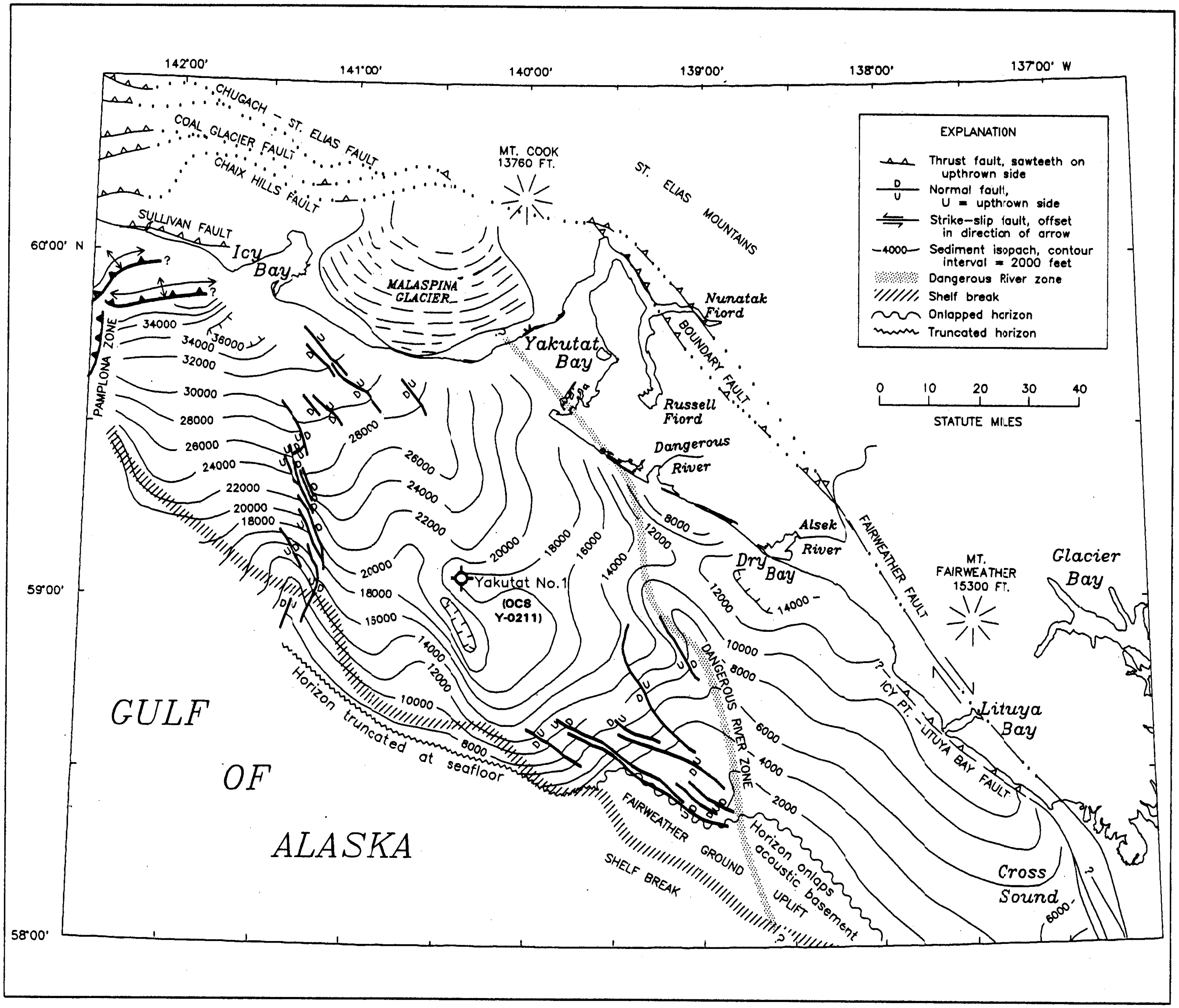


Figure 19. Structure contour map of seismic horizon Y3 on the Yakutat segment of the Gulf of Alaska continental shelf. Horizon Y3 is mapped on a prominent reflector representing acoustic basement. West of the Dangerous River zone, acoustic basement consists of oceanic basalt. To the east, metamorphosed sediments of the Yakutat Group underlie Tertiary strata.

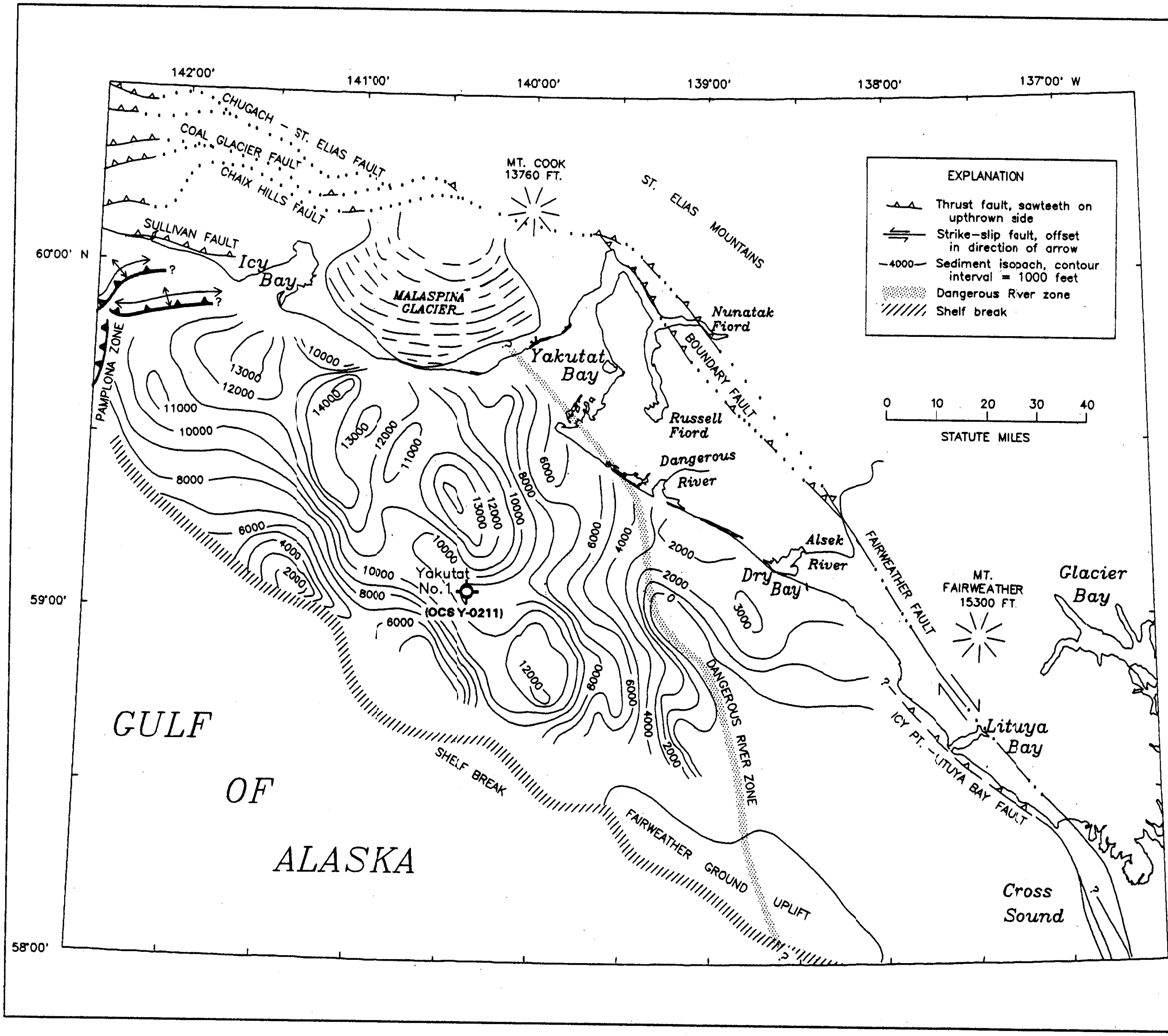


Figure 20. Isopach map of seismic sequence III on the Yakutat segment of the Gulf of Alaska continental shelf. Sequence III strata are Eocene in age and are situated predominantly west of the Dangerous River zone.

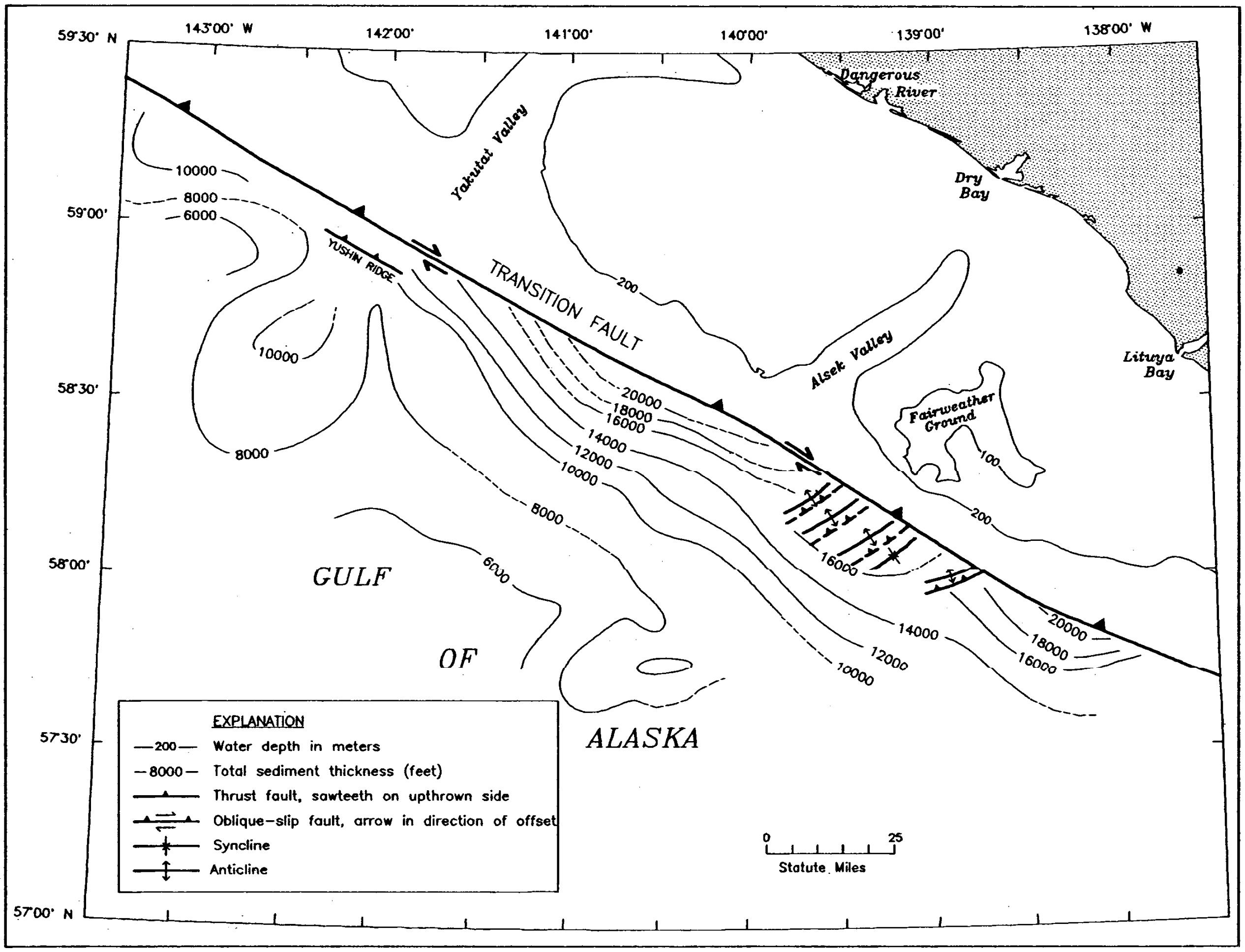


Figure 21. Isopach map of total sediment thickness between oceanic basalt and seafloor at the base of the slope adjacent to the Yakutat shelf margin.

Acoustic basement reflections vary greatly in amplitude, cycle breadth, and lateral continuity. Basement reflections from shallow intrabasinal platform areas tend to be moderate to high in amplitude and relatively continuous, expressing the high velocity-density contrast between younger glaciomarine sediments and older, more highly indurated basement rock. In deeper basinal areas, acoustic basement is represented by low-amplitude, poorly to moderately continuous reflections (e.g., Southeast Alaska subbasin, plate 4, line SE-2, center).

Strata overlying acoustic basement offshore of southeast Alaska were mapped utilizing a network of multichannel seismic-reflection profiles (fig. 22). Interval velocities derived from seismic-reflection stacking velocities were used to convert two-way reflection time to depth (fig. 8). The continental shelf between Cross Sound and Dixon Entrance is covered by a thin veneer of sediments, and is underlain in areas by small, asymmetric, fault-bounded subbasins. The age of strata overlying acoustic basement is inferred largely by correlation with adjacent stratigraphic systems. West of Cross Sound (fig. 22), shelf strata bordering the Yakutat terrane are correlated tentatively with nearby Pliocene(?) through Pleistocene glaciomarine sediments of the Yakataga Formation. However, strata on the southeast Alaska shelf are in part disjoined from rocks of the Yakutat terrane by the Fairweather fault (fig. 22 and plate 4, line SE-6). Seaward of Dixon Entrance, along the southern portion of the shelf margin, strata overlying acoustic basement are tentatively correlated with a late Miocene to Pliocene nonmarine facies of the Skonun Formation of the Queen Charlotte Basin (Shouldice, 1973; Yorath and Chase, 1981).

West of Prince of Wales Island, the southeast Alaska shelf is underlain by a small, structurally isolated subbasin containing approximately 20,000 feet of strata (fig. 22 and plate 4, line SE-2). Strata within the

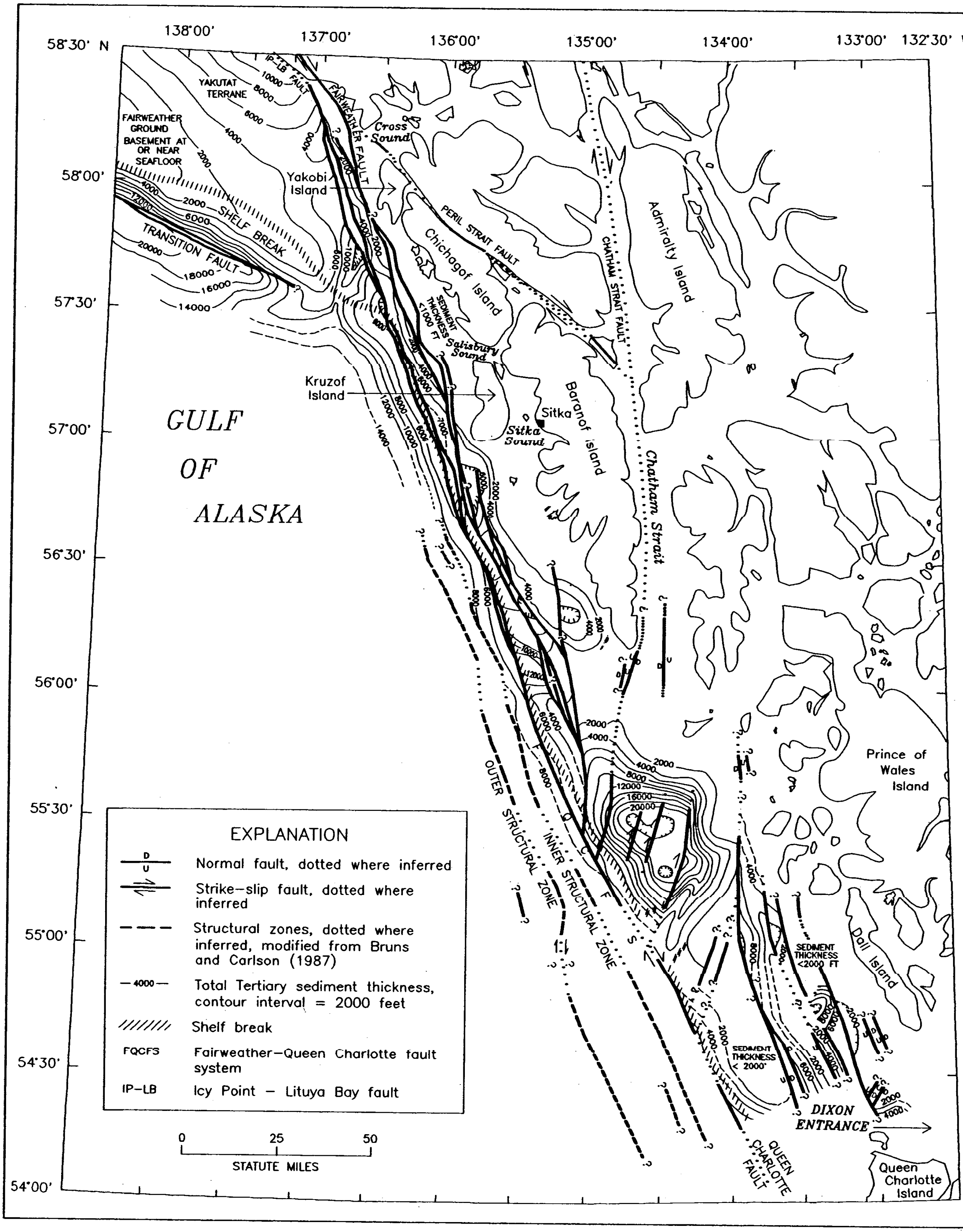


Figure 22. Total Tertiary sediment thickness and structure of the Southeast Alaska continental margin. Sediment thickness is based on local time-depth relationships derived from seismic-reflection stacking velocities.

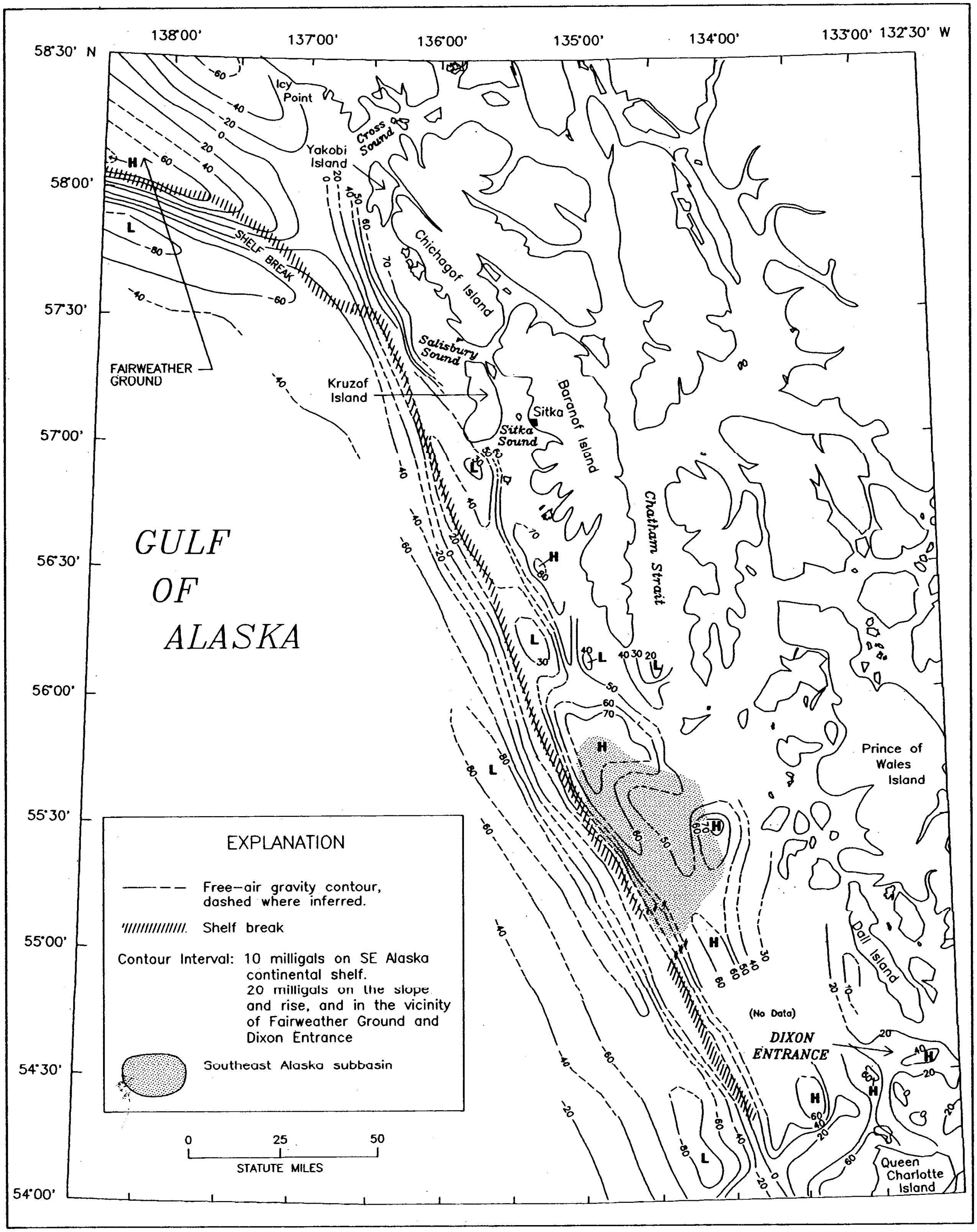


Figure 23. Free-air gravity map of the southeast Alaska continental margin. The Southeast Alaska subbasin, west of Prince of Wales Island, is not defined by a significant gravity low as would be expected for an equivalent thickness of Neogene sediments. Gravity values were compiled from Johnson (1972) and Bruns and others (1981a, b).

subbasin have been truncated by at least four major unconformities (line SE-2, UNC-1 through UNC-4). The margins of the subbasin were uplifted prior to deposition of post-UNC-3 sequences. Wrench deformation, which appears to have offset strata within the central subbasin, ceased before or coincident with the development of unconformity UNC-2. Strata between UNC-4 and the seafloor appear to be coeval to strata of the Neogene Yakataga Formation on the Yakutat terrane to the north. The age of strata below unconformity UNC-4 cannot be determined by seismic correlation, although interpretations based on seismic velocity and gravity data suggest a pre-Neogene age for these sediments. Interval velocities derived from CDP seismic-reflection data through this sequence are 10 to 30 percent greater for corresponding depths than typical Neogene values derived from Yakutat shelf sediments, suggesting a greater degree of induration. Sediment depocenters within the southeast Alaska shelf are normally expressed by a corresponding low free-air gravity anomaly (fig. 23). However, the shelf area west of Prince of Wales Island displays an associated gravity anomaly of only limited amplitude, much less than would be predicted for the mapped volume of Neogene basin fill. This relationship further enforces the proposal that basin strata underlying UNC-2 are of pre-Neogene age.

Slope and Rise

Seaward of the Fairweather-Queen Charlotte fault, the sedimentary section ranges from approximately 5,000 feet thick on the upper shelf, where reflections are largely obscured by near-surface faulting, to greater than 14,000 feet thick along the inner rise (figs. 22 and 24). Slope and rise strata are deformed along two linear structural zones that probably were generated by wrench tectonism (fig. 24) (see chapter 4). The sedimentary section along the base of the slope is middle Miocene and younger in age, based on correlation of seismic-reflection profiles to DSDP hole 178, Kodiak shelf (von Huene and others, 1979; Bruns, 1983b, 1985b; Bruns and Carlson, 1987), and on the middle Miocene age of oceanic magnetic anomalies on the adjoining Pacific plate (Naugler and Wageman, 1973; Berggren and others, 1985).

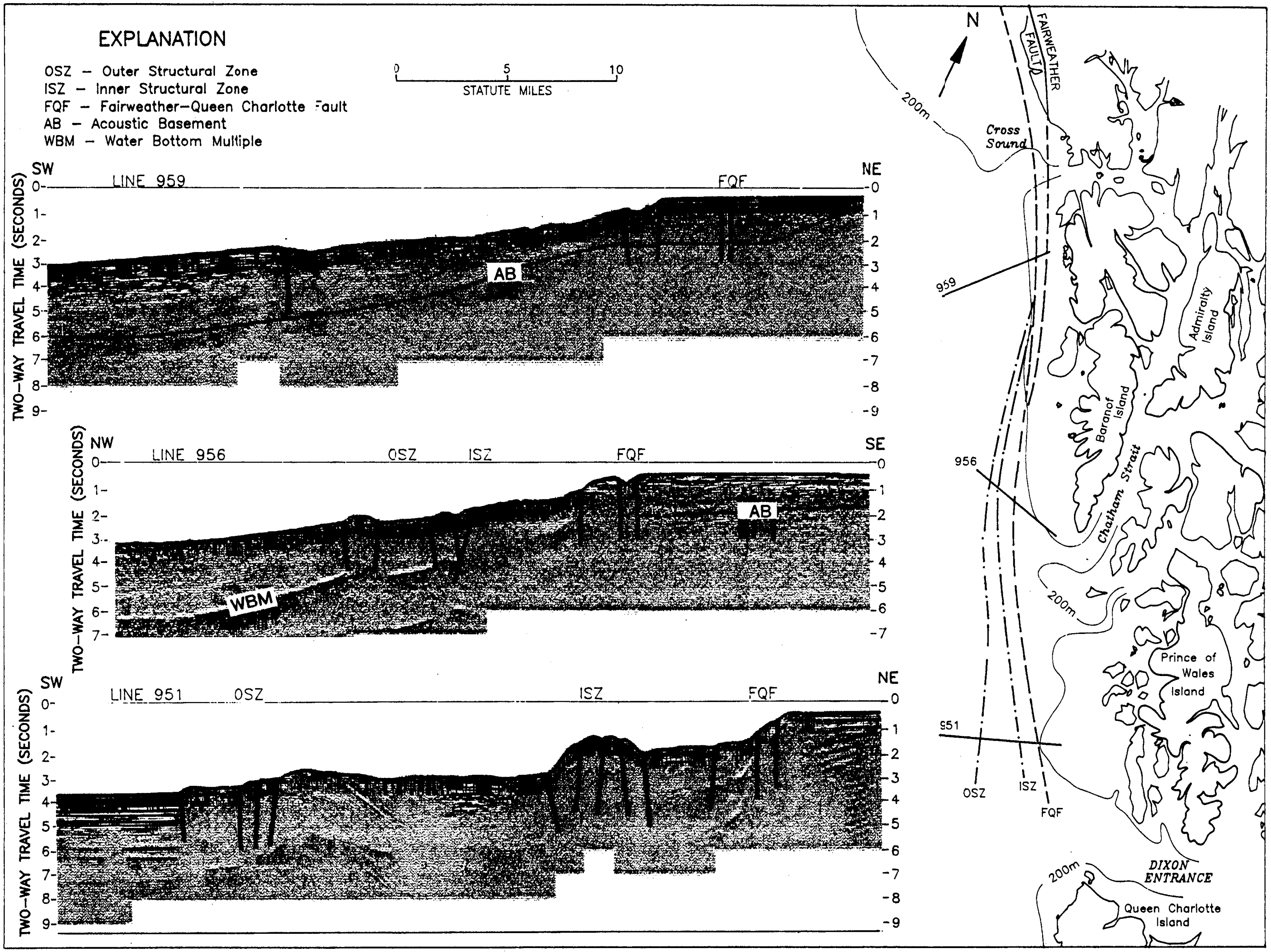


Figure 24. Multichannel seismic-reflection profiles across the shelf margin, southeast Alaska, showing the Fairweather-Queen Charlotte fault system and inner and outer structural zones. Deformation along structural zones, which probably reflects wrench fault activity along splays of the Fairweather-Queen Charlotte fault system, decreases in intensity to the north (von Huene and others, 1979; Snavely and others, 1981; Bruns, 1985b; Bruns and Carlson, 1987).

LOST LIFE ON RIVER

How John Davis Met His Death

BODY EATEN BY WOLVERINES

The Horrible Story of Death in the Arctic Winter, As Told By Emil Shubeck, a Hunter and Trapper in the Copper River Country.

After spending thirteen months continuously in the Copper river basin, at Abercrombie canyon, Emil Shubeck, blond and hairy, came into town this week none the worse for his long period of isolation.

Shubeck was formerly a guide for the survey parties of the Alaska Pacific Railway & Terminal company; later he became a hunter and trapper, and as such he has been employed for several months in the Copper river country.

In The Herald of August 10 was told a brief story of the finding of the bones of a man last February near a deserted cabin on Copper river. The dead man's name was given as Jones, but according to the statement made by Shubeck, who found what the wolverines had left of the body, the man was John Davis, an Australian of twenty years' residence, who went up to Childs Glacier in the employ of J. Stevens, of Valdez, who had located a homestead on the river. On Monday last Shubeck went to Judge Britton's office and formally notified him of his gruesome find.

According to Shubeck's story Davis came up to his (Shubeck's) camp near the rapids on Dec. 26 last year. The weather was cold and windy and Davis remained there eight days. Then he started down the river, despite Shubeck's advice to remain with him until the weather was better. This was the last seen of him alive.

On Feb. 26, last Shubeck left his cabin for Martin river. At an abandoned railroad cabin he saw two guns standing beside the door, and a sack was tied to a pole, evidently as a signal, but he saw no sign of hunan footsteps or life. He called but got no answer. Shubeck then started back to his own cabin, and when about four miles from Childs' glacier, he saw a black spot on the ice of the river; he looked again and saw several smaller spots. "It looked me not good", said Emil in relating his pathetic story. So he went over to the place and found poor Davis' body. The legs, back and hands and arms and a part of the head had been

FLOW OF CRUDE OIL

Five Barrels a Day On Mirror Slough

Out on Mirror slough Maj. S. L. Lovell, manager of the Alaska Coal-Oil Company of Portland, Ore., is conserving the flow of oil found some time ago on the Carless-Barrett-Sinclair property, which he has under lease, and he is saving about five barrels a day. This product he may use for fuel to operate the rig he is erecting or he may conclude to market it. Some of this oil was sent to Cordova to be tested for its value as a lubricant on the railroad, and Master Mechanic Van Cleave reported to Maj. Lovell that it answered the purpose quite as well as the imported refined article.

Maj. Lovell was in town this week from Mirror slough, looking for a boiler for use at his plant. Some parts of his drilling outfit were lost in a railroad wreck in California, while in transit, but he will be able to operate with the machinery he was able to get here, including a boiler. The timbers and other ... are now ... for the plant at the Katalla camp 7, and have the drill

TWO MORE OIL RIGS FOR MARTIN RIVER

...is expected that within a short ...hree oil rigs will be drilling full ...ut on Martin river. Major ... expected with a first class rig ...rtland, and C. F. Sinclair has ...umental in organizing a ...y which will install two ...nd in the Martin river ...ing to Sinclair, Carless, ...ningham. One of the will be that of Cunningham is now located near

THE DIGGINGS OF YAKATAGA

BIG NUGGETS ARE FOUND

...e Thompson and Associates Lease Their Holdings, and the Judge and His Son Will Commence Practice of Law at Katalla.

The Yakataga beach diggings are producing considerable gold, according to a statement made by Judge Julius Thompson, who with Mrs. Thompson and Mrs. Arthur G. Thompson, arrived from Yakataga Sunday morning. With his son, Arthur G. Thompson, Judge Thompson has been engaged in placer mining at Yakataga for the past four ...rs, where they have large holdings, ... lease to other parties. ... as much as $48 have ...nds, and just ...its is ...al. ... of ...y be ...chills ...skirt ...ry. ...uthority ... believes ...developed ...and around ...siastic be... and for ..., with their ... locate in Katalla ...actice of their

TO-NIGHT

GRAND ATHLETIC EXHIBITIO...

...ment of the Katalla Athletic Club, C. L. Brocke...

PIONEER HAL...

"The Ter...

ROUND B...

ONLY LYNCHING IN ALASKA

The only lynching that ever took place in Alaska occurred in January, 1898, at Copper City, one mile from where the thriving town of Valdez now stands. The victim of lynch law was a man named Tanner, a desperado from Montana who, one evening, in cold blood shot and killed two men who had befriended him. There were some fifty men encamped at Copper City, and they quickly gave the murderer a "short shrift and a long rope," hanging him to the limb of a tree until he was dead.

...cording to Otto Hanson, now a ... Katalla, and who was a ...th of Tanner, the lat... rope was ad...ras: "You may ... but remember ...st shot that ever ...a." Tanner died

MISS BENEDICT'S GRAVE CHARGES

Miss Mabel Benedict, a teacher in the Jessie Lee home at Unalacka, has made astounding statements to the Seattle Ministerial association concerning the manner in which women at Unalaska have been treated by the sailors attached to the United States revenue cutters and gunboats. She says that white women have been harassed and insulted and forced to defend their homes and virtue against these deep water invaders, while native women have been torn from their homes and ravished, and robbed and assaulted.

Capt. E. P. Bertholff of ... cutter Bear, and Assistant ...torney Ray of Valdez ...dict story flatly, and ... that Miss Benedict ...attle ministers h... ...ges to the attention

- AT THE SEATTLE AND N...

...of Trade

...zes, Flips, Gins

...of Katalla" Give...

BIG OIL SEEPAGE ON MARY'S CREEK

A fine flow of oil was found this week on Elaine claim No. 5, located on Mary's creek, near Redwood, while assessment work was being performed. This claim is one of a group owned by Judge Britton, A. C. Williams, William Carless, Walter Edkins and others. The seepage was found in an open cut which was run into a bank, and the ... rises at or near bedrock. ... where ... Both

Northern Cafe and... ...company from the ...al & Oil company, the Northern Oil ...y at Redwood, was ... from Bering lake, ...s located. The casing

Portland

Sailing ... or about the 25th of each

...ject to Change Without

For further Information

ALASKA

4. Structural Geology

Middleton Segment

The Middleton segment of the Gulf of Alaska continental margin is underlain by rocks of the Prince William terrane and reflects convergence of the western end of the Yakutat terrane with the inboard terranes of southern Alaska (fig. 25). The Kayak zone, an area of uplift and structural shortening, bounds the Middleton shelf to the east. Seaward, the Pacific plate is subducting beneath and truncating the shelf margin along the active Aleutian subduction zone.

Shelf Structure

The continental shelf of the Middleton segment is characterized by zones of faulted and anticlinally folded strata that trend northeastwardly, and separate areas of local synclinal deformation (figs. 7 and 25, and plate 1). The faults typically display high-angle reverse or thrust offset, with the upthrown side to the northwest. Antithetic faulting is less common and not as well developed. Anticlines associated with the thrust and reverse faults are asymmetric and typically display stratal truncation along the bounding fault.

The central Middleton shelf can be subdivided into five principal zones based on structural associations and orientation of fold and thrust features (fig. 25). Within each zone, strata have been uplifted along parallel axes by reverse faulting and anticlinal folding. The crests of the uplifted zones are commonly truncated, exposing late Miocene and possibly older strata at the seafloor. At three locations, Wessels Reef, Middleton Island, and Fountain Rock, strata within the uplifted zones are subaerially exposed. Structural deformation of all five zones occurred predominantly during the middle to late Pleistocene and later. This deformation appears to have occurred rapidly and simultaneously throughout the Middleton shelf area, with the later deformation continuing to the present time, though at a decreased rate.

Evidence of active tectonism on the Middleton shelf is apparent at Middleton Island, where uplift is occurring at a rate of approximately 1 cm/yr (Plafker, 1969; Plafker and Rubin, 1978). Seafloor offset is apparent across faults at the crests of zones of deformation, indicating many of the reverse and thrust faults are or have been recently active (plate 1, all lines). Along the flanks of the thrust zones even the youngest strata display thinning and/or uplift.

A structurally positive linear feature located southeast of Montague Island, informally designated the Middleton transverse high, trends in a southeasterly direction across the shelf nearly perpendicular to the principal zones of deformation (figs. 7 and 25). Tertiary strata on the flanks of the transverse high have been uplifted and erosionally truncated at the seafloor. Along other portions of the high, strata terminate against the uplift by reverse or thrust faulting. Seismic-reflection profiles across the margins of the high show thinning of late Miocene and younger strata, suggesting ongoing uplift since at least that time. Poor acoustic response from strata beneath the base of the Yakataga section precludes an interpretation of events occurring before the late Miocene. The mechanism of uplift for the Middleton transverse high has not been determined, although it may be related to subduction at the Aleutian trench of a detached piece of the southwest margin of the Yakutat terrane. The southeast end of the high crosses the continental slope at a point where the Aleutian subduction zone disappears beneath the slope, and east-west oriented anticlinal deformation prevails to the east along the base of the Yakutat terrane (fig. 25).

Extending from Wingham and Kayak Islands southwest across the continental shelf and slope, the Kayak zone represents the offshore boundary between the Prince William and Yakutat terranes (fig. 25) (Bruns, 1985b; Plafker, 1987). On seismic-reflection profiles, the Kayak zone appears as a tectonically uplifted region, often reflection free, bounded by and incorporating predominantly up-to-the-northwest high-angle reverse faults (plate 1, line MI-1, south end). The absence of reflections and the widespread presence of diffractions in parts of the Kayak zone suggest that the strata are steeply dipping and intensely deformed, analogous to strata exposed on Kayak Island (Plafker, 1974).

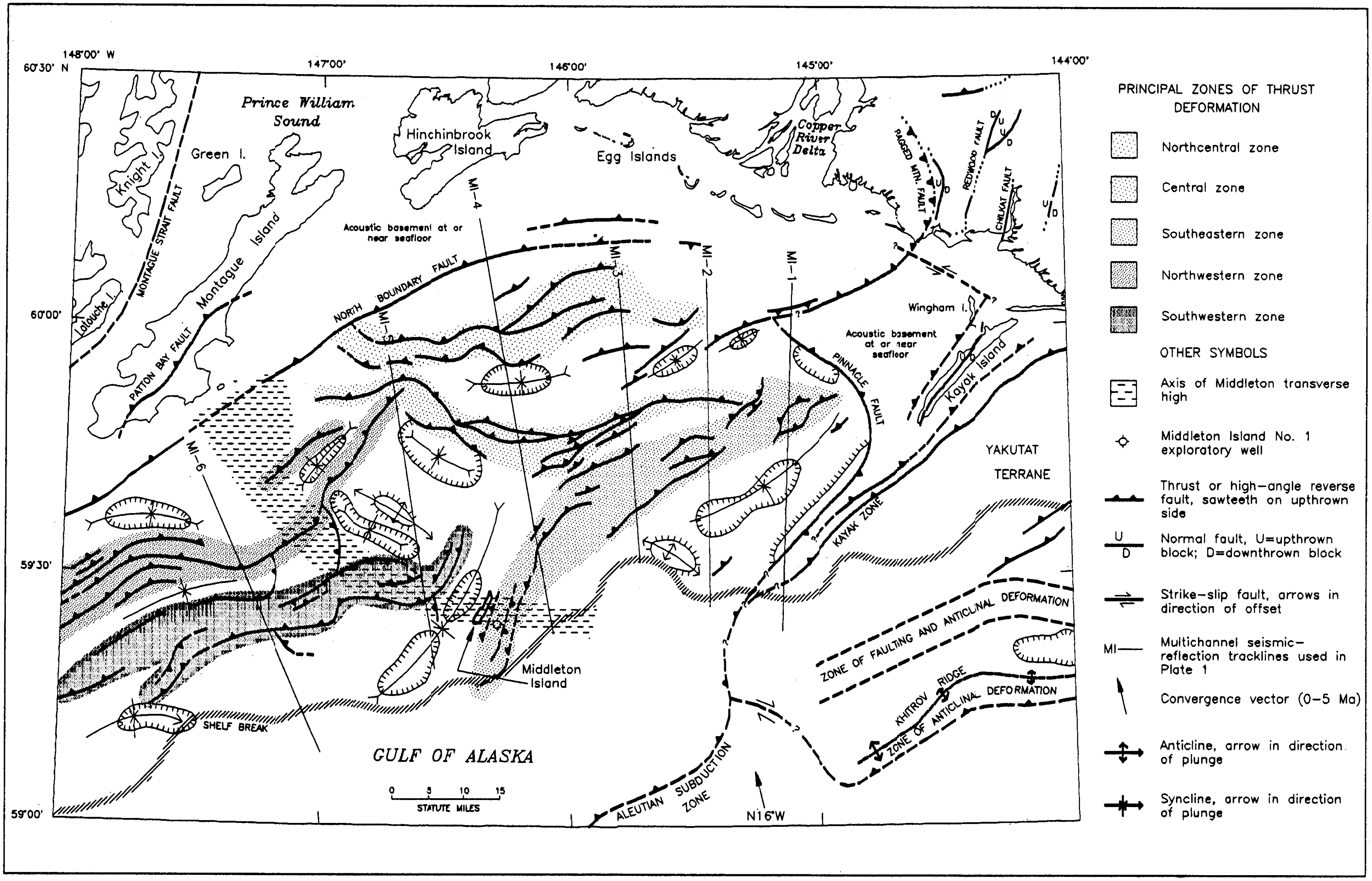


Figure 25. Structural elements of the Middleton segment of the Gulf of Alaska continental margin, including principal zones of thrust deformation, structural highs and lows, and significant tectonic elements. Onshore faults are adapted from Plafker (1967, 1974) and Winkler and Plafker (1981). The convergence vector is from Engebretson and others (1985).

Geologic mapping on Kayak and Wingham Islands revealed a steeply dipping or overturned sedimentary section imbricated by numerous en echelon up-to-the-northwest reverse faults (Plafker, 1974; Winkler and Plafker, 1981). The high degree of reverse faulting and deformation displayed along the Kayak zone suggests that this region is a major zone of structural shortening.

Onshore, the boundary between the Prince William and Yakutat terranes is the Ragged Mountain thrust fault (fig. 25; plate 1, line MI-1, north end). The Ragged Mountain fault separates the highly deformed pillow basalts and deep-water sediments of the Orca Group from deformed Paleogene marine strata to the east (Winkler and Plafker, 1981). The Ragged Mountain fault extends offshore in a southwesterly direction for about 40 miles, eventually merging with structures within the central thrust zone (fig. 25). Seismic profiles across the offshore segment of the fault display high-angle, up-to-the-northwest reverse offset. The timing of thrusting on the offshore extension of the Ragged Mountain fault is difficult to determine. However, the offset of reflections at or near the seafloor along portions of the fault suggests that tectonic movement may have occurred as recently as the Holocene. Onshore, a minimum of 4 miles of eastward-directed thrusting has been documented (Bruns, 1985b).

The Pinnacle fault juxtaposes a thick section of Neogene and Pleistocene glaciomarine strata against rocks to the east that are interpreted to be intensely deformed Paleocene and Eocene rocks of the Orca Group (fig. 25; plate 1, line MI-1, north end). The fault is characterized by high-angle, up-to-the-east reverse offset. The uplifted volcanics and deep-marine strata of the Orca Group east of the fault are defined by a large positive aeromagnetic anomaly (fig. 26). To the north, the Pinnacle fault is abruptly truncated by the Ragged Mountain thrust fault. Late Pleistocene and Holocene strata adjacent to the western downthrown side of the fault display internal thickening in the direction of the fault (line MI-1, north end), indicating that significant offset along the fault occurred during this period.

Middle to late Cenozoic strata of the Middleton shelf are largely terminated to the north and northwest by the North Boundary fault, which exhibits up-to-the-north high-angle reverse offset (plate 1, line MI-4, north end; fig. 25). Rocks underlying the shallow acoustic basement landward of the North Boundary fault and south of Hinchinbrook and Montague Islands are highly magnetic (fig. 26) and have high seismic-refraction velocities (13,125 ft/sec; Bruns, 1985b), which are indicative of the well-indurated and altered volcanic and sedimentary strata of the Orca Group.

Filtered aeromagnetic data from the central Middleton shelf display numerous negative anomalies that appear to correlate geographically to elongated areas of recent uplift within the principal zones of structural deformation (fig. 26). A. Griscom of the U.S. Geological Survey (written communication, 1991) interprets these magnetic lows as originating from reversely magnetized Pleistocene glaciomarine sediments of the upper Yakataga Formation. Uplift within the structural zones has exposed rocks deposited during the Matuyama/Brunhes magnetic reversal (older than 730,000 years) that possess reverse remanent magnetization.

Slope and Base-of-Slope Structure

The base of the Middleton continental slope is marked by the Aleutian subduction zone, the site of the convergence of the Pacific and North American lithospheric plates (figs. 9 and 25). The convergence vector between the plates is calculated to be N16°W (Engebretson and others, 1985), or nearly normal to the shelf margin. A seismic-reflection profile across the slope and base-of-slope reveals relatively undisturbed Neogene and younger strata overlying oceanic basalt and extending shelfward beneath sediments of the lower slope (fig. 9). Underthrusting of bedded oceanic sediments beneath the continental slope appears to be occurring along a low-angle decollement, with only minor deformation of overlying strata (Bruns, 1985b). No appreciable accretion of offscraped sediment is apparent along this portion of the subduction complex.

Yakataga Segment

The western portion of the Yakutat terrane, located between Icy Bay and the Ragged Mountain-Kayak zone, is overlain by intensely folded and thrust-faulted Tertiary strata (fig. 27). The complex structure displayed in this region is the result of oblique compression between the Pacific and North American plates. Seismicity suggests that the major present-day component of convergence is being accommodated along northward-dipping thrust faults and associated folds within the onshore margin of the Yakutat terrane (Lahr and Plafker, 1980; Perez and Jacob, 1980). The zones of complex faulting and anticlinal deformation that trend across the Yakataga shelf and shelf margin can be traced

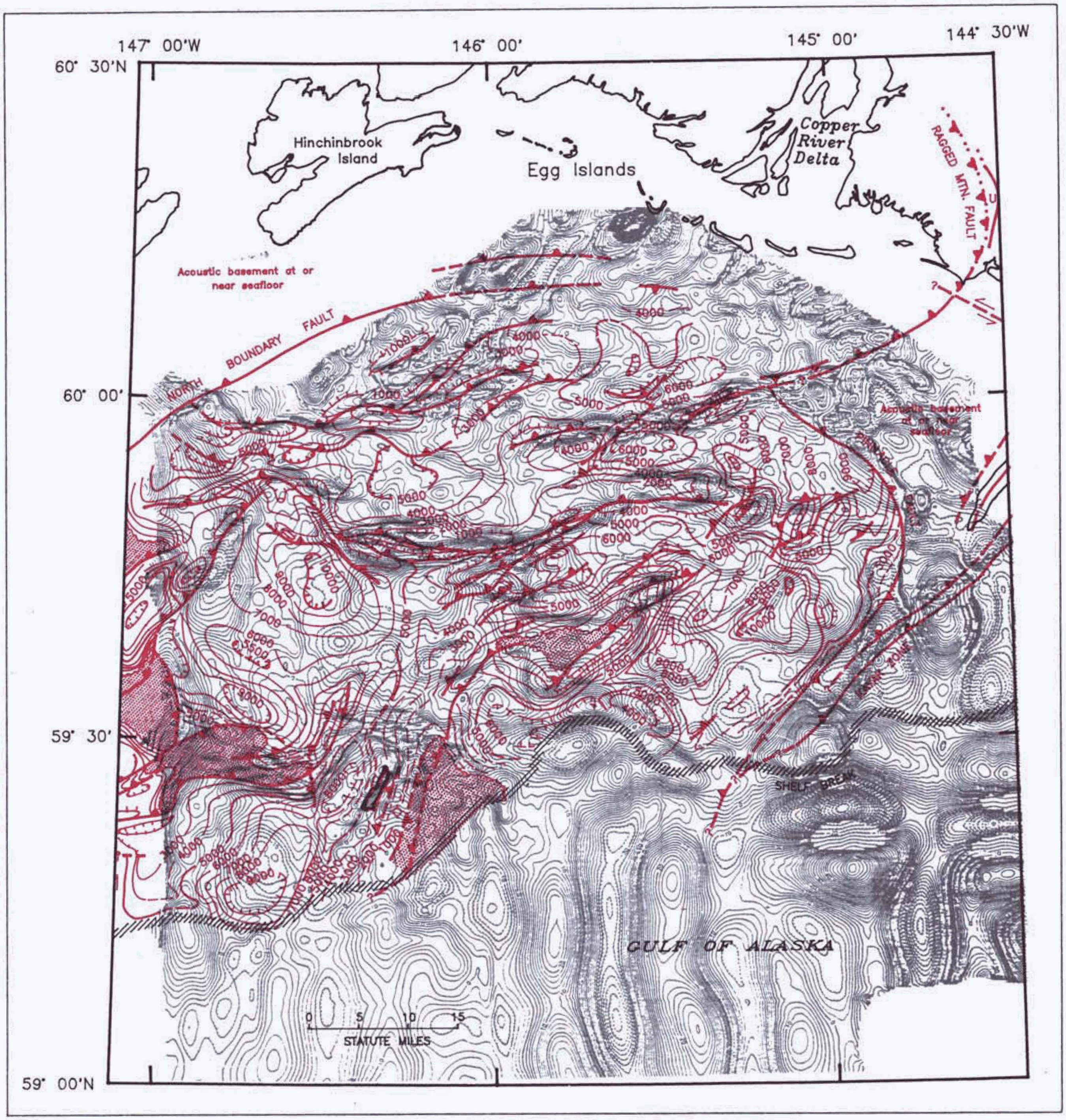


Figure 26. Grey contours display residual magnetic field of the Middleton segment of the Gulf of Alaska. Wavelengths greater than 25 km have been removed. Contour interval = 2 gammas. Filtered magnetic data courtesy of A. Griscom. Structure contours, in red, are mapped on the base of the Yakataga Formation. Contour interval = 1000 feet (see figure 7 for explanation of symbols). Notice the correlation between shallow, elongate negative magnetic anomalies and zones of thrusting and structural uplift. These magnetic lows are interpreted to reflect uplifted areas of reversely magnetized Pleistocene glaciomarine sediments of the Yakataga Formation (A. Griscom, written communication, 1991).

to the west, where they merge with the Aleutian subduction zone south of Kayak Island.

Shelf and Slope Structure

The Yakataga shelf and slope are characterized by northeast-southwest-striking thrust faults, large compression folds, and linear zones of complex fault and anticlinal deformation (fig. 27). The average strike of the structures is approximately N65°E, which is reasonably consistent with the present-day (0-5 Ma) relative convergence vector of N16°W calculated for the region (Chase, 1978; Minster and Jordan, 1978; Engebretson and others, 1985). Interpretation of seismic-reflection profiles reveals a complicated history of southeastwardly progressive structural growth across the Yakataga shelf and shelf margin. The deformational history of each anticlinal zone is unique, but typically involves an initial episode of rapid uplift followed by a period of quiescence or, less commonly, subsidence. Subsequent periods of reactivation have modified many of the observed structures. An extensive study of the structural growth of selected anticlinal structures on the Yakataga shelf is presented in Bruns and Schwab (1983).

Anticlines underlying the Yakataga segment of the continental shelf are typically elongate and doubly plunging (fig. 27). Individual anticlines range from 6 miles to greater than 20 miles in length and 2 to 4 miles in width. The anticlines are commonly bounded on the seaward side by high-angle, northwestwardly dipping thrust faults. Antithetic faults are present locally on the landward side of the anticlines. Dips on the flanks of the anticlines are generally less than 15 degrees, although dips of greater than 30 degrees have been recognized (Bruns, 1985b).

The eastern and southern boundaries of the Yakataga segment are marked by a zone of relatively young anticlinal structural deformation, the Pamplona zone, and its seaward extension (figs. 13 and 27; plate 2, lines YG-5, 6). The Pamplona zone is underlain by northwestward-directed thrust faults, and represents the most southerly and eastwardly migration of the Yakataga fold-and-thrust belt. Deformation within the Pamplona zone appears to have originated in the middle to late Pleistocene and continues into the present. At the western margin of the Yakataga segment, the Kayak zone separates strata of the Yakataga fold-and-thrust belt from sediment overlying the Middleton shelf to the west (fig. 27). The Kayak zone, exposed on Wingham and Kayak Islands, consists of Kayak Island and its structural extension offshore to the southwest, the Kayak Island platform (Bruns and Schwab, 1983), and delineates an area of complex thrust faulting and intense folding (Plafker, 1974).

The greatest degree of deformation on the Yakataga shelf and slope appears to have occurred in latest Pliocene and Pleistocene time (Bruns and Schwab, 1983). However, the limited resolution of seismic-reflection profiles inhibits the recognition of structure within Miocene and older strata. Seismic mapping reveals a pattern of time-transgressive deformation on the Yakataga shelf, with the oldest deformation in the northwest and progressively younger deformation to the southeast. Deformation appears to have occurred as a continuous transgressive process across the shelf and shelf margin, rather than as a series of independent tectonic events. Structural deformation along the outer, southeastern margin continues to the present, as is evidenced by uplifted and truncated strata at the seafloor. Numerous older anticlinal structures to the northwest appear to have undergone one or more periods of structural reactivation. Structural deformation during the periods of reactivation was modest, however, compared to the initial structural development.

Structural shortening across the Yakataga fold-and-thrust belt is a consequence of relative convergence between the Pacific plate, the Yakutat terrane, and inland terranes of the North American plate. A measurement of structural shortening across the Yakataga segment provides an estimate of the extent and rate of convergence of the plate margin. The amount of shortening on horizon K4 (late Pliocene) on the central Yakataga shelf was calculated along several seismic profiles by restoring the strata to a horizontal position and removing apparent slip along thrust faults. From this restoration, it is estimated that 1 to 1.25 miles of structural shortening is attributable to folding, and 1 to 1.75 miles of shortening is the result of thrust faulting. This is generally consistent with values derived by Bruns (1985b) of 2 km (1.2 miles) of shortening due to folding and 4 km (2.5 miles) attributed to faulting. The inconsistency in calculated values for shortening due to overthrusting may be caused by different assumptions of dip values on thrust faults. Values calculated for shortening due to thrust faulting are minimum estimates, as substantial imbrication may exist along the fault planes at a scale not resolvable on available seismic-reflection data (Bruns and Schwab, 1983). Although the magnitude of structural shortening on the slope adjacent to the Yakataga shelf is difficult to determine because of complex faulting and folding

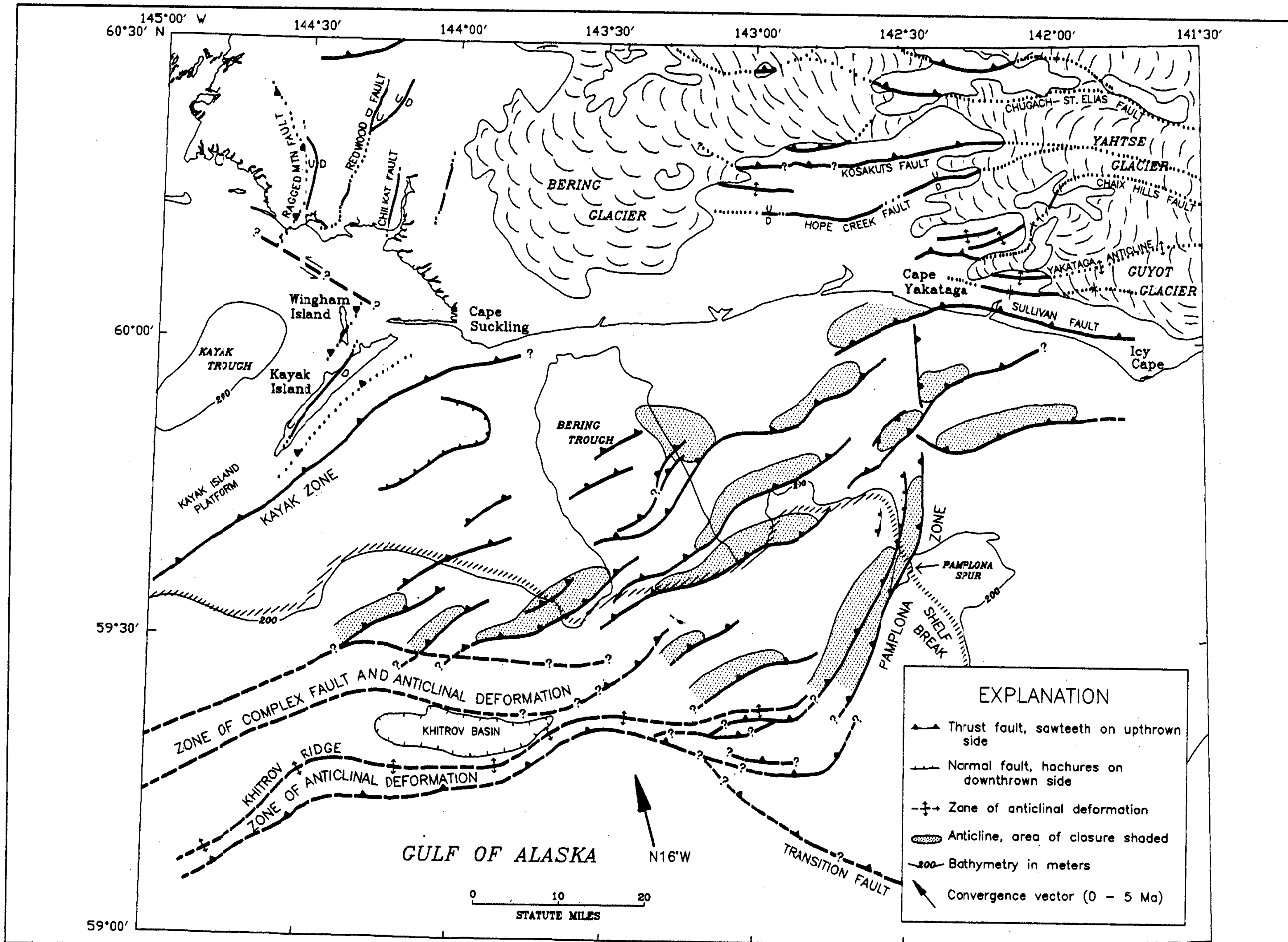


Figure 27. Structural elements of the Yakataga segment of the Gulf of Alaska continental margin, including areas of structural closure, major faults, and zones of anticlinal deformation. Onshore faults were adapted from Plafker (1967, 1974, and 1987), Winkler and Plafker (1981), and Nelson and others (1985). The convergence vector is from Engebretson and others (1985). Zones of complex deformation seaward of the shelf break are in part modified from Bruns and Schwab (1983).

within anticlinal deformed zones (figs. 13 and 27), it is estimated to be in excess of 2 miles.

Base-of-Slope Structure

The base of the continental slope adjacent to the Yakataga shelf is marked by an abrupt zone of late Pleistocene and recent anticlinal deformation (fig. 13, lines 922, 928). This zone, which includes Khitrov Ridge and the off-shelf extension of Pamplona Spur, is expressed at the seafloor as a linear bathymetric high. On the seaward side, this linear anticlinal zone is bounded by one or more landward-dipping thrust faults, and may be underlain by uplifted oceanic strata (Bruns, 1985b). Seaward of the deformed zone, relatively undeformed abyssal fan sediments overlie Paleogene oceanic basalt.

Yakutat Segment

The Yakutat block, that portion of the Yakutat terrane east of the Pamplona zone, is overlain by relatively undeformed strata that are absent the compressional folds and thrusts that characterize equivalent Cenozoic sediments within the Yakataga segment. Sedimentation on the Yakutat shelf reflects various types of structural controls, including regional and local basement subsidence, uplift, paleotopography, and, to a lesser degree, faulting. Seaward of the shelf area, tectonic plate reorganization has juxtaposed Oligocene oceanic crust with the Mesozoic and younger rocks of the Yakutat block (Naugler and Wageman, 1973; Bruns, 1982b).

Shelf Structure

Major structural features of the Yakutat segment of the shelf include: (1) the Dangerous River zone, a possible Paleogene shelf edge, (2) the Fairweather Ground uplift, an elongate structural high along the shelf margin southwest of Lituya Bay, (3) the "Fairweather Ground rift zone," adjacent to and north of the Fairweather Ground uplift, (4) the Yakutat fault zone, a narrow zone extending from east of Icy Bay south across the shelf, and characterized by numerous small discontinuous basement-controlled faults, and (5) two subbasins, herein referred to as the West Yakutat and East Yakutat subbasins, separated by the Dangerous River zone (fig. 28).

The Dangerous River zone is identifiable on seismic-reflection profiles and structure contour maps by a rapid shallowing of acoustic basement from west to east and a change in structural trends (fig. 19). Across most of the shelf, the Dangerous River zone is coincident with a Paleogene basement high, a northwest-southeast-trending structural high separating the West Yakutat and East Yakutat subbasins (figs. 28 and 29). Seismic profiles over the Paleogene basement high reveal that sequence III and basal sequence II strata are terminated by faulting and progressive onlap against this positive structural feature (fig. 29). Little, if any, stratal deformation is apparent adjacent to or above the Paleogene basement high, which suggests that the high was formed before deposition of sequence III strata (pre-Eocene?). This high was a positive structural element until late Eocene or early Oligocene, when it was buried beneath sequence II sediments.

The Dangerous River zone crosses the Fairweather Ground uplift and is truncated at the Yakutat shelf margin (fig. 28). In the vicinity of the Fairweather Ground uplift, the Dangerous River zone is not well defined. The Paleogene basement high to the north may have extended south to the shelf margin, but subsequent uplift centered near Fairweather Ground resulted in erosion and loss of both Tertiary and upper pre-Tertiary section and structure. However, the southern extension of the Dangerous River zone has been recognized on the continental slope, where dredge samples indicate an abrupt lateral east-west transition from Yakutat Group metasediments to probable Paleogene basalt (Plafker and others, 1980; Plafker, 1987).

The northwest extension of the Dangerous River zone appears to underlie the Colorado Oil and Gas Yakutat wells on the Yakutat foreland southeast of Yakutat Bay (Bruns, 1982b). Here, the Paleogene section is thin, typically less than 1,000 feet. In a distance of only 6 miles, the Paleogene section thickens from 750 feet onshore in the Yakutat No. 2 well to greater than 10,000 feet in the offshore basinward of the Dangerous River zone (plate 3A, line YT-2, NE end). Farther northeast, at the entrance of Yakutat Bay, the Dangerous River zone is expressed on seismic-reflection profiles by rapid shallowing of acoustic basement and truncation of Paleogene strata by erosion, faulting, and onlap (plate 3A, line YT-3, NE end). Uplift to the north of and along the Dangerous River zone near Yakutat Bay prior to horizon Y1 time (early Miocene?) appears to have resulted in landward termination of sequence II by onlap and erosion. Thinning of sequence III on the flank of the basement high suggests uplift may have been initiated during early Paleogene time. However, detailed structural interpretation in this area is difficult

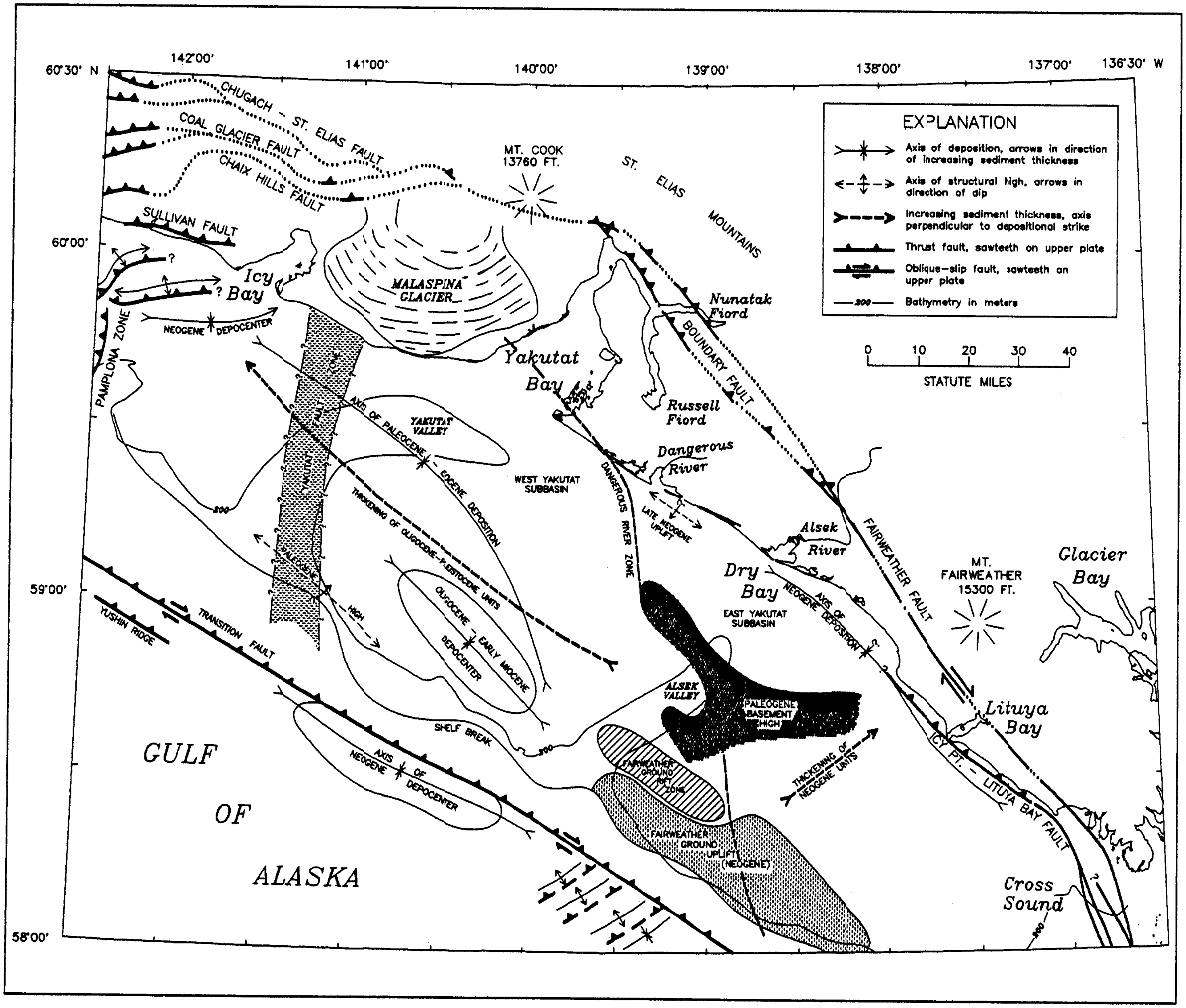


Figure 28. Structural elements of the offshore Yakutat continental margin including the Transition fault, Fairweather Ground uplift, Paleogene basement high, Fairweather Ground rift zone, Yakutat fault zone, and the dominant depositional and stratigraphic trends.

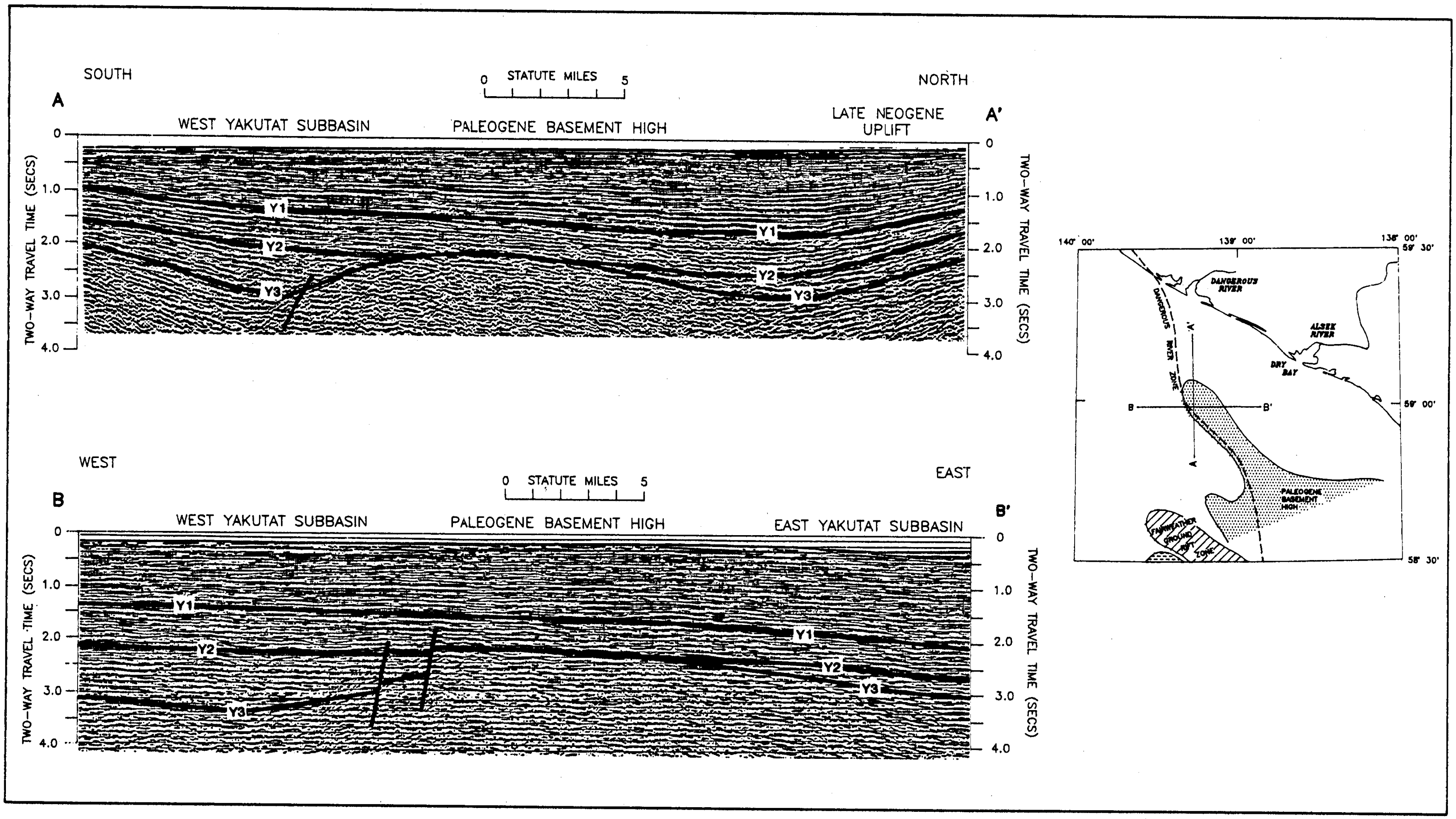


Figure 29. Multichannel seismic-reflection profiles showing the Paleogene basement high, Yakutat shelf. The top of the basement high is approximately coincident with horizon Y2, of late Eocene age. The seismic profiles are courtesy of an anonymous donor.

because of poor acoustic response from the underlying sedimentary section.

In summary, the Dangerous River zone appears to represent the eastern and northern shelf margin of a Paleogene basin (Bruns, 1982b, 1985b; this study). Infilling of this basin occurred largely, if not entirely, after the formation of the shelf-margin paleoslope. Studies by Bayer and others (1978) and Plafker and others (1980) utilizing seismic-refraction and dredge data indicate that the Dangerous River zone is a fundamental boundary between underlying Mesozoic continental crust to the east and oceanic basalt to the west.

The Fairweather Ground uplift is centered roughly on the Fairweather Ground bathymetric high near the continental shelf margin south of Dry Bay and west of Cross Sound (fig. 28). Structural uplift along this segment of the margin has exposed sequence IV (acoustic basement) strata at the seafloor (plate 3B, lines 909, 967). Dredge data obtained by Plafker and others (1980) indicate that acoustic basement at Fairweather Ground is composed of pre-Tertiary metasediments, apparently genetically equivalent to rocks of the Yakutat Group exposed onshore.

Seismic-reflection profiles over Fairweather Ground provide insight into the structural framework and the timing of the shelf-margin uplift (plate 3B, lines 909, 967, and YT-5). Seismic sequences III and II (early Eocene-middle Miocene) and lower sequence I (early Pliocene) have been uplifted, but do not thin over the high, thus predate formation of the structure. However, upper sequence I strata, from north to south, progressively onlap underlying strata, establishing the initiation of shelf-margin uplift as post-early Pliocene (plate 3B, lines 909, 911). The magnitude of late Cenozoic uplift along Fairweather Ground calculated by Bruns (1982b) is in excess of 2 km (6,500 feet).

Along the northern margin of the Fairweather Ground uplift and immediately west of the Dangerous River zone lies an elongate, block-faulted subbasin, the Fairweather Ground rift zone (figs. 28 and 30). Bounding faults and structural features within the zone are oriented northwest to southeast, parallel to the shelf margin. Strata within the rift are probably Eocene, based on seismic correlation to the OCS Y-0211 No. 1 well. Strata dip northeast (fig. 30, line A-A'; plate 3B, line 909), in part owing to post-early Pliocene regional uplift at Fairweather Ground. Timing of faulting within the rift sequence appears variable. Intra-rift faults appear to post-date lower rift sequence strata and, in some cases, the entire rift sequence. It is also possible that faults within the rift zone may have been reactivated during the Pliocene and Pleistocene in conjunction with uplift of Fairweather Ground. Based on structural style, timing, and stratigraphic relationships, the Fairweather Ground rift zone probably originated as a small rift basin during the early to middle Paleogene in response to local and/or regional extension normal to the present basin axis.

The Yakutat fault zone traverses the continental shelf from north to south, seaward of the Malaspina Glacier (fig. 28). This narrow zone is characterized by short, discontinuous, en echelon, basement-involved normal faults (fig. 19). In the southern half of the zone, fault offset is minimal, and appears to disrupt the basement horizon and, less commonly, lower sequence III strata. Direction of offset is typically down to the east or northeast. Along the northern segment of the zone, faulting affects progressively younger strata (plate 3A, line YT-4, NE end), and displacement is down to the southwest. Fault planes are typically steep, often approaching vertical, and in some instances bifurcate upward. Lateral offset along some of the faults is suspected due to variations in reflection characteristics and dip displacement.

The linear distribution of en echelon faults across the shelf and the characteristics of faults at the northern margin of the zone are both indicative of wrench-controlled tectonics. The pattern of faulting observed on horizon Y3 (acoustic basement, fig. 19) is consistent with left-lateral coupling, in which the direction of coupling strikes north-south (Lowell, 1985). Based on this model, the discontinuous, en echelon faults (fig. 19) represent synthetic, or Riedel, shears. The larger tectonic significance of the Yakutat fault zone is uncertain. It is plausible that the portion of the Yakutat terrane to the west of the fault zone is moving northward slower than the adjacent eastern section, in which case the Yakutat fault zone may act as a transform boundary. This is consistent with the observed pattern of deformation in which faulting within the zone is more extensive and better developed along the northern, leading margin of the shelf.

The East and West Yakutat subbasins are two Cenozoic depocenters located on either side of and separated by the Dangerous River zone (fig. 28). The East Yakutat subbasin contains up to 15,000 feet of late Eocene and younger sediment overlying metamorphosed basement rocks of the Yakutat Group. The axis of deposition in

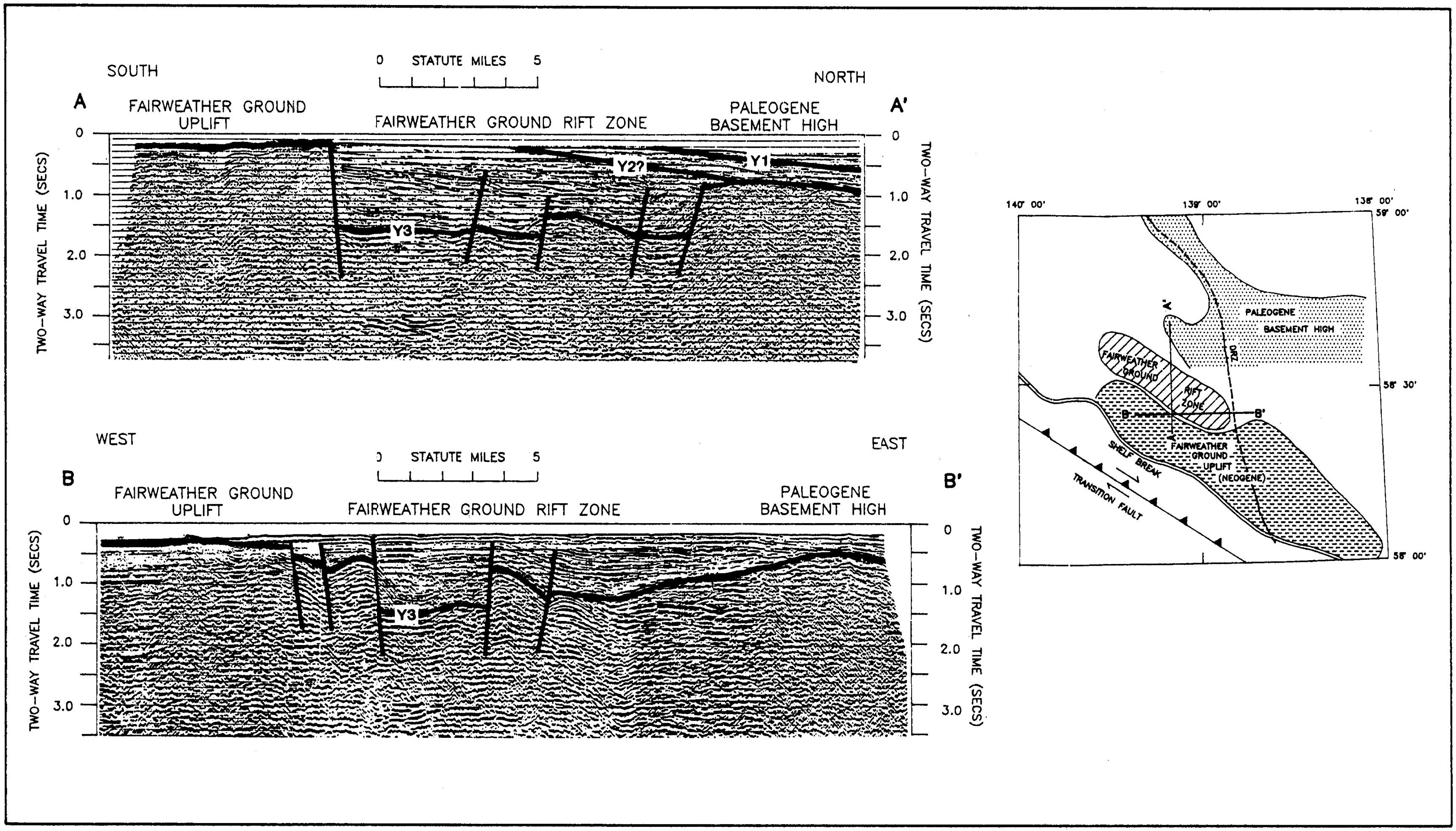


Figure 30. Multichannel seismic-reflection profiles showing the Fairweather Ground rift zone, Yakutat shelf. Reflections within the rift zone are in part obscured by seafloor multiples. Strata within the rift zone are assigned to sequence III, and are most likely predominantly Eocene in age. The seismic profiles are courtesy of an anonymous donor.

the basin is adjacent to, and parallel with, the coastline from Dry Bay to near Lituya Bay. The Icy Point-Lituya Bay fault, the northern extension of the western trace of the Fairweather-Queen Charlotte fault system, in part bounds the basin to the east. Strata within the basin thin to the south and west by onlap against the Paleogene basement high and Fairweather Ground uplift. A late Neogene (Pliocene?) uplift is present near the mouth of Dangerous River (plate 3A, line YT-1, NE end), where acoustic basement rapidly shallows from 12,000 feet to less than 7,000 feet over a distance of 5 miles. The areal extent of the uplift is unknown, but well data indicate that it extends onshore to the northwest as far as Yakutat.

West of the Dangerous River zone, the West Yakutat subbasin contains up to 36,000 feet of Paleogene through Pleistocene strata. The sedimentary section thickens from southeast to northwest, and attains a maximum thickness south of Icy Bay (fig. 19). The basin is truncated to the south at the continental slope, and merges with strata of the Yakataga segment to the west along the Pamplona zone. Structure and isopach maps provide insight into the depositional and structural history of this basin (figs. 15, 17, 18, 19, and 20). The axis of Paleocene-Eocene deposition swings from south of Icy Bay southeastward across the shelf in a broad arc, ending northwest of the terminus of the Fairweather Ground uplift (figs. 20 and 28). Paleogene strata thin by onlap and erosion over an apparent Paleogene high near the present-day shelf edge at the mouth of Yakutat Seavalley. During Oligocene-early Miocene time, local basement subsidence allowed the accumulation of 8,000 feet of sediment in a structural low on the outer Yakutat shelf south of Yakutat Bay (fig. 28). The general pattern of deposition shifted by the beginning of the Neogene Period in response to regional tectonism, with increased accumulation of sediment in the northwest, adjacent to the folds and thrust faults of the Pamplona zone. This depositional pattern continued through Pleistocene time.

Slope and Base-of-Slope Structure

Tertiary strata and Mesozoic basement rock beneath the Yakutat shelf crop out at the seafloor along the length of the continental slope (plates 3A, 3B; Plafker and others, 1980). West of the Yakutat fault zone, Tertiary strata extend seaward down the slope, apparently terminating at the Transition fault zone (plate 3A, line YT-4, SW end). A progressive thickening of lower Tertiary sedimentary units downslope indicates a history of subsidence along this segment of the shelf margin. Between the Yakutat fault zone and the mouth of the Alsek Valley, the Tertiary shelf sequence is exposed on the slope and, where uplift has occurred, on the outer shelf seafloor (plate 3A, lines YT-1 through YT-3, SW ends). In the vicinity of Fairweather Ground, where substantial Neogene and Pleistocene uplift has occurred, both seismic-reflection (plate 3B, lines 909, 967) and dredge data (Plafker and others, 1980) reveal that the continental slope and outer shelf are underlain primarily by metasediments of the Mesozoic Yakutat Group.

The Transition fault, situated at the base of the slope, is a fundamental tectonic boundary. The fault separates the truncated Mesozoic and Paleogene basement rocks and overlying Tertiary strata of the Yakutat block from Oligocene oceanic crust of the Pacific plate to the south (fig. 28 and plates 3A and 3B). The juxtaposition of dissimilar strata and the presence of slickensides on pre-Tertiary to late Oligocene rocks dredged from the contact zone (Plafker and others, 1980; Plafker, 1987) suggest large-scale displacement along the fault system. However, the timing and relative sense of displacement across the Transition fault remain unclear.

Bruns (1985b) suggested that the Transition fault has not been active as either a transform or subduction boundary since at least Miocene time based on the following observations: (1) undeformed Pliocene and Quaternary strata overlie the fault at several locations, (2) a sedimentary fan seaward of, and apparently sourced from, the Yakutat Valley does not appear to be offset (fig. 21), (3) evidence of an accretionary wedge is absent, (4) seismic reflections representing oceanic crust cannot be traced landward past the fault zone, as is characteristic of many subduction zones, and (5) base-of-slope sediments of Pliocene and Quaternary age appear to be in place.

Alternatively, Plafker and others (1978b), Perez and Jacob (1980), and Plafker (1987) proposed that dextral oblique slip has occurred on the Transition fault system during the last 5 million years. Evidence to support this conclusion includes the following: (1) the orientation of folds and probable thrust faults in late Quaternary strata southwest of Fairweather Ground reflect oblique compression (fig. 28), (2) in the vicinity of Yakobi Valley, focal-mechanism solutions for selected earthquakes occurring along the fault trace indicate northward-directed thrusting (Page, 1975; Perez and Jacob, 1980), (3) sheared late Pliocene (?) to Holocene strata are present along the shelf margin, and (4) orientation of the Transition fault system relative to present-day Pacific plate motion suggests, and is compatible with, a model of dextral oblique slip. The magnitude of oblique convergence at the Transition fault zone is estimated from relative plate motions and observed seismicity to be about 0.4 cm/yr (Lahr and Plafker, 1980; Plafker and Jacob, 1986).

Seaward of the Transition fault, a sedimentary section up to 20,000 feet thick overlies oceanic basalt in an elongate asymmetric trough adjacent to the base of the continental slope (figs. 21 and 28). This section is thickest near the base of the slope and thins rapidly seaward. Shor (1965) describes the deeper part of this trough as a filled trench comparable in depth to the modern-day Aleutian Trench. Based on correlation of seismic horizons to DSDP hole 178 near Kodiak Island (von Huene and others, 1979; Bruns and Plafker, 1982; Bruns, 1985b), the lower half of the stratigraphic section is pre-Pliocene and the upper sequence Pliocene to Quaternary. The maximum age of the basin fill is probably middle to late Oligocene, based on the age of nearby ocean-floor magnetic anomalies (Naugler and Wageman, 1973).

Strata along the base of the continental slope are undeformed except near the slope and rise adjacent to Fairweather Ground, where a series of probable thrust faults and related folds trend obliquely to the shelf margin (plate 3B, lines 909, 967, SW end; figs. 21 and 28) (Bruns, 1982b, 1983a; Plafker, 1987). Deformation of abyssal strata may be related to Pliocene and Quaternary uplift centered on Fairweather Ground (Bruns, 1982b) and/or to oblique convergence across this section of the Transition fault (Plafker, 1987). Bathymetric data (Atwood and others, 1981) suggest that substantial growth has occurred on the youngest structures during Quaternary time. Additional features present at the base of the continental slope include two Pliocene to Quaternary sedimentary fans located seaward of the mouths of Alsek and Yakutat Seavalleys (fig. 21) (Atwood and others, 1981; Bruns, 1985b) that are composed of up to 9,000 feet of mounded strata.

Southeast Segment

The southeast Alaska margin is dominated by strike-slip tectonism associated with the Fairweather-Queen Charlotte fault system. The Fairweather-Queen Charlotte fault system separates the Mesozoic and Paleozoic continental basement rocks of the North American plate from the adjacent Miocene oceanic crust of the Pacific plate (Plafker and others, 1978b), and appears to be currently accommodating the displacement generated by relative motion between the plates. This is supported by observed seismicity (Page, 1969; 1975), Holocene offset along the onshore segment of the Fairweather fault (Plafker and others, 1978b), and surface and subsurface fault expression on offshore seismic-reflection and bathymetric data (von Huene and others, 1979; Atwood and others, 1981; Carlson and others, 1985; and this study).

Fairweather-Queen Charlotte Fault System

The Fairweather-Queen Charlotte fault system as discussed herein follows the definition and usage of Carlson and others (1985) and Bruns and Carlson (1987). It includes, from northwest to southeast, (1) the onshore Fairweather fault, (2) the Icy Point-Lituya Bay fault, a proposed reverse fault adjacent to the coastline northwest of Icy Point, and (3) the southeastward extension of these faults, a sub-parallel pattern across the outer shelf and upper slope of the southeast Alaska margin that eventually merges and connects with the Queen Charlotte fault offshore of British Columbia (fig. 31).

Onshore, the Fairweather fault is defined by offset geomorphic features and, commonly, by a prominent linear trench that reflect a late Quaternary history of right-lateral strike-slip (Plafker and others, 1978b). The Fairweather fault can be traced offshore onto the shelf near the Yakobi Valley, where it appears to align with the eastern set of two relatively continuous, sub-parallel sets of fault traces that extend south-southeast across the shelf and upper slope of the southeast Alaska continental margin (fig. 31). The two sub-parallel sets of fault traces appear to merge on the upper continental slope south of Chatham Strait and west of Prince of Wales Island. The western set of traces is better defined, more continuous, and exhibits evidence for accommodating the majority of the fault system activity. Seafloor scarps and offsets of shallow seismic reflections (plate 4, lines SE-3 through SE-6) indicate Holocene displacement along the western trace.

The eastern fault trace is complex. The dominant traces are sinuous, often bifurcating and converging, and locally are ill-defined. The eastern set may connect with the onshore Fairweather fault (Carlson and others, 1985), although the paucity of seafloor scarps and near-surface faults suggests less Holocene activity on this sub-system.

South of Chatham Strait, the merged fault sets extend as a continuous, well-defined system along the upper continental slope (fig. 31 and plate 4, lines SE-1 through SE-2), eventually merging with the Queen Charlotte fault west of Dixon Entrance.

Shelf Structure

The southeast Alaska continental shelf is 15 to 20 miles wide between Cross Sound and the southern tip of Baranof Island, and increases to 30 miles or more in width between Chatham Strait and Dixon Entrance. The topography is relatively flat along the northwestern segment, from Cross Sound to Chatham Strait, and is disrupted only in a few places by low-relief fault scarps associated with the active Fairweather-Queen Charlotte transverse fault system (plate 4, lines SE-4, 5, and 6). Sediment thickness varies from a thin veneer on the shoreward portion of the shelf, to approximately 7,000 feet in the narrow, transverse-fault-bounded, asymmetric subbasins situated along the outer shelf (fig. 22). These subbasins are areally limited and typically offset or deformed by secondary transverse faulting. Relict transverse faults that do not offset Holocene reflections are evident on seismic-reflection data shoreward of the active Fairweather-Queen Charlotte fault traces (plate 4, line SE-4). None of the fault-bounded subbasins extend seaward of the western trace of the Fairweather-Queen Charlotte fault system.

The continental shelf between Chatham Strait and Dixon Entrance is a relatively horizontal platform mantled by a thin cover of Pleistocene(?) and Holocene sediments that is offset by numerous fault scarps (fig. 31). The Southeast Alaska subbasin underlies the shelf west of Prince of Wales Island and contains up to 20,000 feet of Tertiary(?) and Quaternary strata (plate 4, line SE-2). Two relict wrench zones bisect the lower sequence of Tertiary(?) strata in the central part of the subbasin. South of the Southeast Alaska subbasin and west of Dall Island and Dixon Entrance, the shelf platform is underlain by numerous isolated, elongate, asymmetrical subbasins, all bounded to the west by northwest-southeast-trending transverse faults (fig. 22; plate 4, line SE-1). The maximum sediment thickness in these smaller wrench-related subbasins rarely exceeds 8,000 feet. The presence of seafloor fault scarps and offset Holocene reflections indicates recent activity along transverse faults in the vicinity of Dall Island and Dixon Entrance.

Slope Structure

Multichannel seismic-reflection profiles across the continental slope of southeast Alaska reveal sediment thicknesses varying from less than 6,000 feet along the upper slope, to 14,000 feet or greater along the slope–rise transition zone (fig. 32). Exact sediment thicknesses beneath the slope are difficult to determine because acoustic basement is masked by water-bottom multiples and, less commonly, by diffractions associated with near-surface faults. Studies by von Huene and others (1979) utilizing seismic-refraction data and gravity modeling predicted more than 30,000 feet of sediment infilling an oceanic crustal flexure beneath the slope adjacent to Dixon Entrance. Subsequent studies by Snavely and others (1981) employing multichannel seismic-reflection and sonobuoy methods were unable to confirm the existence of this basement trough.

The continental slope between Dixon Entrance and Sitka Sound is structurally deformed along two linear zones (figs. 31 and 32). Strata within these zones are buckled into broad, en echelon, fault-bounded folds, with the magnitude of deformation diminishing from south to north. Folds and faults in the western, outer structural zone appear to disrupt near-surface strata, suggesting a Quaternary age of deformation (Bruns, 1985b; Bruns and Carlson, 1987). To the east, folded and faulted strata in the inner zone are overlain locally by as much as 1,500 feet of relatively undisturbed section, suggesting an earlier period of deformation, possibly in Pliocene or early Pleistocene time (Bruns, 1985b; Bruns and Carlson, 1987). Locally (fig. 32, line 951), deformed strata of the inner zone breached the seafloor and trapped Pleistocene(?) sediments between the two structural zones and, to a lesser degree, shelfward of the inner zone. The en echelon pattern of folding and faulting reflected in the inner and outer structural zones suggests deformation in a strike-slip tectonic regime, possibly developed along splays of the Fairweather-Queen Charlotte wrench-fault system (von Huene and others, 1979; Snavely and others, 1981; Bruns, 1985b; Bruns and Carlson, 1987).

North of Sitka Sound, strata beneath the continental slope appear relatively undeformed (fig. 32, lines 959, 961). Minor faulting may be present deep within the section (pre-Pliocene?) (Bruns, 1985b), but interference by the water-bottom multiple precludes a definitive interpretation of the lower portion of the seismic-reflection profiles.

Continental Rise

A wedge of mid-Miocene and younger strata thickens to the east beneath the continental rise seaward of the Southeast Alaska shelf margin. Between Dixon Entrance and Sitka Sound, relatively undeformed rise strata terminate abruptly against the outer structural zone at

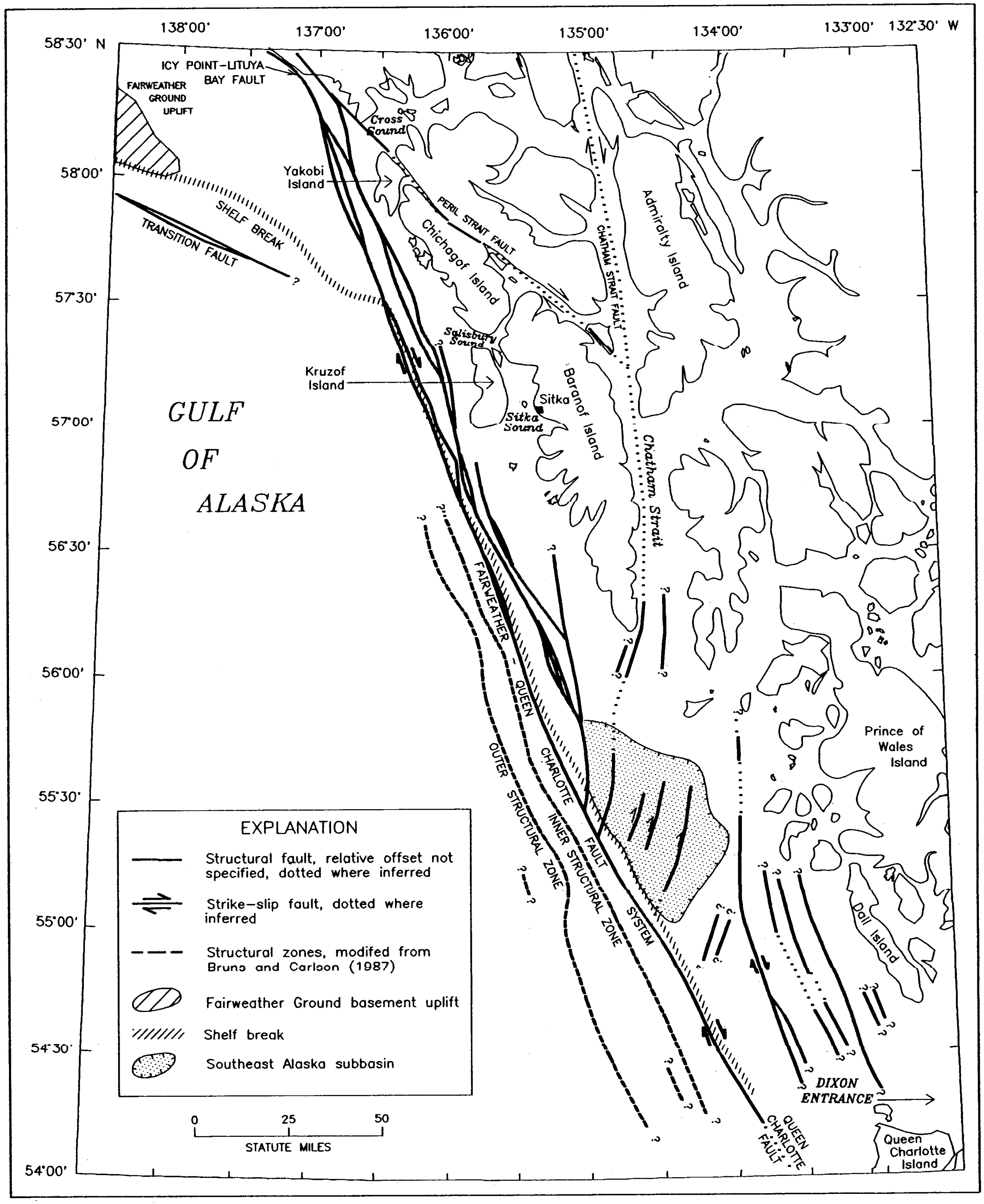


Figure 31. Structural elements of the southeast Alaska continental margin, including the Fairweather-Queen Charlotte fault system, secondary associated faults, inner and outer structural zones, and the Southeast Alaska subbasin.

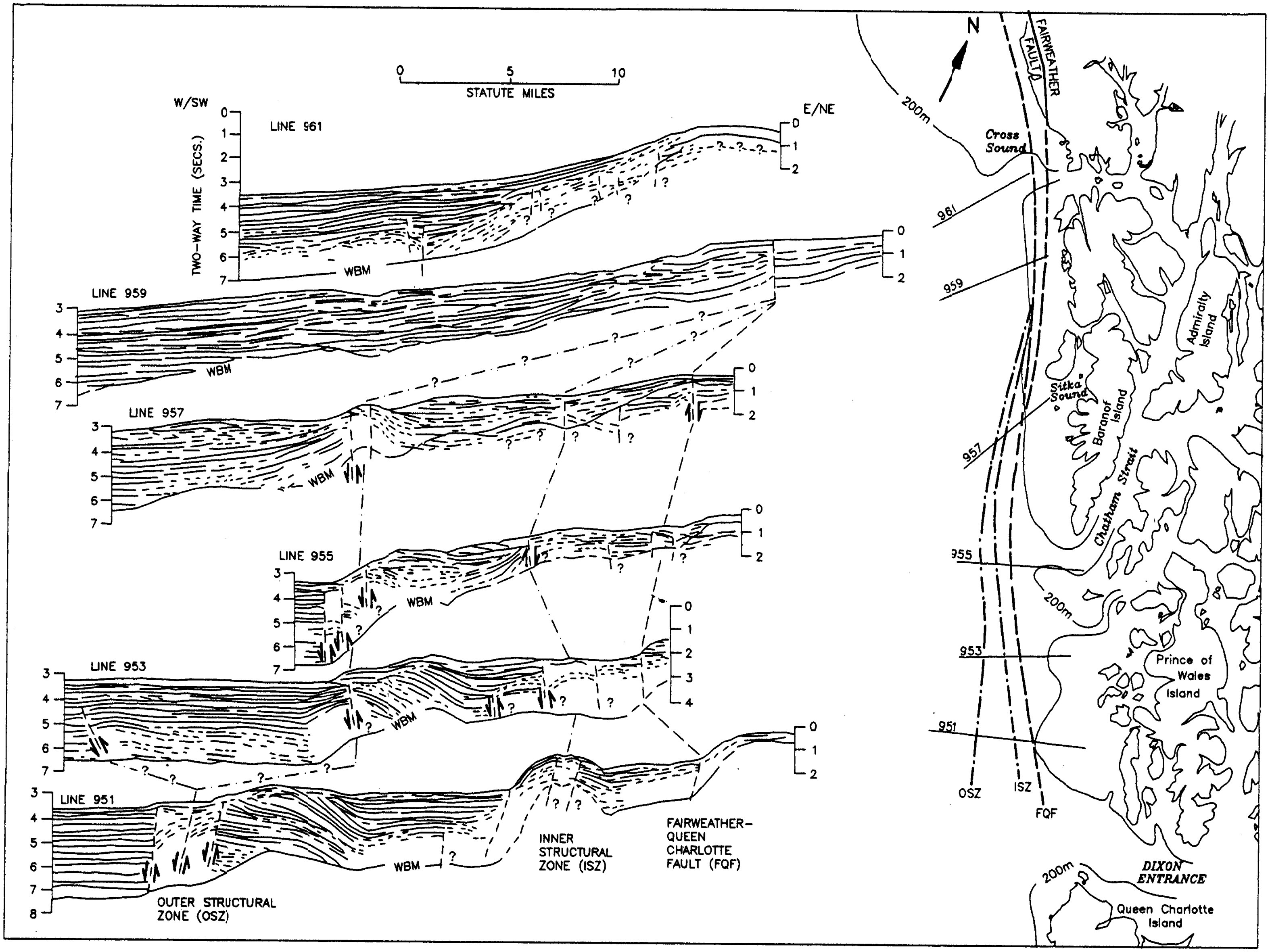


Figure 32. Simplified line representations of selected portions of multichannel seismic-reflection profiles across the southeast Alaska continental margin depicting the layered nature of the strata and the location and orientation of dominant structural zones and the Fairweather-Queen Charlotte fault system. The line drawings and interpretation are adapted from Bruns and others (1984), Bruns (1985b), and Bruns and Carlson (1987). The water bottom multiple is indicated by WBM.

the base of the continental slope (fig. 32, line 951, SW end). North of Sitka Sound, reflections appear to grade laterally into strata of the lower slope (fig. 32, line 959). The maximum thickness of rise sediments adjacent to the base of the slope is difficult to discern from seismic-reflection data because acoustic basement reflections are obscured by the water-bottom multiple. However, west of Kruzof Island the sediment thickness appears to exceed 14,000 feet.

An oil strike that is little less than phenomenal was made last week at Mirror slough, Martin river ... miles west of K...

PROGRESS IN OIL WORK

At Mirror Slough And At Redwood

After many delays, caused by the many difficulties which confront operators in this region, Manager Lovell, of the Alaska Coal - Oil company, has succeeded in landing his oil rig and other machinery at Mirror slough in good condition. The tug Corsair, which left Cordova on June 4, with a barge in tow, on which was the oil rig, got into Martin river last Saturday evening, having been aground on the Copper river mud flats for nearly two weeks.

The work of assembling the machinery on the Barrett-Carless-Sinclair property on Mirror slough, where the rig will be operated, is well under way. The derrick has been erected, and it is expected that within ... week or ten days ... will be actively ... Maj. Love... property ... soon hav... seepage ... prod...

of acres have been ... in the Bering lak... sections. Many o... heretofore made ... good deal of land ... More will be open... That the oil field... entire region are ... longer be doubted, ... and the exci... oil boom" of sev... it a memory. T... res of oil lands ... Katalla to Mart... indoned when t... doing assessm... ny thousands ... a few compa... which annu... rformed. In... oil fields is ... he interest i... ot within. ... demonstrati... a feeling t... nt, and a ... that these ... s of excit... be set do... that the ... will ...

POPULAR COUPLE MARRIED YESTERDAY

Miss Susie Duval, daughter of Mr. and Mrs. Michael Duval was married Friday at high noon, at Pioneer hall to Mr. Thomas George White. The ceremony was witnessed by a large number of friends, and the service wa... conducted by Judge G. C. Britton.

Miss Duval wore a beautiful gown shimmering creme liberty satin, charmingly simple in its long Directoire lin... A wreath of orange blossoms held veil in place.

The bride entered the hall on arm of her father, and was atte... by her sister, Miss Nellie Duval, Mr. James E. Rison acted as best ... The ushers were Mr. Frank H. ...brook and Mr. Dan Lambert. J. A. Payzant was matron of ... The Lohengrin wedding mar... played by Miss Frances Root.

Following the ceremony an ... lunch was served and toa... drunk to the health of the groom, felicitous responses ... by Judge Britton, Judge ... and others, after which the ... to the home of M... reception ...

"JUMPING" CHARGED

Northern Oil Company Gets Busy

All the week reports have been rife to the effect that the Northern Oil company has "jumped" oil claims which have been held for years by the Pacific Coal & Oil company, known locally as the "English company."

The Northern Oil company is a corporation organized under the laws of the state of Washington, but its stockholders are all said to be residents of Vancouver, B. C. Recently the company began the erection of an oil rig at Redwood on ground owned by O. L. Willoughby adjoining that of the Pacific Coal & Oil company. Just how many claims the Northern Oil company or its agents are alleged to have appropriated, is not known. Reports differ. One states that ... held by the P...

"In one of the English ... wells," said the postmaster, ... orders to drill 800 ... had ren... ...

FIRST TO FIND OIL

AND THE FIERY CONSEQUENCES

Tom White's Thrilling Experiences With Fire and Crevasses---Thirteen Years Continuously a Resident of Katalla--Believed in Future.

...an who first found oil in this ... according to authenticated ... was Thos. G. White, a well ... of Katalla, where he ... tinuously for the past ... in 1896. He had ... followed its trail ... smelt oil and ... ...dians that it ... ity. Pres... of the ...

WORK IN CANYON

Large Number of Men Are Employed

STEAMER CHITTYNA A SUCCESS

Thos. G. White Has a Battle For His Life in the Rushing Water of Copper River.---Four Camps Have Been Established.

Thos. G. White, the well known Katalla pioneer, had a narrow escape from death in the water of the Copper river one day last week. ... Going up the river the boat overturned and was swamped and Mr. White was forced to swim for his life in the swift and treacherous current. He struck out boldly for a point ... feet distant which jutted out into the stream, and fortunately reached it, little the worse for his experience. ... the new steamer Chittyna, of the ... river and Northwestern railway, successfully navigating the Abercrombie canyon ... 170 miles ... 110 feet ... water ...

SHOVEL USE... LOCAL

The big steam shovel, now in ... tion at Camp 2 of the Katalla C... pany, is using local crude oil as fu... the shovel having been equipped fo... burning oil under the direction of Alfred White, the efficient superintendent of machinery for the company.

Drilling the rock on Martin Point ... is under way, and the trestles this side ... are being filled with the muck and dirt taken out by the steam shovel.

The shoo-fly track which is being built over Martin Point to Camp 7 has a 61-2 per cent. grade, but when completed will greatly facilitate the work of construction and handling ... supplies for points beyond.

...it black.

"And natural gas? Why, there's enough coming out of the ground at a dozen places to light any old town if it was piped."

"That's so," said Postmaster A. C. Williams, "Why over on Mirror slough ...side of Martin river there is a big ... of gas coming right up from the ...

waiting until the time is ripe for it to go into the oil producing business on an on an extensive scale. Waiting sometimes precludes possible litigation and anyway, the English company is a sort of strange concern. But that there is oil here in great commercial quantities you need not doubt and a short time now will demonstrate that fact. You've ...

5. Lithostratigraphy

Introduction

The Cenozoic stratigraphic section on the Gulf of Alaska continental margin consists of marine and nonmarine clastics with a maximum thickness that exceeds 36,000 feet. All of the Tertiary and Quaternary epochs are represented by strata within the region (fig. 33). Three major subdivisions that are present in Cenozoic onshore outcrops can be correlated with three offshore seismic sequences:

(1) An upper Tertiary and Quaternary stratigraphic sequence of glaciomarine and marine clastic sediment of middle(?) to late Miocene, Pliocene, and Pleistocene age that reflects both the uplift and the glaciation of the Chugach and St. Elias Mountains. The tectonism resulted from the collision and partial underthrusting of the Yakutat terrane with the North American plate. This sequence is represented by the Yakataga and Redwood Formations (fig. 33).

(2) A middle Tertiary stratigraphic sequence of late Eocene, Oligocene, and middle to late Miocene transgressive-marine clastic sediments. On the Yakutat terrane, the sequence is represented by the deep-marine glauconitic shales and siltstones of the Poul Creek Formation; and on the very eastern part of the terrane by the shallow-marine Topsy Formation and Cenotaph Volcanics (fig. 33). On the Prince William terrane, this sequence is represented by deep-marine siltstone and shale equivalents of the Sitkinak(?) Formation.

(3) A lower Tertiary sequence of nonmarine to deep-water marine strata of late Paleocene(?), Eocene, and early Oligocene(?) age. The sandstones, siltstones, shales, and coals of this sequence exhibit a generally regressive lithofacies pattern and represent deltaic, prodeltaic, and basinal sediments of a progradational depositional system. On the Yakutat terrane, the sequence includes the Tokun, Kulthieth, Stillwater, and Haydon Peak Formations, and an informal siltstone unit referred to by Plafker (1987, p. 244) as "the siltstone of Oily Lake," hereafter referred to as the Oily Lake siltstone in this report. On the Prince William terrane, this sequence is represented by fore-arc, deep-marine and trench-fill clastics of the Sitkalidak Formation.

The upper Tertiary and Quaternary sequence forms an overlap sequence that depositionally crosses both the Yakutat and Prince William terranes. The mineralogy of the Neogene sediments demonstrates a nearby provenance in the adjacent Chugach and St. Elias Mountains (Plafker and Addicott, 1976) and indicates that sedimentation occurred after docking of the Yakutat terrane. Neogene depocenters on the Yakutat terrane lie slightly offshore and subparallel to the modern coastline, and the Neogene section thins toward the Transition fault, which marks the seaward edge of the basin (plate 5). The distribution of Neogene sediment on the Prince William terrane is complex and has been more strongly controlled by tectonic deformation than on the Yakutat terrane.

The principal accumulation of Paleogene strata (lower and middle Tertiary sequences) along the Gulf of Alaska is on the Yakutat terrane. On the Prince William terrane, much of the Paleogene section is complexly deformed and has undergone low-grade metamorphism. Paleontologic, paleomagnetic, and petrologic data from Paleogene sediment and basaltic basement of the Yakutat terrane suggest that deposition occurred hundreds of miles to the southeast, when the terrane was adjacent to uplifted sediment sources in the crystalline complex of the Coast Mountains in British Columbia and southeastern Alaska (Hollister, 1979; Plafker and others, 1980; Chisholm, 1985; Van Alstine and others, 1985; Davis and Plafker, 1986; Plafker, 1987). The main Paleogene sedimentary basin is on the western segment of the Yakutat terrane that is floored by Eocene oceanic basalts. Paleogene strata thin or wedge-out across the Dangerous River zone onto the eastern continental segment of the Yakutat terrane, which is floored by the low-grade metasediments of Jurassic(?) and Cretaceous age of the Yakutat Group (fig. 34a, b).

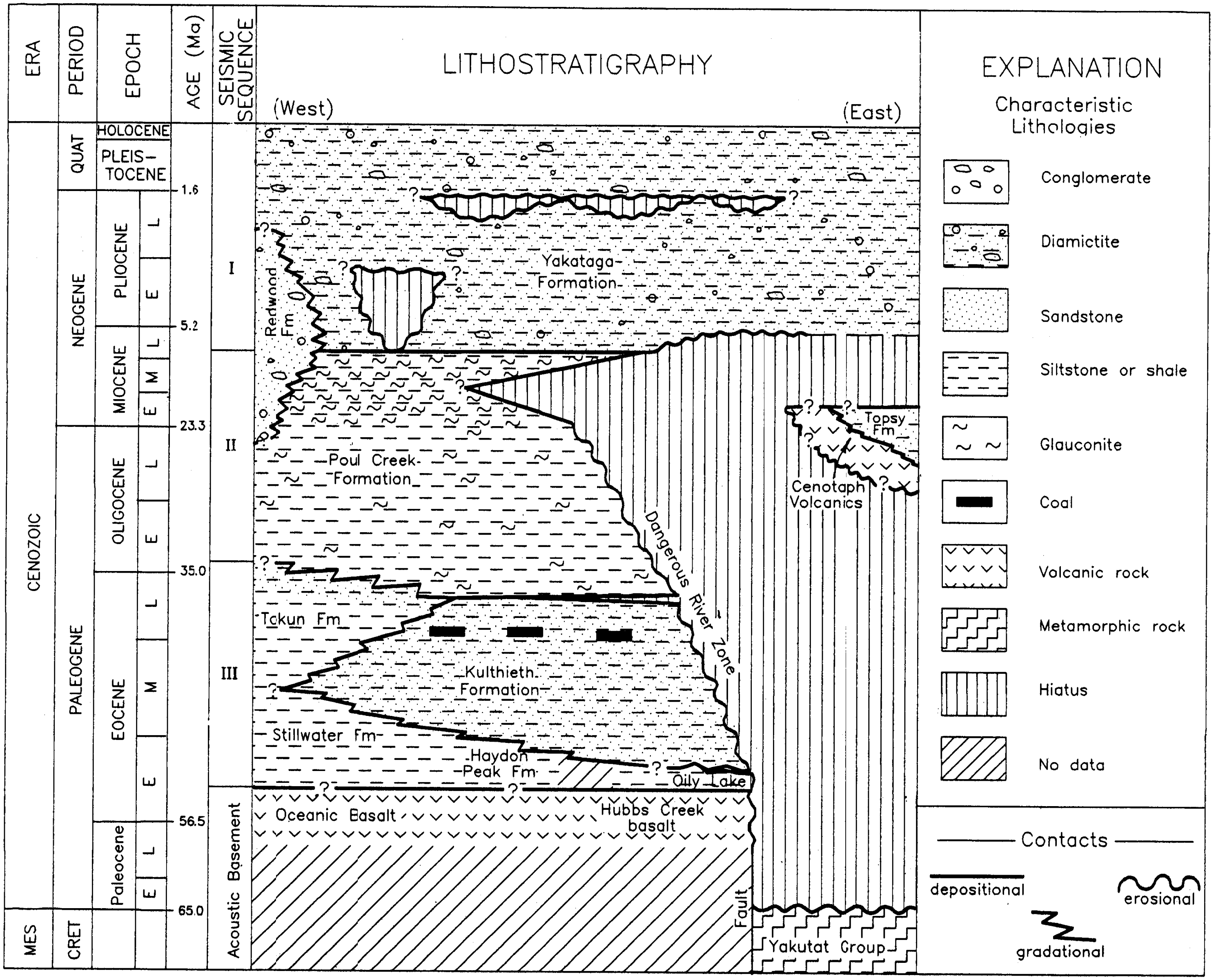


Figure 33. Generalized lithostratigraphic chart of the Yakutat terrane on the Gulf of Alaska margin between the Katalla and Lituya Bay areas (modified from Plafker, 1987, and the Correlation of Stratigraphic Units of North America—Southern Alaska Region Correlation Chart, Schaff and Gilbert, 1987).

Upper Tertiary and Quaternary Sequence

Yakataga Formation

The Yakataga Formation (Taliaferro, 1932) is a glacially influenced marine clastic sedimentary sequence of middle(?) Miocene to Holocene age (fig. 33) that may reach a thickness of over 16,000 feet (Plafker and Addicott, 1976). The Yakataga Formation represents one of the longest and most complete sedimentary records of late Cenozoic glaciation in the world (Plafker and Addicott, 1976). The Yakataga Formation is exposed along the Gulf of Alaska coast from Kayak Island to Cross Sound and outcrops offshore as far west as Middleton Island (plate 5). Principal exposures of the Yakataga Formation are in the Yakataga and western Malaspina districts (figs. 34a and 34b). The Yakataga Formation floors most of the Gulf of Alaska continental shelf on the Yakutat and eastern Prince William terranes. All of the offshore exploratory wells in the Gulf of Alaska encountered the Yakataga Formation and 6 of the 13 wells drilled entirely through the formation into the underlying Poul Creek Formation or equivalent rocks (plate 6).

The Yakataga Formation rests either conformably or disconformably on the Poul Creek Formation westward from Yakataga Reef on the mainland and west of the Dangerous River zone in most offshore wells (figs. 34a and 34b, plate 6). Along the flanks and crest of the Dangerous River zone structural high in the Malaspina and Yakutat districts, the Yakataga Formation discordantly overlaps the Poul Creek and Kulthieth Formations and the Cretaceous metasedimentary rocks of the Yakutat Group (Plafker and Addicott, 1976). East of the Dangerous River zone in the Yakutat and Lituya districts, the Yakataga Formation apparently disconformably overlies the Topsy and Cenotaph Formations and unconformably overlies the Yakutat Group.

Yakataga Formation sediments were mainly eroded and transported by glaciers that flowed from the metamorphic and igneous terranes of the Chugach and St. Elias Mountains. Striated boulder pavements in Yakataga exposures on Middleton Island near the edge of the continental shelf indicate that glacial ice extended far offshore (Eyles, 1988). Sediment depocenters trended along an axis that lies slightly offshore and generally parallel to the present coastline (plate 5). Sedimentation rates were high: average rates for the entire formation calculated from onshore and offshore wells are generally 2 to 3 feet (0.6 to 3.0 meters) per 1,000 years, and sedimentation rates during glacial periods were doubtless even higher than these overall formation averages. Holocene sedimentation rates adjacent to the Malaspina Glacier, for example, are 16 millimeters/year, or equivalent to 16 meters (52 feet) per 1,000 years (Molnia, 1983b). Fifty-six paleocurrent measurements from Yakataga sandstone cross-beds between Icy Bay and the Bering Glacier yielded a northwesterly trend and suggest that sedimentation has been controlled by the counterclockwise flow of the Alaskan Gyral marine current system since the late Miocene (Lyle and Palmer, 1976).

The Yakataga Formation consists of both marine and glaciomarine clastic sediments. The glaciomarine lithofacies that characterize the Yakataga Formation include tillite-like diamictite (conglomeratic sandy mudstone) and laminated marine siltstones and mudstones that contain accessory floating sand grains and striated and faceted pebble-to-boulder dropstones indicative of ice-rafting (Plafker and Addicott, 1976). Nonglacial lithofacies represent shallow-shelf to deeper marine turbidite deposits and include mudstones, siltstones, and sandstones that are tabular, thinly to thickly bedded, moderately to well sorted, and frequently bioturbated (Lyle and Palmer, 1976; Armentrout, 1983b; Zellers, 1990). Nonmarine glacial till and glaciofluvial sandstone and conglomerate are locally abundant in the younger, upper part of the section, but represent a minor component of the formation overall (Armentrout, 1983b).

Armentrout (1983b) subdivided the Yakataga Formation (fig. 35) into a predominantly glaciomarine upper section and a lower section of alternating marine and glaciomarine strata that presumably represent glacial and interglacial periods. He correlated the boundary between the upper and lower Yakataga sections with the climatic deterioration that began near the middle of the Pliocene. Continental glaciation began over vast areas of the northern hemisphere just after the beginning of the late Pliocene (Poore, 1979; Shackleton and others, 1984; Raymo and others, 1986; Einarsson and Albertsson, 1988). The boundary separating the upper and lower sections of the Yakataga Formation was generally difficult to define using wireline logs and drill cuttings from offshore wells. Because of this, the Yakataga Formation was subdivided in this report at the late–early Pliocene boundary (plate 6) on the basis of biostratigraphic data.

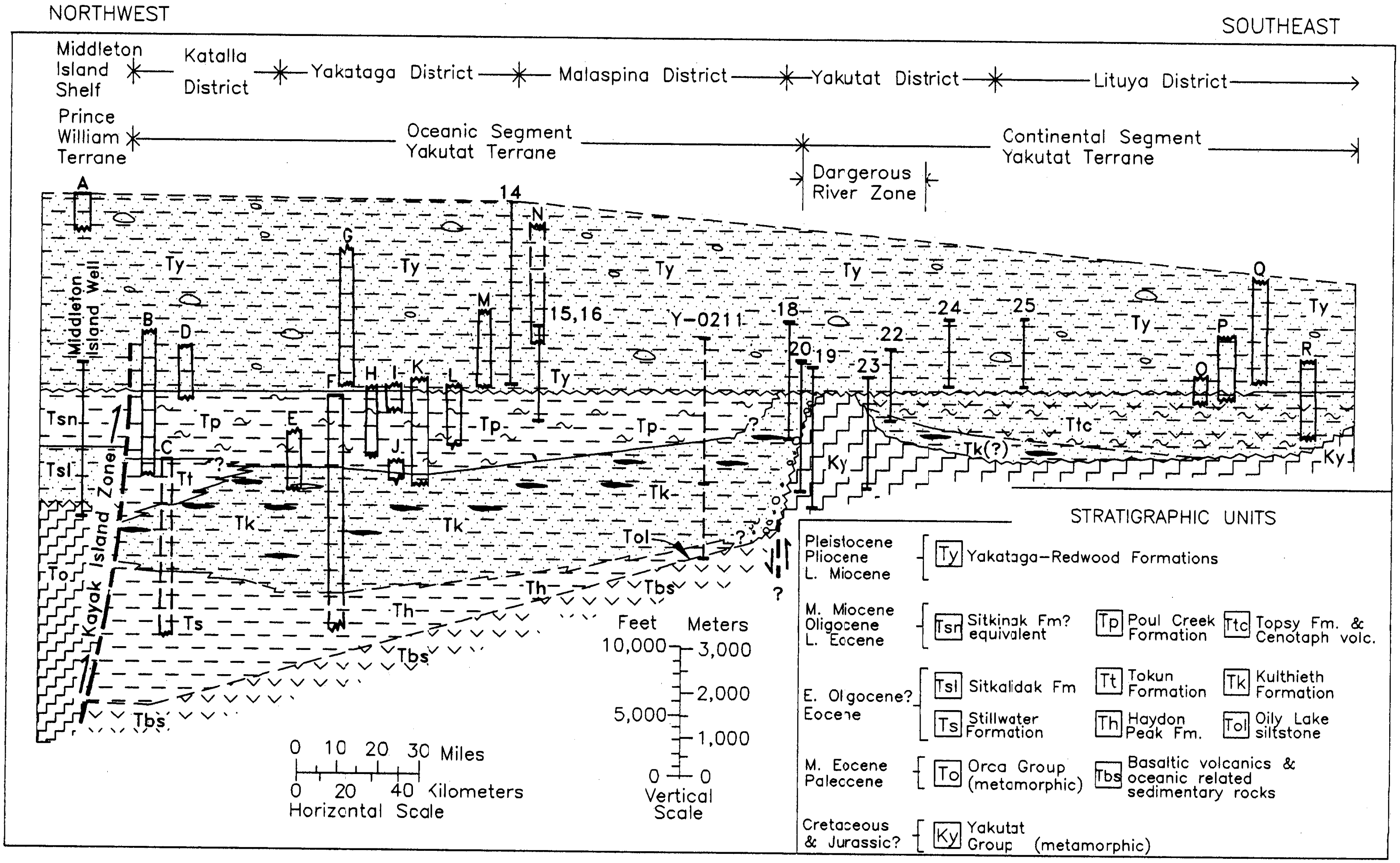


Figure 34a. Diagrammatic stratigraphic section of the northern Gulf of Alaska coastal margin. The lithologic patterns and contacts are as in figure 33. Numbered locations of measured outcrop sections (columns) and exploratory wells (lines) are shown on figure 34b. Vertical exaggeration is approximately 17. (Modified from Plafker and others, 1978a.)

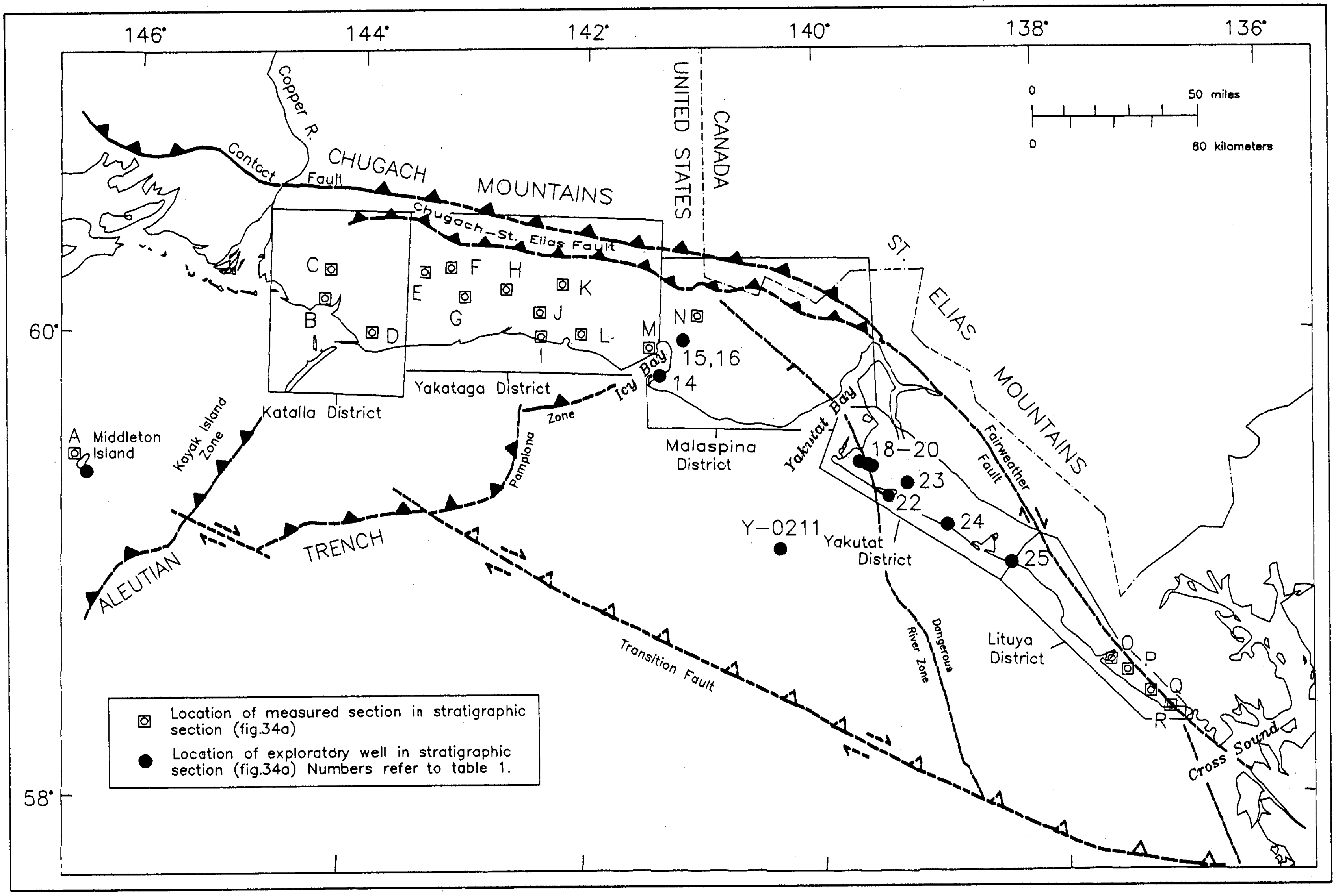


Figure 34b. Generalized geologic map of the northern Gulf of Alaska continental margin showing locations of stratigraphic control points in figure 34a. Primary data sources: Katalla district, Miller (1975), Winkler and Plafker (1981); Yakataga district, Miller (1957, 1971); Malaspina district, Plafker and Miller (1957), Plafker (1987), Rodgers (1987); Yakutat district, Rau and others (1983); Lituya district, Plafker (1987); all districts, Plafker and others (1978a), Rau and others (1983).

The upper section of the Yakataga Formation (late Pliocene, Pleistocene, and Holocene age) is characterized by glaciomarine sediment that infills fiord-like mega-channels (fig. 36) that incise underlying Yakataga strata (Armentrout, 1983b). The mega-channels are 160 to 1,600 feet deep with maximum widths of about 10,000 feet, and have steep-walled margins that are sometimes grooved and striated (Armentrout 1983b). These glacial mega-channels are manifested on offshore seismic profiles by U-shaped features in the upper Yakataga Formation (fig. 16). Striated boulder pavements and glaciomarine channel-fill sediments from early Pleistocene exposures on Middleton Island near the edge of the continental shelf also indicate that glacial ice extended far offshore (fig. 37) (Eyles, 1987, 1988). Upper Yakataga strata attain thicknesses in excess of 10,000 feet in the offshore (plate 6).

The lower section of the Yakataga Formation is middle(?) to late Miocene, early Pliocene, and earliest late Pliocene in age. The lower Yakataga Formation contains a smaller percentage of glaciomarine lithofacies than the upper section, although the base of the Yakataga Formation is defined by the first appearance of glaciomarine lithofacies (Plafker and Addicott, 1976). For example, along Icy Bay, the exposed Yakataga Formation (mid to late Pliocene) contains a lower section that was deposited under normal marine conditions with little or no glaciomarine influence (Zellers, 1990). In exposures at Munday Peak west of Icy Bay, Armentrout (1983b) identified three interglacial normal-marine intervals that alternate with four thinner glaciomarine intervals (fig. 35).

Geographically, variable amounts of the lower Yakataga Formation are thin or missing, probably as a result of an intraformational unconformity or unconformities. Onshore in the Yakataga and Malaspina districts, angular discontinuities between folded and channelled Yakataga strata indicate contemporaneous structural growth and erosion in the Pliocene (Plafker and Addicott, 1976; Armentrout, 1983b). Offshore, the lower Yakataga Formation is over 5,000 feet thick in the Texaco OCS Y-0032 No. 1 well, but thins westward to less than 100 feet in the Exxon OCS Y-0080 No. 1 well (plate 6; Lattanzi, 1981). Offshore seismic lines also show that lower Yakataga strata thin or wedge out in this area. It is highly probable that the Yakataga Formation experienced numerous large shifts in sediment progradation, sedimentation rates, and paleobathymetry, given the active tectonics of the region and the wide fluctuations in sea level and crustal downwarping from ice loading that accompany glacial advances and retreats.

The maximum age of the basal Yakataga Formation is of special stratigraphic interest

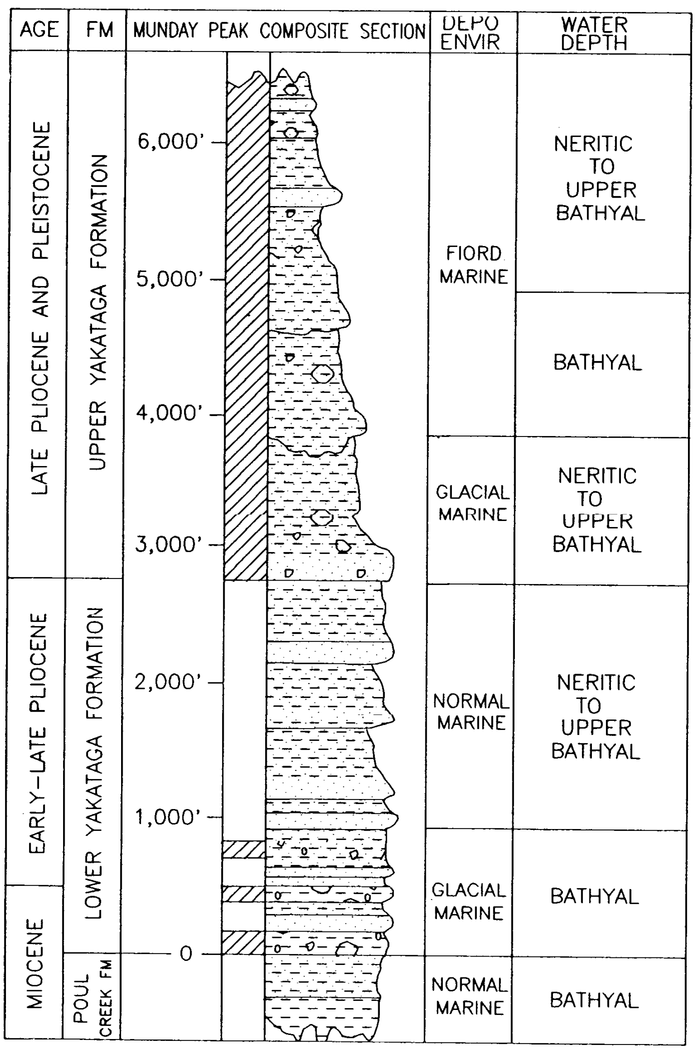


Figure 35. Composite stratigraphic section of the Yakataga Formation at Munday Peak, Robinson Mountains. Rock types include shale (dash), siltstone (dash-dot), and sandstone (dot). Circular blocks are clasts floating in a finer grained matrix. Intervals of glacially influenced deposits are noted by diagonally ruled column to the left of the measured section. Water depth is based on benthic foraminiferal paleoecology (fig. 56). Depositional environments interpreted from lithofacies and biofacies (modified from Armentrout, 1983a, fig. 4).

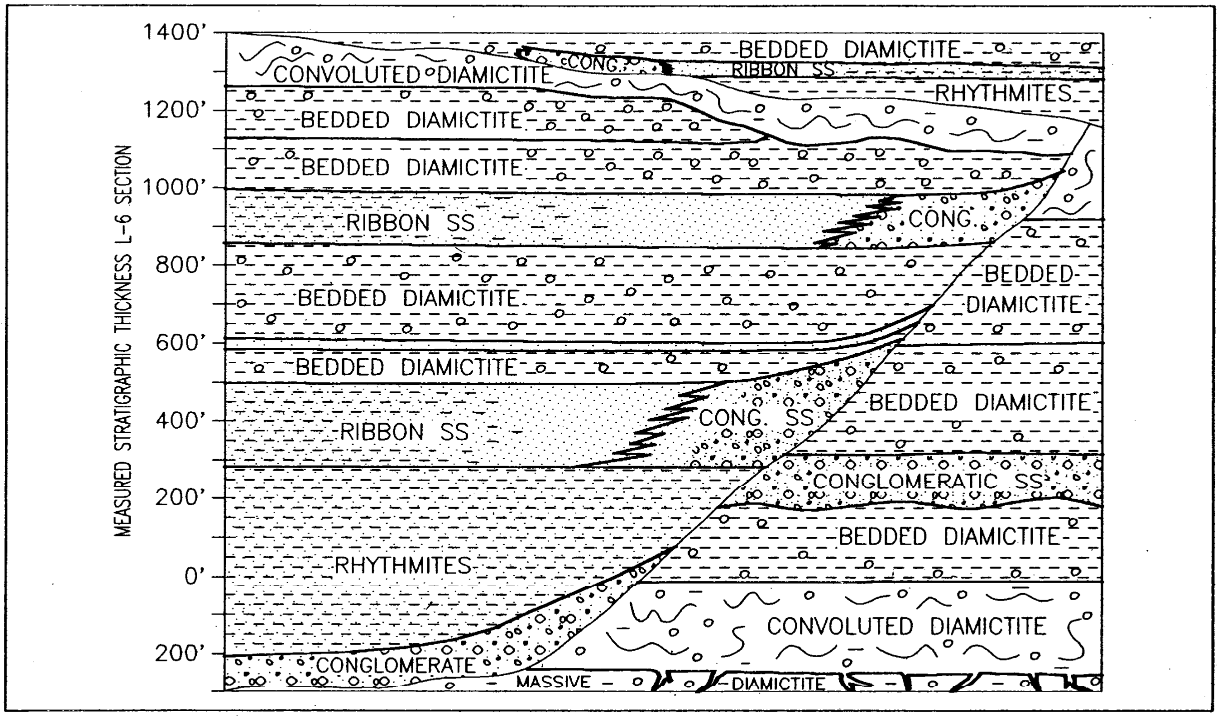


Figure 36. Diagram of a glaciomarine fiord-like megachannel in outcrops of upper Yakataga Formation strata near Munday Peak. Ribbon sandstone consists of thin, rippled sandstone beds interbedded with marine siltstones. Rhythmites consist of rhythmically interbedded mudstone and thin, gravity-flow sandstone (after Armentrout, 1983b, fig. 21).

because it marks the inception of coastal piedmont glaciation along the Gulf of Alaska. The glaciation recorded by the Yakataga Formation is generally attributed to orogenic uplift and increased precipitation resulting from the collision of the Yakutat terrane with the North American plate (von Huene and Kulm, 1973; Plafker and Addicott, 1976; Plafker, 1987; Eyles and others, 1988; Eyles and Lagoe, 1989). Uplift associated with the collision probably began in the late Oligocene, as attested to by volcanism in the Wrangell Mountains that began about 26 Ma (Richter and others, 1990). Plafker (1987) suggests that after collision along the leading western edge of the Yakutat terrane, uplift spread progressively eastward, so that the basal Yakataga Formation becomes progressively younger to the east.

The maximum age of the Yakataga Formation is controversial and is interpreted to be as old as late Oligocene(?) and early Miocene (Plafker, 1987; Marincovich, 1990) to as young as late Miocene (Armentrout, 1983b; Lagoe, 1983; Lagoe and Eyles, 1988; Eyles and others, 1988). The older (late Oligocene to early Miocene) dates are based mainly on the biostratigraphy of mollusks and benthic foraminifera (Allison, 1978; Addicott and others, 1978; Ariey, 1978; Rau and others, 1983; Marincovich, 1990), whereas the younger, late Miocene dates are based mainly on the biostratigraphy of planktonic foraminifera and radiometric dates from glauconite (Armentrout and others, 1978; Armentrout, 1983b; Lagoe, 1983).

The oldest rocks that have been included in the Yakataga Formation are at Kayak Island (Plafker, 1974, 1987). The section included in the Yakataga Formation there is dated by mollusks as early as middle Miocene in age (Marincovich, 1990). In addition, a cross-cutting dacite intrusion radiometrically dated at 6.2 Ma establishes a minimum late Miocene age for this Kayak Island locality (Plafker, 1987). However, the lower 500 feet of this section is nonglacial in origin and was deposited prior to the first appearance of the glaciomarine lithofacies that are interpreted as middle Miocene (Marincovich, 1990). The early Miocene nonglacial lithofacies reflects uplift resulting from the docking of the Yakutat terrane, but predates the initial Neogene glaciation. These early Miocene nonglacial rocks are correlative with nearby exposures of equivalent nonglacial marine rocks of the Redwood Formation in the Katalla area rather than the

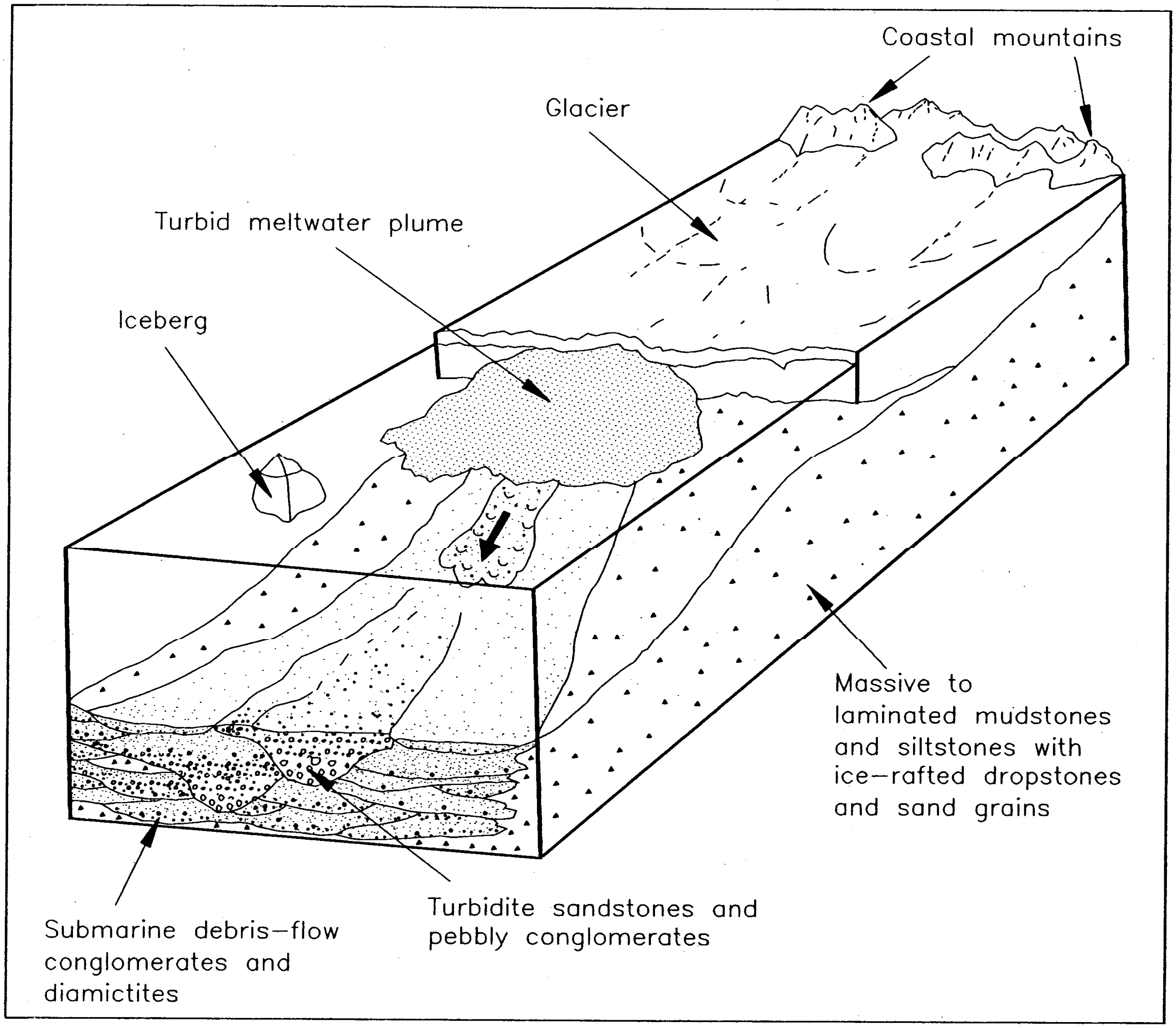


Figure 37. Block diagram showing depositional modes of glaciomarine sedimentation of the Yakataga Formation (modified from Eyles, 1987, fig. 15).

glaciomarine Yakataga Formation (see discussion of Redwood Formation).

The age data from the glaciomarine lithofacies of the Yakataga Formation on Kayak Island indicate that glaciation began earlier than 6.2 Ma (late Miocene), but no earlier than 15-16 Ma (early middle Miocene) (Marincovich, 1990). However, the early middle Miocene date is based on molluscan biostratigraphy, which is generally held to be less reliable than that based on planktonic foraminifera; no planktonic foraminifera older than late Miocene are known from Yakataga glaciomarine rocks (see chapter 6). Furthermore, as noted by Armentrout (1983b) and Marincovich (1990), the early middle Miocene coincides with a global peak in Neogene climatic warming (Wolfe and Poore, 1982; Haq, 1982). This seems an unlikely time for the onset of glaciation in temperate latitudes, and we suspect that the initial glaciation occurred after this time.

Paleoceanographic oxygen-isotope studies (fig. 38) indicate that shortly after the early middle Miocene warming event, one of the most abrupt episodes of global climatic cooling in all of the Cenozoic occurred at about 14 to 15 Ma (Woodruff and others, 1981; Miller and Fairbanks, 1985; Miller and others, 1987). In the temperate latitudes of southern Alaska, glaciation would likely have occurred after establishment of the climatic effects of this middle Miocene cooling episode. This assumption is consistent with the planktonic biostratigraphy of the Yakataga Formation as well as maximum ages of isolated stratigraphic occurrences of Neogene glacial or periglacial deposits in other areas of southern Alaska. None of these other glacial deposits appear to be older than late Miocene. Diamictite outcrops on the northeastern flank of the Wrangell-St. Elias Mountains contain glacially faceted and striated clasts (Denton and Armstrong, 1969; Eyles and Eyles, 1989). The diamictites are interbedded with volcanic flows that have been radiometrically dated from 2.7 to 10.2 Ma (Denton and Armstrong, 1969). Along the eastern flank of upper Cook Inlet, tillites have been identified in exploratory wells in the late Miocene Beluga and late Miocene to Pliocene Sterling Formations (Boss and others, 1976).

This evidence suggests that the onset of glaciation and subsequent deposition of the glaciomarine Yakataga Formation in the Gulf of Alaska began considerably later than the docking of the Yakutat terrane with the North American plate in the late Oligocene (26 Ma). The conditions necessary to establish regional glaciation apparently included not only mountainous uplift, but also global climate cooling in the middle Miocene.

In summary, the glaciomarine deposits of the basal Yakataga Formation are older than 6 Ma (latest Miocene) and younger than 15 to 16 Ma (early middle Miocene). Evidence from surrounding regions of the Gulf of Alaska suggests that these glaciomarine deposits are probably at least as old as the middle–late Miocene boundary (10.4 Ma).

Redwood Formation

The Redwood Formation (Taliaferro, 1932) outcrops in the Katalla area (plate 5), where it consists of as much as 4,500 feet of marine conglomerate, sandstone, siltstone, and mudstone (fig. 39). The formation is named for the noted British petroleum geologist Sir Boverton Redwood, who also worked in the area in 1903. The Redwood Formation is described by Miller

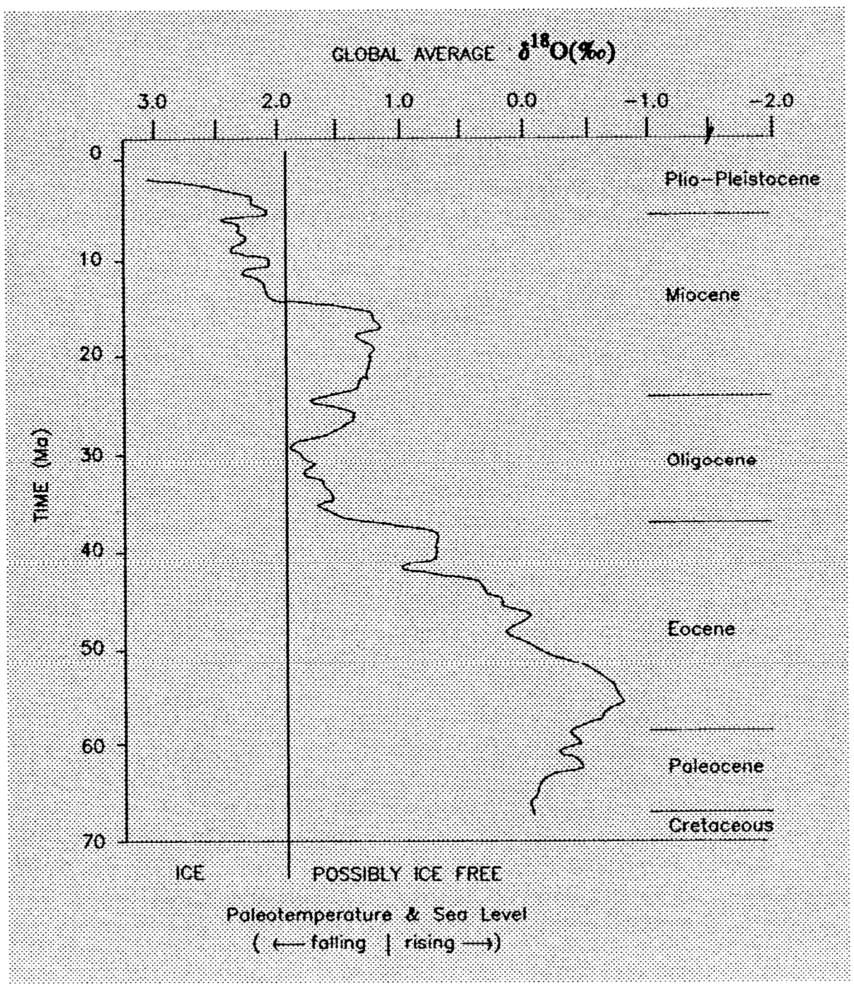


Figure 38. Cenozoic paleoclimate as indicated by composite global deep-sea oxygen isotope records (modified from Miller and Fairbanks, 1985; Miller and others, 1987). During colder glacial periods, the light isotope oxygen-16 (^{16}O) is preferentially evaporated from the oceans and concentrated in glacial ice, whereas the ocean water is relatively enriched in the heavier isotope ^{18}O. The relative abundance of ^{18}O (expressed as $\delta^{18}O$) in $CaCO_3$ of benthic foraminifera tests is an indicator of polar ice buildup, paleotemperature, and sea level. $\delta^{18}O$ values greater than 1.8 parts per thousand (‰) provide evidence for significant ice sheets (Miller and others, 1987), and suggest that major polar icecaps in the Cenozoic have persisted since about 15 Ma in the middle Miocene. It is probable that glaciation in the Gulf of Alaska dates from or subsequent to this time.

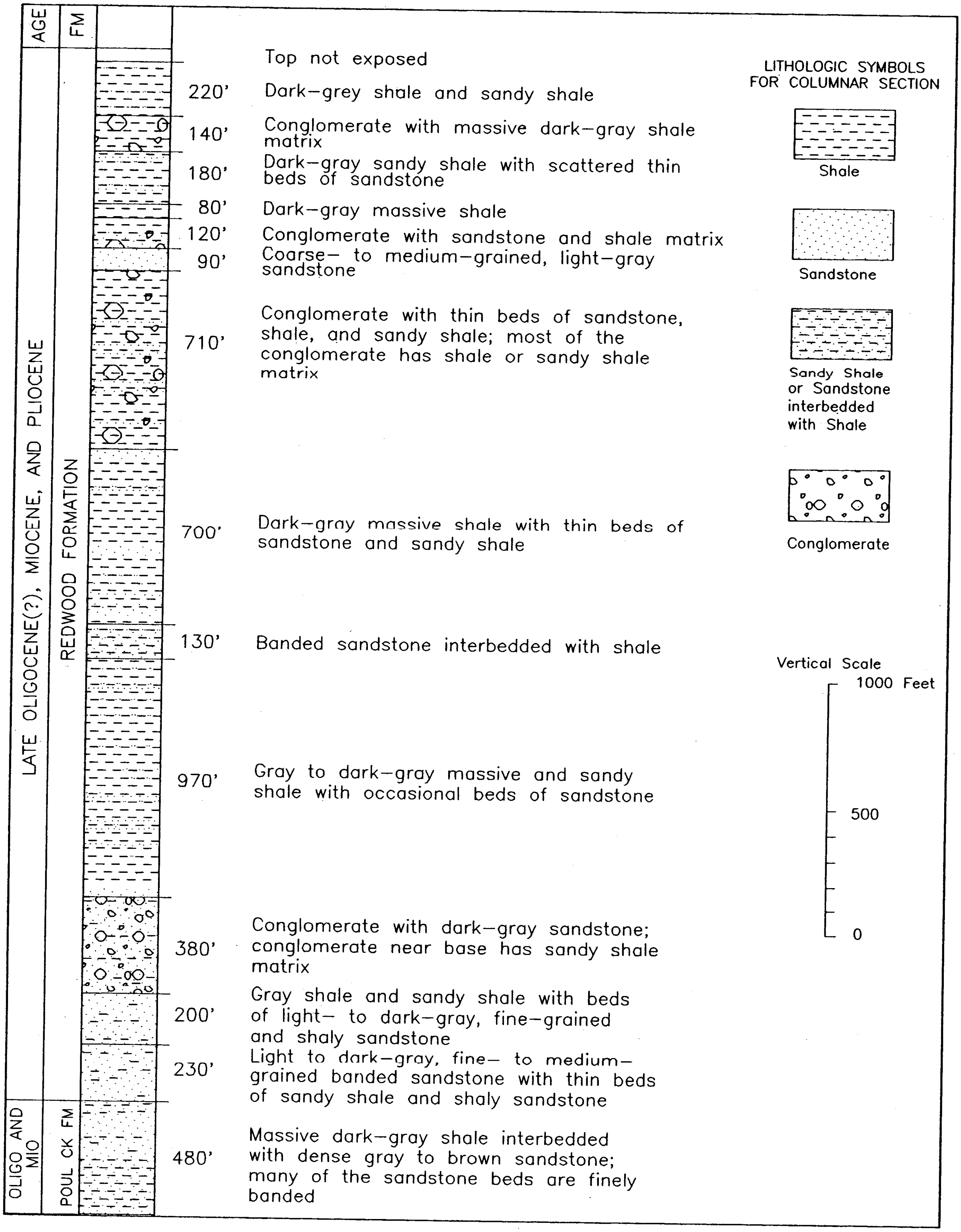


Figure 39. Stratigraphic column of the Redwood Formation in the Katalla district (after Miller, 1975).

(1975) as consisting of a basal 400- to 500-foot-thick unit of thick-bedded, fine- to medium-grained, marine sandstone with subordinate siltstone interbeds, and an upper 3,700-foot-thick unit of interbedded siltstone, mudstone, conglomerate, and sandstone (fig. 39) that was deposited in neritic to bathyal depths. The top of the Redwood Formation is not exposed; the lower contact with the Poul Creek Formation varies from sharp to gradational and is apparently conformable.

The Redwood Formation has yielded a sparse, poorly preserved molluscan fauna that suggests an age of late Oligocene(?) to Miocene, and a sparse foraminiferal assemblage from the upper third of the formation that suggests a late Miocene to Pliocene age (Miller, 1975; Addicott and others, 1978; Rau and others, 1983). Redwood strata appear to be laterally equivalent to upper Poul Creek strata and lower Yakataga strata, and may represent a transitional rock unit between the deep-marine Poul Creek Formation and the glaciomarine Yakataga Formation.

The conglomeratic marine sediments of the Redwood Formation range from clast-supported conglomerate to conglomeratic mudstone. The Redwood conglomerates and diamictites are similar to those of the Yakataga Formation, except that no angular boulders or striated clasts indicative of glacial ice-rafting have been observed in the Redwood Formation (Plafker and Addicott, 1976). Redwood conglomerate clasts are subrounded to well rounded and reflect abrasion by fluvial and/or beach processes prior to their deposition in marine waters (Miller, 1975).

Plafker and Addicott (1976) suggest that the Redwood conglomerates are beach-worked glaciofluvial outwash that was deposited along the coast at the onset of glaciomarine sedimentation. However, Redwood conglomerates appear to be largely older than the onset of glaciation, and so they may instead be deposits of braid and fan deltas and submarine fans formed at the onset of coastal uplift associated with the initial docking of the Yakutat terrane that appears to have occurred in the late Oligiocene (26 Ma) (Richter and others, 1990). Coarse-grained braid and fan deltas are commonly formed along active continental margins (Wescott and Ethridge, 1980; McPherson and others, 1987). Furthermore, as Anderson (1983) and Zellers (1990) point out, scattered dropstones may be evidence of ice-rafting by shore-fast ice rather than glacial icebergs.

The Redwood Formation has not been recognized in the geologic literature elsewhere than in the Katalla area.

However, at Kayak Island, the basal 500 feet of the section that has been included in the Yakataga Formation consists of nonglacial, coarse marine clastics of early Miocene age (Plafker, 1974; Marincovich, 1990). Because these rocks appear to have been deposited prior to glaciation, we do not consider them to be part of the Yakataga Formation, but rather correlate them with the Redwood Formation.

Middle Tertiary Stratigraphic Sequence

Poul Creek Formation

The Poul Creek Formation was originally assigned by Taliaferro (1932) to a 3,000-foot-thick sequence of deep-water marine, reddish-brown-weathering, glauconitic mudstone, siltstone, and minor sandstone, mainly of Oligocene and Miocene age, that crops out along the Gulf of Alaska coast between the Bering and Malaspina Glaciers. Miller (1957) redefined the formation to include all of the approximately 6,100 feet of lithologically and genetically similar marine strata of late Eocene, Oligocene, and Miocene age between the Yakataga and Kulthieth Formations. Because the stratigraphy of the Yakutat terrane extends westward to the Kayak Island zone, Winkler and Plafker (1981) extended the stratigraphic nomenclature of the Yakataga district to the Katalla district and reassigned the strata of the former Katalla Formation (Martin, 1905; Miller, 1975) to the Poul Creek Formation. Thus defined, the Poul Creek Formation (fig. 33) extends from the Kayak Island zone in the west to the Dangerous River zone in the east (fig. 34a).

Onshore, the Poul Creek Formation is truncated by an unconformity at the Yakataga–Poul Creek contact along the western flank of the Dangerous River zone beneath the Malaspina Glacier (Plafker and others, 1978a; Larson and others, 1985a). East of the Dangerous River zone in the Malaspina, Yakutat, and Lituya districts (fig. 34a, b), the Poul Creek Formation is absent. Offshore, however, strata age-equivalent to the Poul Creek Formation (seismic sequence II) are continuous over the Dangerous River high and represent a thin unit offshore of the Yakutat and Lituya districts (fig. 18). Seismic sequence II appears to represent the shallow-marine, coarser grained lithofacies of the Topsy Formation and Cenotaph Volcanics that crop out in the Lituya district (figs. 33 and 34a) (Miller, 1961b; Plafker, 1967).

A facies change in the strata of seismic sequence II occurs across the offshore segment of the Dangerous River zone. This change reflects the transition from the proximal shelf facies of the Topsy Formation and the Cenotaph Volcanics on the eastern continental segment of the Yakutat terrane to the basinal facies of the Poul Creek Formation on the western oceanic segment of the Yakutat terrane. During deposition of the Poul Creek and Topsy Formations, the Dangerous River zone apparently represented a basin-margin paleoslope (Bruns, 1983b; 1985b). Poul Creek strata basinward of this paleoslope contain benthonic foraminifera that indicate deposition in deep-marine, bathyal environments (Lagoe, 1983; Rau and others, 1983; and chapter 6, this report).

In the Katalla area, the Poul Creek Formation was thoroughly described by Miller (1975) because of the considerable interest attracted by numerous oil seeps and the shallow Katalla oil field that was developed from fractured Poul Creek strata. Miller (1975) subdivided the Katalla Formation (now considered the Poul Creek Formation) into three members with a combined thickness of about 5,200 feet (fig. 40). These three members characterize the vertical succession of Poul Creek lithofacies in most onshore exposures, and also appear representative of Poul Creek strata offshore based on the few offshore wells that penetrated the formation.

The upper Poul Creek Formation in the Katalla area (Burls Creek Shale Member of the former Katalla Formation) consists of as much as 2,800 feet of gray to dark-gray siltstone, dark-green pyritic and glauconite-rich sandstone, dark organic-rich shale, and lenticular limestone. This upper Poul Creek member appears to be mostly late Oligocene to late middle or early late Miocene based on planktonic foraminiferal assemblages and on radiometric dates of glauconite from the Yakataga district (Armentrout and others, 1978; Armentrout, 1983a, 1983b; Lagoe, 1983; Marincovich, 1990; and chapter 6, this report).

The glauconitic sandstones of the upper Poul Creek member consist of angular to subround grains of glauconite in a brownish-green silt to clay-sized matrix with common pyrite. The glauconitic sandstone beds are massive and exhibit rapid lateral changes in thickness from 3 to as much as 60 feet, and in some areas are absent altogether (Miller, 1975). At the Yakataga Reef locality, an equivalent sandstone consists of over 80 percent pelletal glauconite (Lagoe, 1983). The pelletal morphology of the glauconite suggests a biogenic origin, although at Kayak Island the glauconite is interpreted by Plafker (1974) to have formed by the alteration of basaltic detritus. The Poul Creek Formation locally contains abundant, interbedded, water-laid volcanic flows and pyroclastic rock (Miller, 1957, 1975; Plafker, 1974).

The organic-rich shales and mudstones of the upper Poul Creek member are described as brown to black, pyritic, and massive to finely laminated (Miller, 1975; Armentrout, 1983a). These organic shales and mudstones occur in onshore exposures as one or more horizons with a total thickness varying from 50 to 800 feet, with the thickest and organically richest section occurring to the west at Kayak Island (Plafker, 1974; Miller, 1975). Total organic carbon (TOC) contents from onshore samples of the organic-rich units are generally between about 1.5 and 8 percent, and the kerogen is predominantly of marine-algal origin (Plafker, 1974; Lagoe, 1983; Armentrout, 1983a; Mull and Nelson, 1986). The marine origin of the kerogen in the upper Poul Creek organic shales contrasts with most other Tertiary strata (including most of the Oligocene section of the Poul Creek Formation) in which the preserved kerogen is predominantly terrestrially derived (Armentrout, 1983a; and chapter 10, this report).

The middle Poul Creek member (Basin Creek Member of the former Katalla Formation) is mainly early Oligocene in age (Plafker, 1987) and consists of 550 to 1,000 feet of locally glauconitic gray shale or siltstone with interbeds of very fine-grained sandstone that are locally glauconitic. Concretions of silty limestone, many of which contain fossil crabs, are common in the middle member near Katalla (Miller, 1975), although limestone concretions and thin beds are common throughout the formation (Miller, 1957, 1975; Plafker, 1967, 1974).

The lower Poul Creek member (Split Creek Sandstone Member of the former Katalla Formation) is late Eocene to early Oligocene in age (Rau and others, 1983; Plafker, 1987) and consists of about 700 to 1,400 feet of massive- to thin-bedded, fine- to coarse-grained, brownish-gray sandstone with minor amounts of interbedded siltstone or shale. In the Yakataga district, the equivalent basal lower sandy section of the Poul Creek Formation varies from 900 to 2,500 feet in thickness.

Offshore, the Poul Creek Formation was encountered in 5 of the 12 exploratory wells that were drilled on the Yakutat terrane (plate 6). Three of these offshore wells, the Shell OCS Y-0014 No. 2, Texaco OCS Y-0032

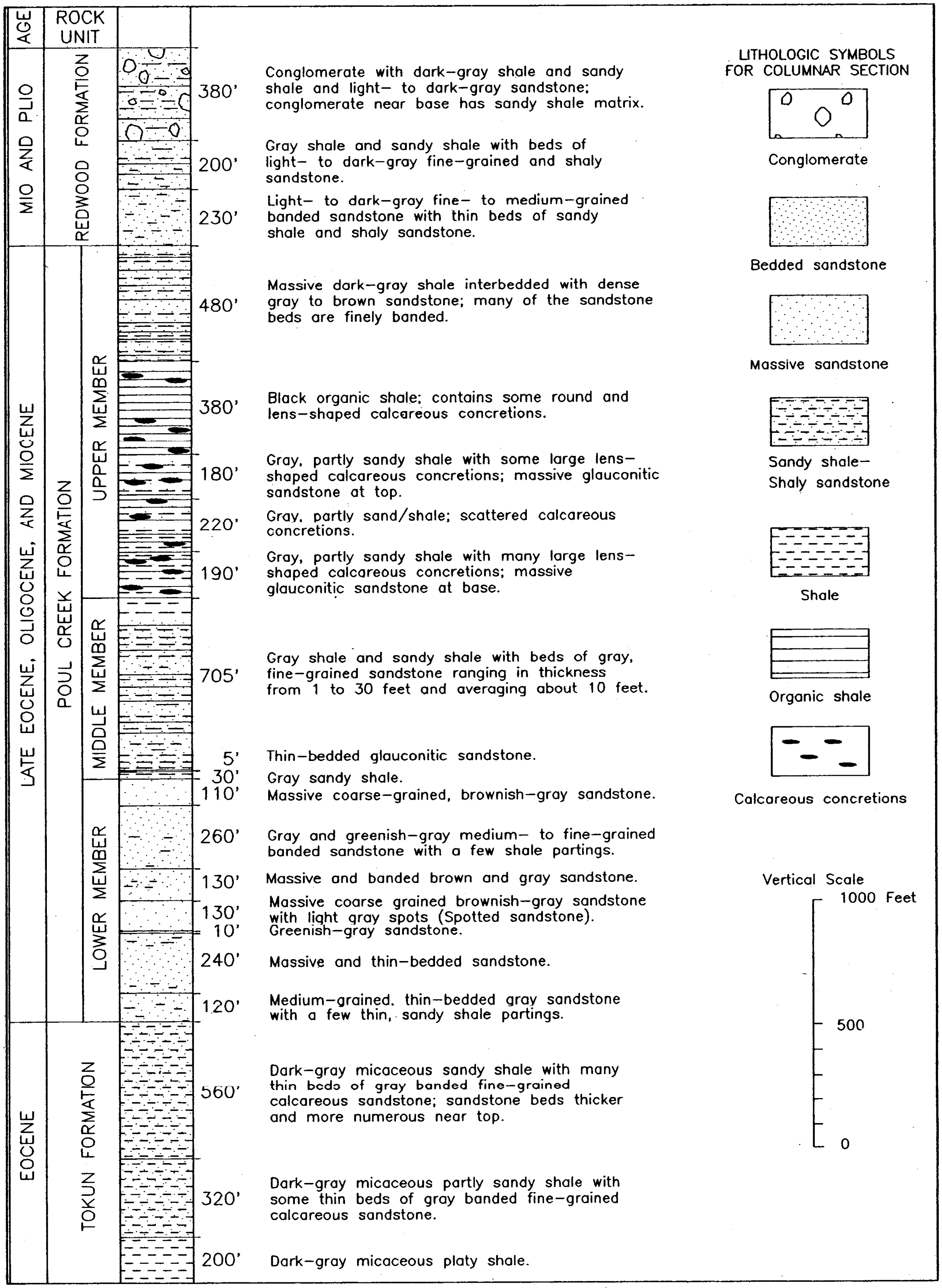


Figure 40. Stratigraphic column of the Poul Creek Formation (formerly the Katalla Formation) in the Katalla district (after Miller, 1975).

No. 1, and Exxon OCS Y-0080 No. 1, were either abandoned after penetrating the upper part of the Poul Creek section or failed to reach underlying formations because of steeply dipping and possibly fault-repeated sections (plate 6). The ARCO OCS Y-0007 No. 1 well encountered upper Eocene strata in the basal 1,970 feet of the well, which Plafker (1987) correlated with the Tokun Formation. As a result, the OCS Y-0007 No. 1 well may have penetrated through the entire Poul Creek Formation. However, this correlation is uncertain because both the Tokun and Poul Creek Formations have late Eocene sections and the two formations are too similar lithologically to distinguish using drill cuttings and logs in the OCS Y-0007 No. 1 well.

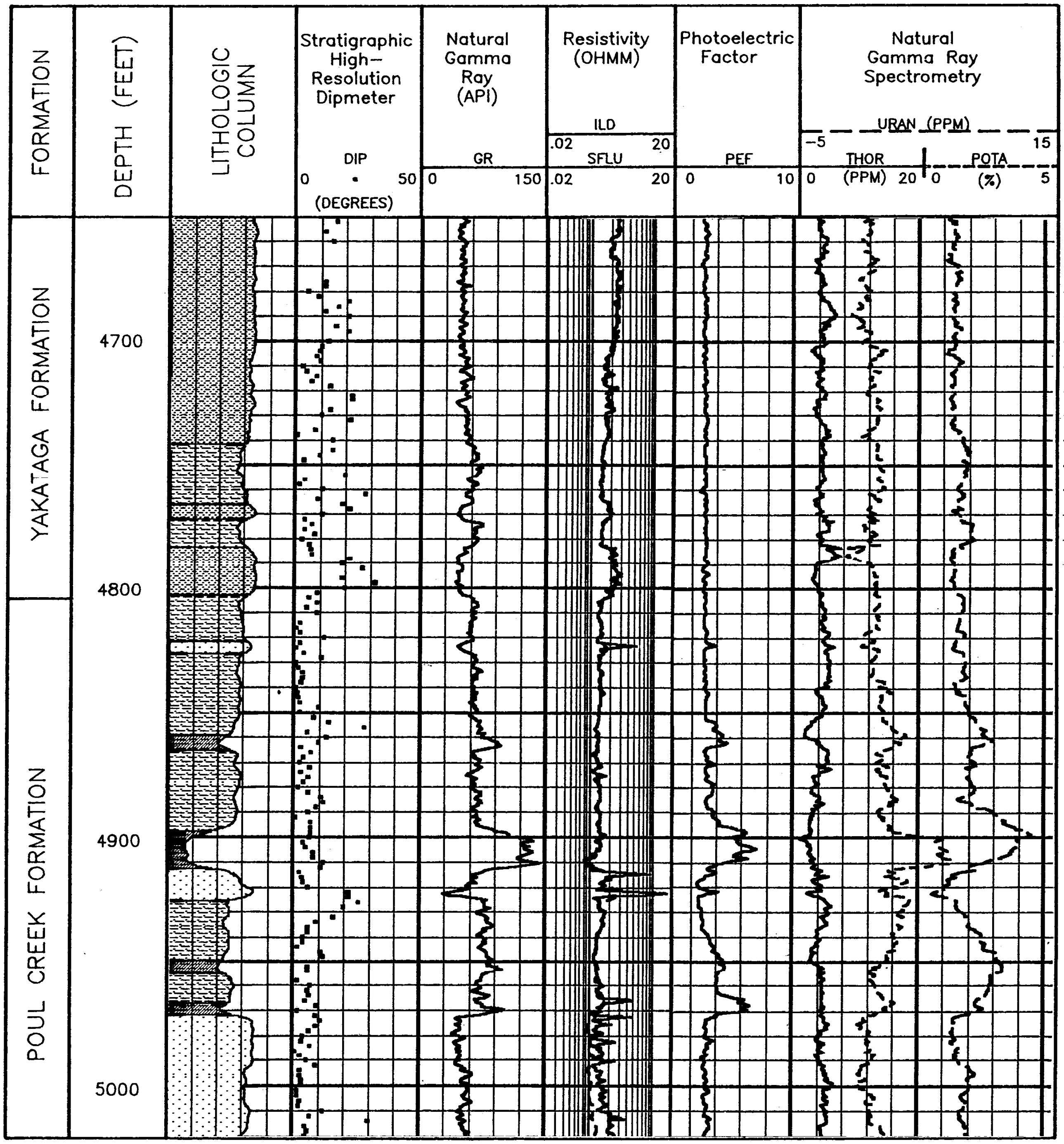
The only offshore well that is known with certainty to have penetrated the entire Poul Creek Formation is the ARCO OCS Y-0211 No. 1 well (plate 6). This well was drilled in a relatively undisturbed structural setting east of the Pamplona zone and penetrated essentially flat-lying strata. The well (plate 7) encountered a 3,765-foot section of upper Eocene, Oligocene, and lower to middle Miocene strata containing characteristic Poul Creek lithofacies: dark, pyritic and glauconitic siltstone and shale, glauconitic sandstone, and occasional shaly limestone or calcareous concretions. Microfossil assemblages indicate deposition in bathyal environments (see chapter 6).

The contact of Miocene Poul Creek strata with the Yakataga Formation in the OCS Y-0211 No. 1 well was picked from wireline logs near the first downhole occurrence of abundant glauconite in drill cuttings. Dip patterns from the dipmeter log exhibit a much wider scatter in the overlying poorly stratified glaciomarine strata of the Yakataga Formation than in the nonglacial, deep-water marine strata of the Poul Creek Formation (fig. 41). The lower contact of the Poul Creek Formation was identified from the wireline logs at the top of the underlying sandstone sequence of the Kulthieth Formation. A local, slightly angular discordance that may correspond to the Poul Creek–Kulthieth contact was interpreted by Bruns (1983a) from seismic data over the broad structure that was tested by the OCS Y-0211 No. 1 well.

The Poul Creek Formation in the OCS Y-0211 well can be subdivided into three lithologic units that we interpret to be approximately equivalent to those described by Miller (1975) in the Katalla area. The upper Poul Creek unit (4,805 to 5,770 feet) is late Oligocene to early or middle Miocene in age and can be differentiated from the other two units by more frequent SP log deflections (plates 6 and 7) that reflect sandstone beds. Near the top of the upper unit, a zone of higher radioactivity on the gamma ray logs reflects abundant glauconite and associated sediments. The middle Poul Creek unit (5,770 to 7,350 feet) is mostly early to late Oligocene in age and is predominantly shale and siltstone, as attested to by the flat response of the SP and resistivity logs. The lower Poul Creek unit (7,350 to 8,570 feet) is late Eocene to possibly early Oligocene in age and is distinguished from the overlying shaly middle unit by a higher resistivity log response that indicates the lower unit is siltier and sandier than the middle unit. A 32-foot conventional core (core 1, appendix F-2) from this lower unit consisted of gray, massive, silty to occasionally sandy mudstone that was locally burrowed and bioturbated and contained traces of pyrite, carbonaceous fragments, mica, and glauconite (Barnes and others, 1983).

Sandstone in the upper section of the Poul Creek Formation in the OCS Y-0211 No. 1 well is relatively abundant compared to that encountered in other OCS wells that penetrated the formation (plate 6). The OCS Y-0211 No. 1 well site may have been closer to the paleoshoreline than the other OCS wells during deposition of the upper Poul Creek Formation. We interpret the late Oligocene to middle Miocene paleoshoreline to have been located to the east-northeast of the OCS Y-0211 well site, probably parallel with the trend of the Dangerous River zone (see discussion of the OCS Y-0211 No. 1 well data in the Kulthieth Formation section of this chapter).

The uppermost Poul Creek strata of Miocene age in the OCS Y-0211 No. 1 well are particularly rich in glauconite and contain several beds composed almost entirely of glauconite pellets that are interbedded with thin units of dark-brownish-gray to black organic-rich siltstone or mudstone. The glauconitic beds were identified from drill cuttings and from gamma ray spectral and lithodensity well logs (figs. 41 and 42). The anomalously higher uranium levels displayed by the gamma ray spectral log (6 to 8 ppm uranium) appear to result from associated organic shales and marine phosphatic minerals (carbonate fluorapatite), which we tentatively identified in the form of cements associated with glauconite pellets. Phosphatic or apatite group minerals are commonly uranium bearing and frequently occur in association with glauconitic facies (Pettijohn, 1957, p. 474; Adams and Weaver, 1958; Serra and others, 1980; Pettijohn and others, 1987, p. 189). We also tentatively identified phosphatic minerals in conventional core samples of the OCS Y-0080 No. 1



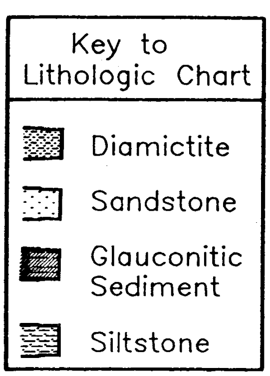


Figure 41. Lithologic interpretation of OCS Y-0211 No. 1 well logs at the Yakataga–Poul Creek formational contact. The base of the Yakataga Formation at 4,805 feet is marked by a change from widely scattered dip magnitudes in the poorly stratified glaciomarine sediment to more consistent dips in the Poul Creek marine sediments. In the Poul Creek section, four glauconitic beds are apparent between 4,850 and 5,000 feet. Glauconitic beds are indicated by zones of higher radioactivity on the gamma ray (GR), uranium (URAN), and potassium (POTA) log traces, and higher values on the photoelectric factor (PEF) log trace. The glauconitic zones represent condensed sections formed when clastic deposition was very slow and sedimentation was dominated by slowly accumulating authigenic glauconite.

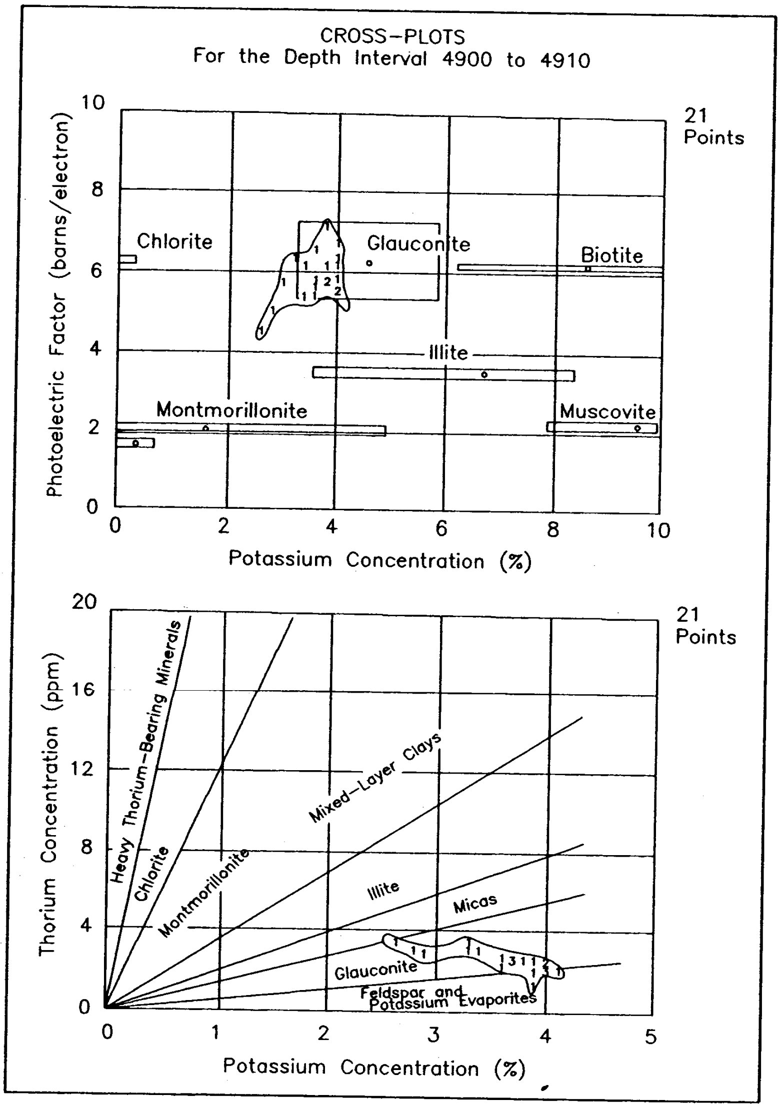


Figure 42. Clay mineral identification from cross-plots of natural gamma ray spectrometry and litho-density logs in the OCS Y-0211 No. 1 well in the upper Poul Creek Formation. Cross-plots of thorium/potassium and photoelectric factor/potassium indicate that glauconite is the primary clay mineral in the interval from 4,900–4,910 feet (fig. 41). The mineral identification charts are after Schlumberger Log Interpretation Charts CP-18 and CP-19 (1985).

well from the Miocene glauconitic lithofacies of the upper Poul Creek section.

Glauconitic-phosphatic sediments are generally interpreted as having formed in marine environments where clastic sedimentation rates were low and biogenic activity was high, and phosphate in particular is often linked to upwelling nutrient-rich currents and restricted, anoxic bottom-water conditions (Cloud, 1955; Pettijohn, 1957; Porrenga, 1967; Odin, 1972; Kolodny, 1981; Pettijohn and others, 1987). That restricted environments occurred in the Miocene during deposition of the Poul Creek glauconitic-phosphatic lithofacies is also evidenced by an impoverished microfauna containing shark teeth recovered from a core in the upper Poul Creek section of the OCS Y-0080 No. 1 well (see chapter 6). In a study of onshore localities, Armentrout (1983a) also interpreted Miocene Poul Creek strata as having been deposited in restricted marine environments.

The Miocene section of the Poul Creek Formation appears to be a condensed time-stratigraphic section, and in some areas is absent altogether, perhaps as a result of nondeposition. Slow sedimentation rates are demonstrated by the glauconitic-phosphatic lithofacies and by the anomalously thin or absent Miocene Poul Creek section indicated by biostratigraphic data from onshore and offshore areas (Lagoe, 1983; Armentrout, 1983a). The thick Miocene Poul Creek section in the OCS Y-0080 No. 1 well (plate 6) appears to be a result of drilling through steeply dipping and fault-repeated strata. The same may be true of the Miocene Poul Creek section in the OCS Y-0014 No. 2 well, which is faulted and may contain a repeated Miocene section (plate 6). The sandy interval beneath the fault in the OCS Y-0014 No. 2 well (between about 13,400 and 14,400 feet) is similar in lithology and log response to Yakataga Formation strata, and may be a fault-repeated section of the Yakataga Formation within the Poul Creek Formation. However, this is not confirmed by biostratigraphic data from the well.

In some areas, the thin or missing Miocene section of the upper Poul Creek Formation may be a result of the post-depositional erosion manifested by an unconformity at the base of the Yakataga Formation. However, at Yakataga Reef a middle Miocene hiatus occurs within the Poul Creek Formation, even though deposition was apparently continuous through the overlying upper Miocene interval which spans the Yakataga–Poul Creek contact (Lagoe, 1983). Therefore, the hiatus at Yakataga Reef is not a result of erosion at the Yakataga–Poul

Creek formational boundary, rather it is most likely a result of nondeposition. The middle Miocene hiatus is also evident offshore in the Texaco OCS Y-0032 No. 1 well (fig. 63). A middle Miocene hiatus was also encountered on the adjacent Prince William terrane in the Tenneco Middleton Island No. 1 well and in oceanic sediments from the Deep Sea Drilling Project (DSDP) site 178 on the adjacent Pacific plate (Keller and others, 1984).

The regional occurrence of a middle Miocene hiatus in the Yakutat and Prince William terranes and the adjacent Pacific plate suggests that this hiatus may have resulted from a paleoceanographic eustatic event. Depositional hiatuses and subsequent condensed stratigraphic sections are interpreted to result from abrupt sea-level rises that produce regional transgressions that shift depocenters shoreward and cause basinward sediment starvation (Loutit and others, 1988). A mid-Miocene marine transgression is consistent with the global oxygen isotope record (Miller and Fairbanks, 1985; Miller and others, 1987) and eustatic cycles inferred from seismic stratigraphy (Vail and others, 1977) which suggest a trend of rising sea level in early and early middle Miocene time (fig. 38).

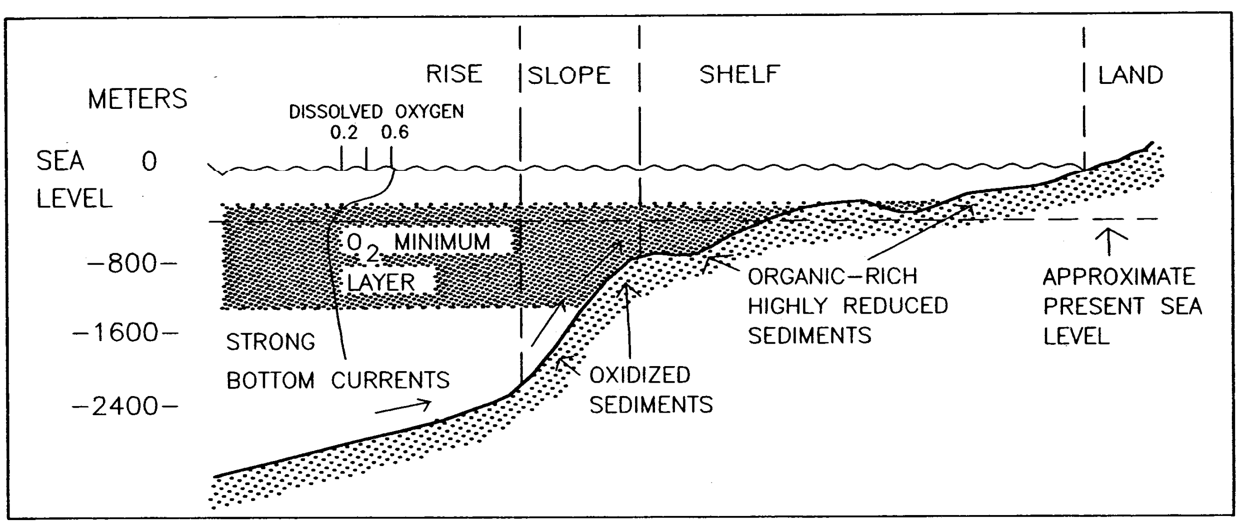
Armentrout (1983a) also suggested that the Miocene upper Poul Creek Formation was deposited during a marine transgression and hypothesized that the organic-rich sediments resulted from an upwelling system that moved shoreward and depressed the oxygen minimum zone along the basin margin (fig. 43). He further postulated that the deposition was a consequence of a climatically induced oceanographic system similar to that which is thought to have influenced deposition of the Monterey Formation and equivalent Miocene rocks around the north Pacific margin (Ingle, 1981; Summerhayes, 1981).

The organic shales of the Poul Creek and Monterey Formations correlate with an early to middle Miocene, ocean-wide carbon isotope ($\delta^{13}C$) anomaly, termed the Monterey carbon excursion, that is interpreted to indicate increased extraction of organic carbon from the oceans and a probable decrease in atmospheric CO_2 (Berger and Mayer, 1987). The timing of the Monterey carbon excursion just prior to the middle Miocene polar cooling event suggests a cause-and-effect link between the inferred atmospheric CO_2 reduction and the subsequent climate cooling indicated by the $\delta^{18}O$ record (fig. 44). The paleoceanographic events influencing the deposition of the Poul Creek organic shales may also have set the stage for climatic cooling and the resulting glaciation that occurred along the Gulf of Alaska subsequent to the docking of the Yakutat terrane in the late Oligocene.

Topsy Formation and Cenotaph Volcanics

The Topsy Formation and Cenotaph Volcanics (Miller, 1961b; Plafker, 1967) are exposed in a few areas between Lituya Bay and Cross Sound (plate 5). This sequence unconformably overlies Yakutat Group basement rocks and is unconformably overlain by the

Figure 43. Interpretative hydrographic profile for middle Miocene deposition of the upper Poul Creek Formation. Organic-rich sedimentation is interpreted to have occurred during a period of transgression when upwelling currents and resulting organic blooms depressed the oxygen minimum zone to the sea floor, possibly within a shelf-margin basin (after Armentrout, 1983a, fig. 7).



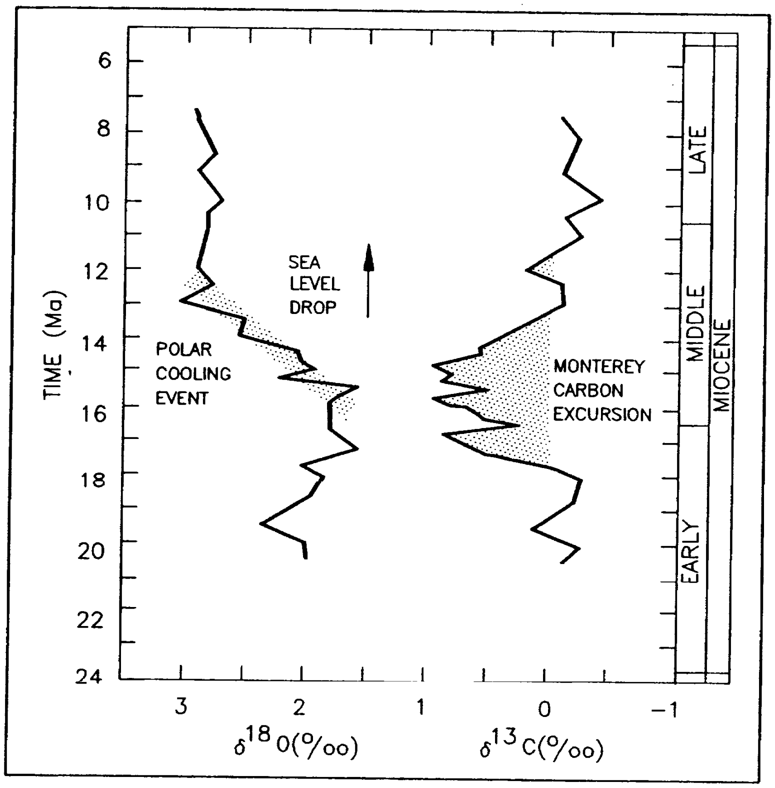


Figure 44. Relationship between oceanic organic carbon and Miocene paleoclimate as indicated by carbon and oxygen isotope records (modified from Berger and Mayer, 1987). The oceanwide Monterey carbon-13 isotope ($\delta^{13}C$) excursion correlates with organic shales of the Monterey Formation and equivalent shales of Pacific continental margins such as the upper Poul Creek Formation. The Monterey $\delta^{13}C$ excursion indicates oceanwide extraction of organic carbon and a probable reduction in atmospheric CO_2, evidently as a result of increased deposition and storage of organic matter on continental shelves. This event was apparently a precursor to the Miocene polar cooling that the $\delta^{18}O$ record indicates began about 15 Ma and which may have set the stage for glaciation in the Gulf of Alaska (see fig. 38).

Yakataga Formation (figs. 33 and 34a). These two rock units are interpreted to be post-early Oligocene to pre-middle Miocene in age and are largely age-equivalent to the Poul Creek Formation (Plafker, 1967).

The Topsy Formation consists of over 3,700 feet of sparsely fossiliferous, calcareous marine siltstone and sandstone (fig. 45). The underlying Cenotaph Volcanics consist of about 1,250 feet of andesitic breccia or agglomerate, tuff, and flows that are interbedded with tuffaceous siltstone, glauconitic sandstone, pebble-cobble conglomerate, and minor coal (fig. 45). Depositional environments range from shallow marine to nonmarine. The Topsy strata intertongue with and, in part, unconformably overlie the Cenotaph Volcanics.

Cenotaph and Topsy strata have not been identified in the onshore exploratory wells drilled east of Yakutat Bay. Most of those wells encountered a relatively thin section of Yakataga Formation unconformably overlying either Kulthieth strata or Yakutat basement rocks, or bottomed in Yakataga strata. However, the Colorado Oil and Gas No. 2 Core Hole (well No. 22, plate 5 and fig. 34a, b) penetrated about 2,000 feet of lower Neogene and Paleogene strata beneath the Yakataga Formation that consist of sandstone, conglomerate, mudstone, and, locally, coal. Plafker and others (1975) include these strata with the Poul Creek Formation and tentatively with the Kulthieth Formation. However, some of these strata should probably be included with the Topsy rather than the Poul Creek Formation. The nonmarine to marginal marine lithofacies in the well are analogous to those of the Topsy Formation, but not to the generally deep-marine facies of the Poul Creek Formation. Furthermore, the location of Core Hole No. 2 is east of the Dangerous River zone on the continental segment of the Yakutat terrane (plate 5) where the Topsy Formation crops out, whereas the Poul Creek Formation appears to be restricted to the oceanic segment of the Yakutat terrane.

The Colorado Oil and Gas Dangerous River No. 1 well (well No. 23, plate 5 and fig. 34a, b) encountered a 550-foot section of sandstone, siltstone, conglomerate, and basaltic volcanics between the overlying Yakataga Formation and the underlying Yakutat Group basement rocks that may be correlative with the Topsy Formation and Cenotaph Volcanics. However, the volcanics in the Dangerous River No. 1 well are undated and, based on lithology, have been correlated with the basalt of Hubbs Creek (Plafker, 1987). Neither correlation is certain without age data on the volcanics or interbedded sediments.

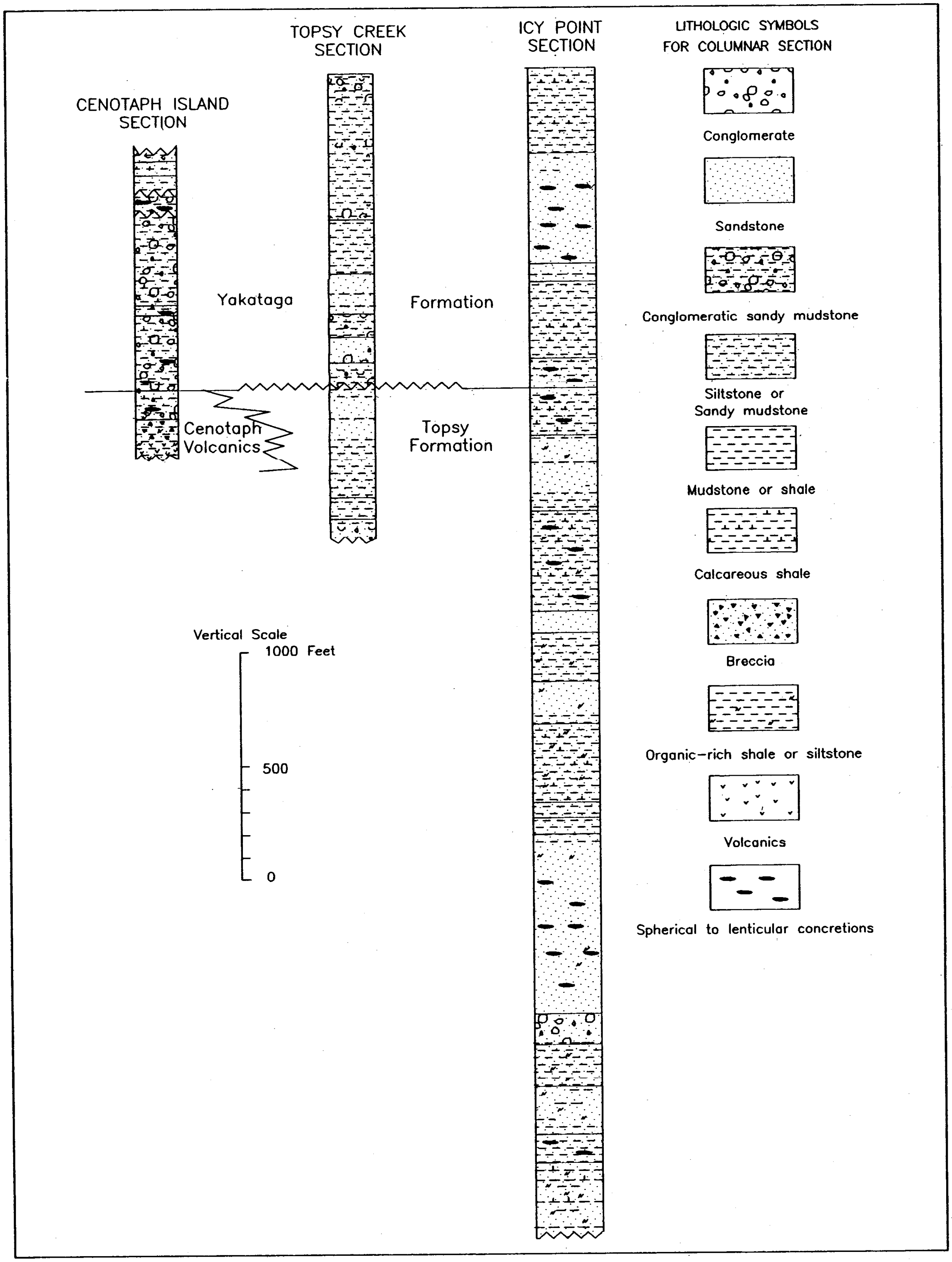


Figure 45. Stratigraphic columns and correlation of the Topsy Formation and Cenotaph Volcanics in the Lituya Bay district (after Rau and others, 1983).

Sitkinak Formation

On the Prince William terrane, the Sitkinak Formation (early Oligocene) and an unnamed shallow-marine siltstone sequence (late Oligocene to early Miocene) are largely age-equivalent to the Poul Creek, Topsy, and Cenotaph Formations on the Yakutat terrane. Outcrops of these strata in the Kodiak Island area consist of coal-bearing nonmarine to marine clastics that apparently represent fan-delta, shelf, and subsea-fan deposits of a forearc basin (Moore, 1969; Moore and Allwardt, 1980).

The Tenneco Middleton Island No. 1 well (plate 6) drilled through a lower Miocene to Oligocene section that has been correlated with the Poul Creek Formation (Rau and others, 1983; Larson and others, 1985b). However, because this well was located across the Kayak Island zone on the Prince William terrane, the strata deposited there before the early to middle Miocene probably were not contiguous with coeval Poul Creek strata deposited on the Yakutat terrane. Consequently, these strata are interpreted as correlatives of the Sitkinak Formation and related strata of the Kodiak Island area rather than the Poul Creek Formation.

The Oligocene to lower Miocene section penetrated by the Middleton Island No. 1 well is 4,175 feet thick (plate 6) and consists predominantly of deep-marine (lower to middle bathyal) siltstone and mudstone, with minor sandstone, conglomerate, and interbedded volcaniclastics. Shallower water species mixed with the predominantly deep-marine microfossil assemblages suggests downslope transport of sediment from nearby slope and shelf regions (Keller and others, 1984).

Lower Tertiary Stratigraphic Sequence

Tokun Formation

The Tokun Formation (Martin, 1908) is exposed only in the Katalla-Bering Glacier area and on Kayak and Wingham Islands where it consists of up to 3,500 feet of Eocene and early Oligocene mostly marine clastic sediments (Miller, 1961a, 1975; Plafker, 1974). Tokun sediments consist predominantly of gray concretionary siltstone with variable amounts of interbedded micaceous sandstone (Miller, 1975; Tysdal and others, 1976; Winkler and Plafker, 1981). In the Bering River Coalfield in the northern part of the outcrop area, the Tokun Formation consists of greenish-gray, micaceous and glauconitic sandstone and siltstone with subordinate carbonaceous shale and coal that occur predominantly as stacked, fining- and shoaling-upward sequences (Turner and Whateley, 1989). Fossils from the Tokun Formation indicate depositional environments ranging from inner to outer neritic (Miller, 1975; Tydsal and others, 1976; Wolfe, 1977; Marincovich and McCoy, 1984). Recent study suggests that Tokun strata may represent tidal-inlet and back-barrier lagoon and marsh deposits of a mesotidal barrier island–estuarine complex (fig. 46) (Turner and Whateley, 1989).

The upper contact of the Tokun Formation with the Poul Creek Formation varies from sharp to gradational and is considered conformable (Miller, 1975; Winkler and Plafker, 1981). The base of the Tokun Formation in the Bering River area is defined by a laterally extensive shale-pellet conglomerate that displays a diachronous relationship with underlying Kulthieth strata (Turner and Whateley, 1989). This conglomerate is thought to mark a marine transgression that moved eastward across the fluvio-deltaic sediments of the Kulthieth Formation (Turner and Whateley, 1989). Tokun strata appear to represent a transitional depositional phase between the progradational deltaic sediments of the Kulthieth Formation and the deep-water basinal shales and siltstones of the overlying Poul Creek Formation.

The only onshore exploratory well that encountered the Tokun Formation was the Richfield Bering River No. 1 well in the Katalla district (well No. 1, plate 5). The Bering River No. 1 well drilled Tokun strata beneath a thin mantle of Quaternary deposits to the total depth at 6,175 feet. The Tokun section encountered in the well was a monotonous sequence of dark siltstone and shale. The dipmeter log indicated that some of the strata were steeply dipping and possibly faulted in two places. Because of this, the 6,100-foot-thick Tokun section penetrated in the well does not represent true stratigraphic thickness.

Tokun Formation lithofacies are not recognized east of the Katalla district in either outcrops or onshore wells. In the Yakataga district, all of the shaly marine strata between the Kulthieth and Yakataga Formations, including any of the basal strata of possible late Eocene age, are assigned to the Poul Creek Formation (Miller, 1957; Plafker, 1967).

Offshore, only the ARCO OCS Y-0211 No. 1 and OCS Y-0007 No. 1 wells penetrated strata that are old enough to be equivalent to the Tokun Formation. The age-equivalent section of the Tokun Formation in the OCS

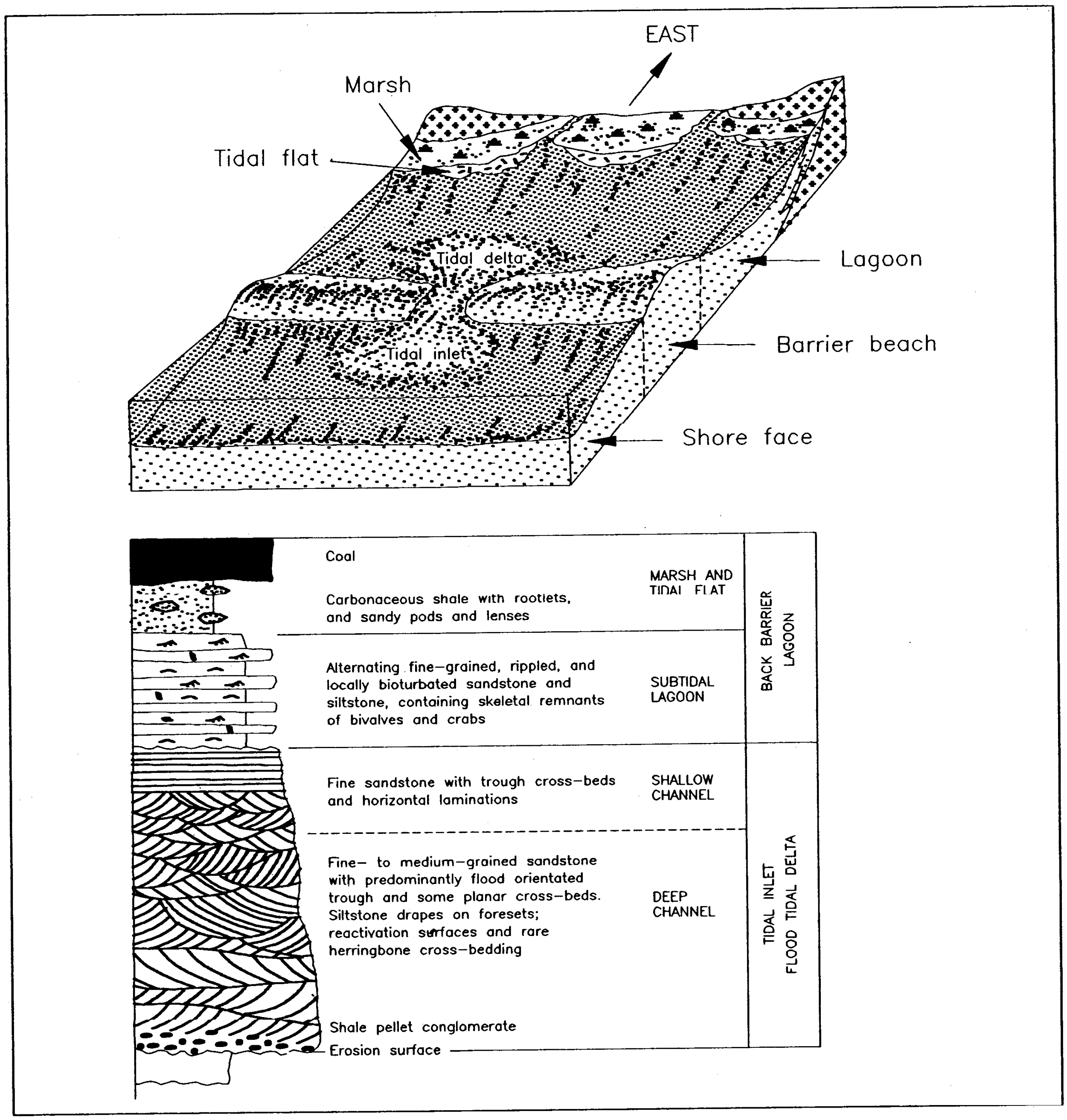


Figure 46. Generalized Tokun Formation fining-upward sequence, interpretation of depositional environments, and block diagram of mesotidal barrier island-estuarine depositional setting (from Turner and Whateley, 1989).

Y-0211 No. 1 well is a predominantly sandy lithofacies that correlates with the Kulthieth Formation (Plafker, 1987). The OCS Y-0007 No. 1 well (plate 6), as previously indicated in the Poul Creek Formation discussion, penetrated 1,970 feet of upper Eocene strata in the bottom of the well that could be age-equivalent to either the upper Tokun Formation or the basal Poul Creek Formation. It is uncertain to which formation these upper Eocene strata correlate because there is no apparent lithologic break in logs or drill cuttings in this part of the well.

Kulthieth Formation

The Kulthieth Formation (Miller, 1957) is exposed on the southern flanks of the Chugach and St. Elias Mountains from approximately Kayak Island to Yakutat Bay (fig. 34a, b). The exposed section is Eocene in age (fig. 34a), at least 9,000 feet thick, and consists of nonmarine and shallow-marine sandstone, siltstone, and mudstone with interbedded coal (fig. 47). In the offshore, seismic sequence III, interpreted to mainly represent the Kulthieth Formation or its equivalents, is locally over 14,000 feet thick (fig. 20).

Exposures of Kulthieth strata are interpreted to represent fluvial and paralic sediments that were deposited as a complex of coalescing deltas (Plafker, 1987). In the Katalla area, equivalent coal-bearing strata formerly referred to as the Kushtaka Formation (Martin, 1905, 1908) are now included with the Kulthieth Formation (Winkler and Plafker, 1981; Plafker, 1987). Fossil fauna and flora from the Kulthieth Formation indicate a middle to late Eocene age, with the youngest strata possibly being early Oligocene (Wolfe, 1977; Addicott and others, 1978; Rau and others, 1983). An isolated outcrop of coal-bearing strata north of the Samovar Hills contains late Paleocene mollusks (Addicott and Plafker, 1971), but the relationship of this older unit to the Kulthieth Formation is uncertain (Plafker, 1987).

The Kulthieth Formation is characterized by sandstone generally described as arkosic to feldspathic, micaceous, with significant admixtures of volcanic rock fragments (Miller, 1957, 1971; Plafker and Miller, 1957; Winkler and others, 1976). Kulthieth sandstone provenance studies indicate a predominantly plutonic and high-grade metamorphic source terrane that differs significantly from the metavolcanic and metasedimentary terranes of the surrounding Chugach and St. Elias Mountains. It is thought that the Kulthieth and Poul Creek sediments were deposited when the Yakutat terrane was farther south and adjacent to coastal uplifts along southeastern Alaska and British Columbia (Hollister, 1979; Plafker and others, 1980; Plafker, 1983, 1987; Chisholm, 1985). Other paleomagnetic, paleontologic, and petrologic studies also place the Yakutat terrane farther south during the Eocene, but disagree as to how far south, and variously place the Yakutat terrane from southern California to British Columbia (Bruns, 1983a; Keller and others, 1984; von Huene and others, 1985; Van Alstine and others, 1985; Davis and Plafker, 1986).

The Kulthieth Formation was deposited in a Paleogene basin that was formed along a continental-oceanic margin when transform faulting along the Transition fault isolated oceanic crust (Plafker, 1987). During deposition of the Kulthieth Formation, the Dangerous River zone (fig. 34) apparently represented a paleoslope along the northeastern margin of the basin (Bruns, 1983b, 1985b; Plafker, 1987). Onshore well and offshore seismic data indicate that the Kulthieth section thickens rapidly westward away from the Dangerous River zone (figs. 20 and 34a). Basal Kulthieth conglomerates unconformably overlie the Jurassic(?) to Cretaceous metasedimentary rocks of the Yakutat Group along the western flank of the Dangerous River zone in the Colorado Oil and Gas Yakutat No. 3 well (well No. 20, fig. 34b), and at the Samovar Hills (plate 5). The Samovar Hills are thought to mark the continuation of the Dangerous River zone after it trends beneath the Malaspina Glacier (Plafker, 1987). Farther northwest along this trend in the Haydon Peak area (plate 5), shaly, deep-water marine equivalents of the Kulthieth Formation also overlie Yakutat Group basement rocks with angular unconformity (Plafker and Miller, 1957).

The Kulthieth fluvio-deltaic complex prograded southwesterly to possibly southeasterly away from the northeastern to northern continental margin of the basin. Paleocurrent measurements from cross-bedding in sandstones northwest of the Bering River area indicate southwesterly flowing streams (Turner and Whateley, 1989). In the Katalla area, Kulthieth fluvio-deltaic sediments intertongue to the southwest with tidally influenced marine sediments of the overlying Tokun Formation and the prodelta marine sediments of the underlying Stillwater Formation (Miller, 1951, 1961a; MacNeil and others, 1961; Plafker, 1987; Turner and Whateley, 1989). A few paleocurrent measurements from Kulthieth sandstones in the Grindle Hills along the eastern side of the Bering Glacier suggest southeasterly streamflow in the Eocene (Lyle and others, 1976).

Kulthieth deltas appear to have been deposited in a moderately deep-water marine basin. Deep-water marine environments are known to have been present on the seaward, southwestern side of the Yakutat terrane during Kulthieth time because middle and late Eocene sedimentary rocks containing bathyal microfaunas were dredged from strata that subcrop along the continental slope (plate 5; Plafker and others, 1980). Kulthieth strata penetrated in onshore exploratory wells along the Gulf of Alaska coast contain both coal-bearing lithofacies and marine sediments with a sparse benthic microfauna indicative of deposition in outer neritic to upper bathyal environments (Rau and others, 1983). This vertical mixture of shallow-shelf to deep-marine environments is suggestive of rapid lateral changes in paleobathymetry.

Lithostratigraphic data on offshore Eocene strata equivalent to the Kulthieth Formation are largely limited to the ARCO OCS Y-0211 Yakutat No. 1 well. The well was drilled near the Paleogene basin axis or depocenter

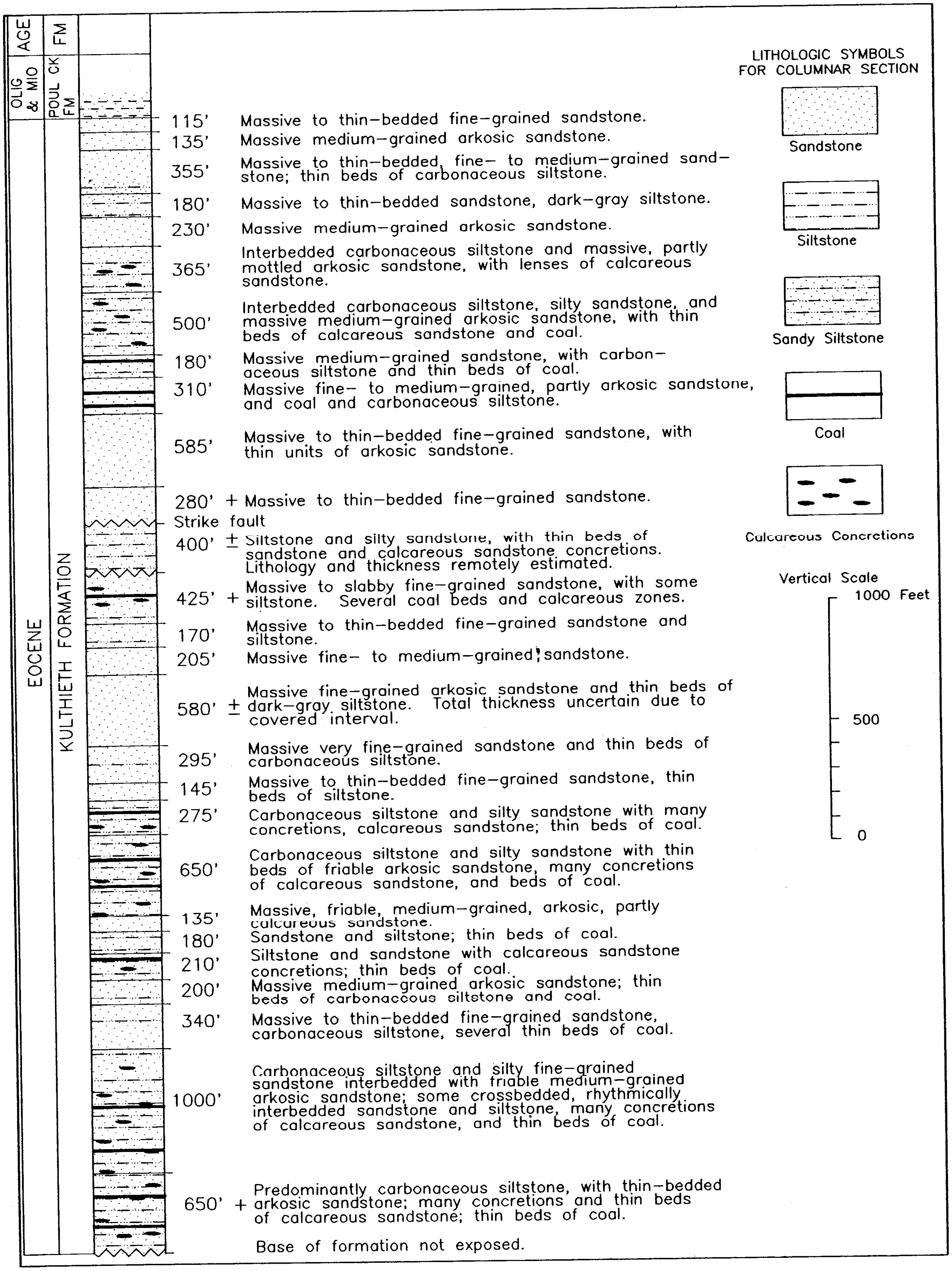


Figure 47. Stratigraphic column of the Kulthieth Formation, Kulthieth River, Yakataga district (after Miller, 1957, sheet 2, section 2).

(plate 5) and penetrated a complete 7,860-foot-section of middle and late Eocene, marine sandstone and shale (plate 7). The Kulthieth benthic microfauna in the well (fig. 64) indicate deposition in outer neritic to upper bathyal water depths (300 to 1,500 feet). The Kulthieth section of the OCS Y-0211 No. 1 well (plate 7) is divisible into an upper sandstone unit (8,570 to 11,650 feet), a middle predominantly siltstone and shale unit (11,650 to 15,360), and a basal sandstone unit (15,360 to 16,430).

The upper Kulthieth sandstone unit in the OCS Y-0211 No. 1 well consists of 3,080 feet of late Eocene sandstone, siltstone, and mudstone. The sandstone is feldspathic, micaceous, very fine to fine grained and occasionally medium to coarse grained, with frequent interlaminae of carbonaceous and micaceous siltstone. The sand–shale ratio increases upward in this unit, suggesting an overall regressive or progradational vertical sequence. The abundant carbonaceous plant detritus and a leaf fragment recovered from core 2 (appendix F-3) suggest that these marine sediments originated from deltaic depositional systems, which are typically the source of terrigenous carbonaceous detritus in offshore marine environments (Selley, 1984).

Wireline log patterns in the OCS Y-0211 No. 1 well indicate that the upper Kulthieth sandstone unit has two different lithofacies associations that subdivide the unit approximately in half. The lower half of the unit consists of relatively large scale (about 50 to 300 feet), thickening- and coarsening-upward shale-sand progradational sequences. An interpretation of sedimentological data from conventional core 4 (fig. 48) of the basal coarsening-upward sequence (11,450 to 11,650 feet) (plate 7) indicates that it is built of aggradational, fining-upward beds that appear to reflect deposition by sediment-gravity flows. The sandstone bed capping this sequence contains cross-bedding near the base that indicates traction transport processes and possibly channelized flow. This lithofacies association, in combination with the outer neritic to upper bathyal microfauna, suggests that it represents a submarine-fan depositional lobe sequence (fig. 49).

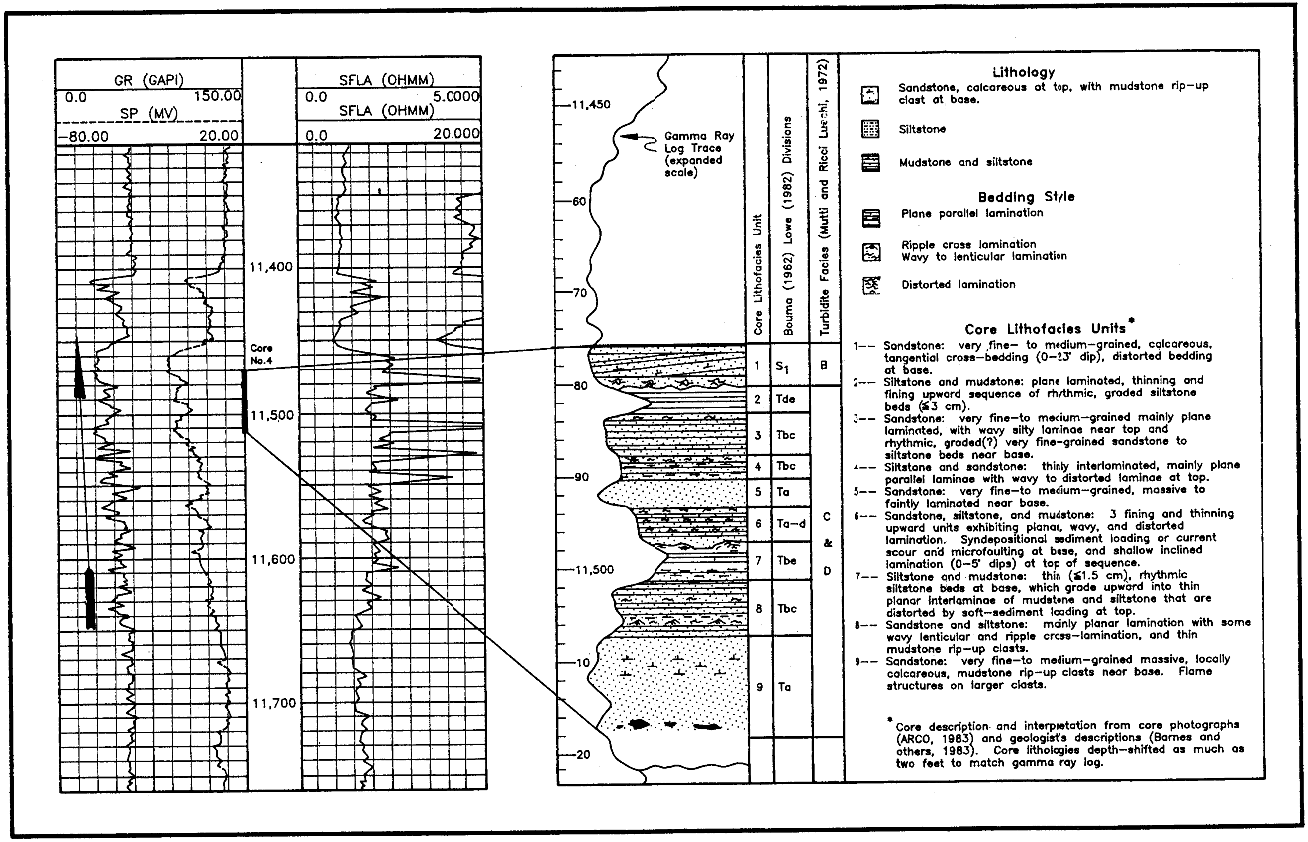
In contrast, the lithofacies association of the upper half of the upper Kulthieth sandstone unit of the OCS Y-0211 well consists of sandstone of mixed bedding styles indicative of a variety of depositional processes (fig. 50). The stratigraphic position of this mixed sandstone lithofacies above inferred submarine-fan depositional lobes suggests middle to upper submarine-fan sedimentation. The diverse depositional processes indicated by the mixed-sand lithofacies are consistent with the variety of channel, channel-mouth, and interchannel depositional environments that are found in the upper to middle portions of submarine fans (Shanmugam and Moiola, 1991; Pickering and others, 1989). On the other hand, conventional cores 2 and 3 from this upper sand facies association are extensively bioturbated (fig. 51), a common, although not diagnostic, characteristic of shallow-marine environments (Pettijohn and others, 1987, p. 118-122; Bottjer and Droser, 1991). However, interchannel areas of submarine fans that receive largely pelagic sedimentation are also commonly bioturbated (Pickering and others, 1989). It may be that both shelf and upper submarine-fan deposits are represented in the mixed-sand lithofacies association of the upper half of the upper Kulthieth sandstone unit in the OCS Y-0211 well.

The middle Kulthieth unit of the OCS Y-0211 well (plate 7) consists of 3,710 feet of middle Eocene siltstone and mudstone with subordinate beds of fine-grained sandstone. A conventional core (core 5, appendix F-6) from the lower part of this unit recovered dark-gray, carbonaceous, micaceous, slightly silty mudstone with local plant detritus and interlaminae of siltstone (Barnes and others, 1983). These finely laminated sediments indicate quiet-water deposition and show no bioturbation. Overall, the middle Kulthieth unit may represent deposition mainly in basinal environments.

The basal Kulthieth unit of the OCS Y-0211 well consists of 1,070 feet of middle Eocene sandstone with subordinate siltstone and mudstone (plate 7). The microfauna of these sediments, like that of the upper and middle Kulthieth units, indicates deposition in an outer neritic to upper bathyal marine environment. Wireline logs display a large-scale vertical thickening- and coarsening-upward succession that suggests a progradational sequence like that of the upper Kulthieth sandstone unit. Depositional processes in this unit were probably analogous to those of the upper sandstone unit, although this is uncertain, as no cores were recovered to allow sedimentological interpretation.

Data from stratigraphic high-resolution dipmeter logs (SHDT) of the OCS Y-0211 No. 1 well suggest that marine-current trends during deposition of the Kulthieth Formation were generally northwest to northeast (fig. 52). Dipmeter logs indicate that the Kulthieth strata at the OCS Y-0211 well site generally dip about 6 degrees or less northwest to northeast. These shallow structural dips reflect the regional northwesterly axial

Figure 48. Log and core data from the basal part of the upper Kulthieth sandstone unit in the OCS Y-0211 No. 1 well that is interpreted to be a depositional lobe of a submarine fan sequence. The large-scale coarsening- and thickening-upward log profile indicates an overall progradational depositional sequence. At the bed-form scale, the conventional core and logs indicate that the sequence was built by fining- and thinning-upward aggradational bedding units. The lower cored beds (core lithofacies units 2–9, 11,481 to 11,521 feet) are interpreted to be low-density turbidite deposits as indicated by evidence of density flow and both traction and suspension deposition: thin graded beds, abundant plane-parallel lamination, abundant mica and carbonaceous detritus, soft sediment deformation, and partial Bouma sequences (fig. 49). The upper bed (core lithofacies unit 1, 11,450 to 11,481 feet), which was cored at the base, is interpreted to be a sandy, high-density turbidite that was probably deposited in a submarine channel near the intersection point of the middle and lower fan (fig. 49). Evidence for this is its stratigraphic position at the top of the lobe sequence, the characteristic channel-like log profile (abrupt base and gradational top), and the large-scale tangential cross-bedding near the base of the bed that indicates traction sedimentation and turbulent flow.



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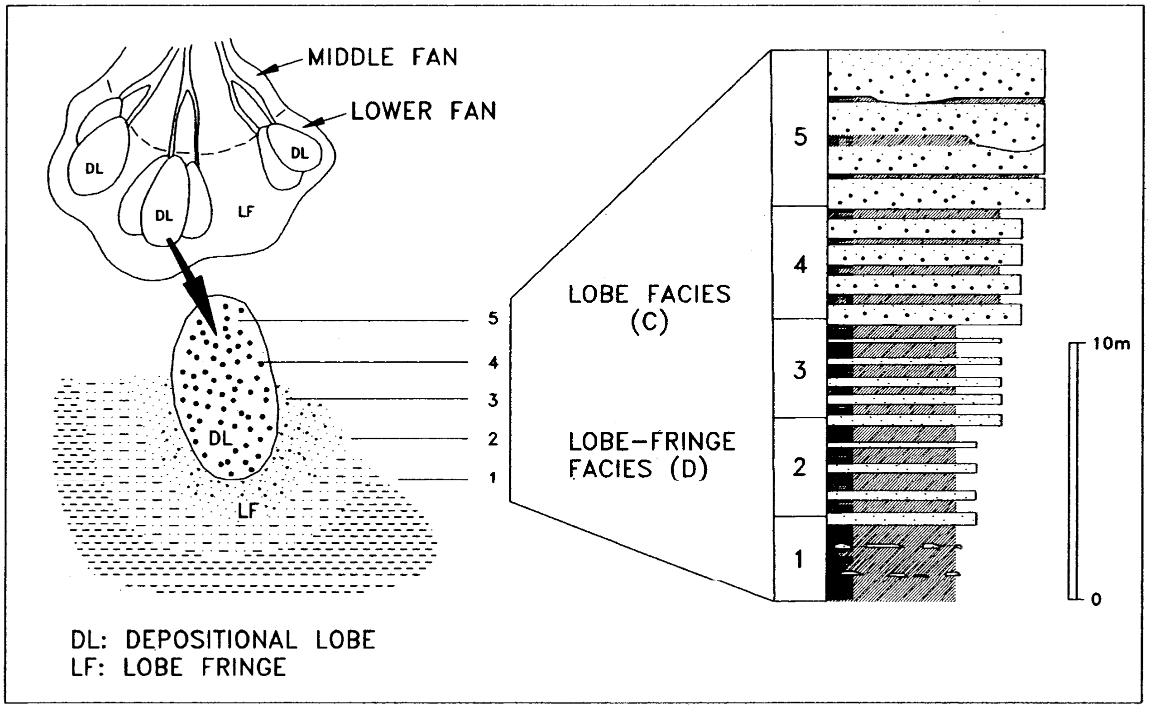
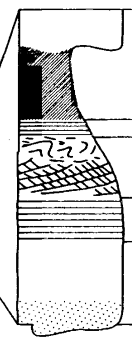


	Facies	Lithology	Bedding	Features
	A	conglomerate, coarse sandstone	thick, irregular, amalgamated	channel fill, shale clasts, poor sorting
	B	coarse to medium sandstone	thick, lenticular	channel fill, shale clasts, dish structures
DL	C	medium to fine sandstone, minor shale	medium, continuous	complete Bouma sequences
LF	D	fine to very fine sandstone, siltstone, shale	thin, remarkably continuous, parallel	Bouma sequence with base missing
	E	sandstone, siltstone	thin to medium, irregular, discontinuous	beds with sharp upper contacts
	F	complex	chaotic	slumps
	G	shale, marl	laminated, remarkably, continuous, parallel	homogeneous texture

Turbidite facies classification of Mutti and Ricci Lucchi (1972)

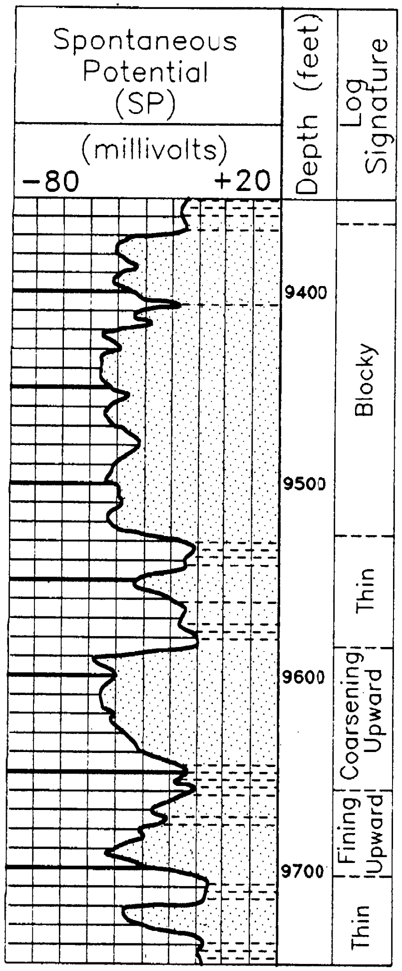


Grain Size	Bouma (1962) Divisions		Interpretation
Mud	Te	laminated to homogeneous mud	deposition from low–density tail of turbidity current settling of pelagic or hemipelagic particles
Silt	Td	upper mud/silt laminae	shear sorting of grains & flocs
Silt & Sand	Tc	ripples, climbing ripples, wavy or convolute laminae	lower part of lower flow regime
	Tb	plane laminae	upper flow regime plane bed
Sand	Ta	structureless or graded sand to granule	rapid deposition with no traction transport, possible quick (liquified) bed

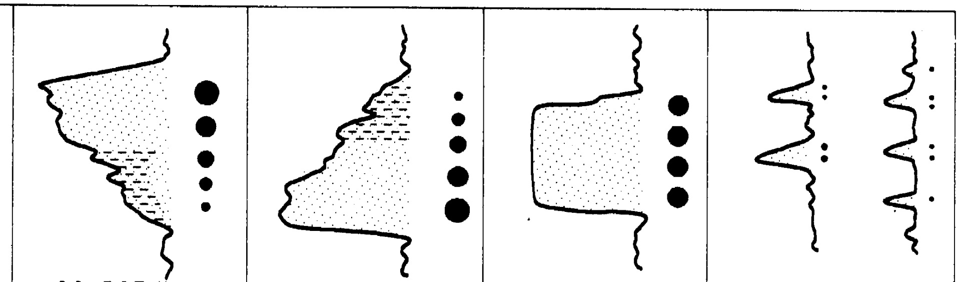
Turbidite bedding sequence of Bouma (1962)

Figure 49. Depositional-lobe model of a submarine fan showing large-scale thickening-upward trends, and distribution of turbidite facies and small-scale bedding sequences in turbidite deposits (modified from Pickering and others, 1989; and Shanmugam and Moiola, 1991).

plunge of the eastern part of the Paleogene basin that is evident on seismic structure contour maps (fig. 19). Dip azimuth frequency plots (rose diagrams) constructed from relatively high-angle dips (10 to 40 degrees) also indicate a predominant northwesterly trend, generally parallel or subparallel to the plunge of the Paleogene basin axis (fig. 52). These high-angle dips are interpreted to primarily represent high-energy sedimentary features such as cross-bedding, foreset bedding, channel fill, and current scour surfaces. Removal of the shallow, structural-dip component from the high-angle dips by dip vector rotation was not found to have a significant effect on the inferred sedimentary dip directional trends. Distortion of sedimentary directional trends generally does not become significant until structural dip exceeds approximately one-third of the magnitude of sedimentary dips (Hocker and others, 1990).



Log signatures of upper Kulthieth sandstones in the OCS Y-0211 No. 1 well.



LOG SIGNATURE	COARSENING UPWARD	FINING UPWARD	BLOCKY	THIN AND SYMMETRICAL
DEPOSITIONAL PROCESSES	Gradual sand influx, increasing energy upward, and abrupt termination	Rapid sand influx, decreasing energy upward, and gradual termination	Rapid sand influx and termination, with constant energy	Short, intermittent pulses of sand deposition; variable energy
SHALLOW WATER	Coastal barriers Offshore bars Distributary mouth bars Thin, distal crevasse splays	Valley and fluvial channel fills Meander point bars Tidal channel fills Proximal crevasse splays	Braided streams Distributary channels of deltas Shelf sandstones Eolian sheets Fan deltas	Thin, transgressive (destructional) sands Shelf sands
DEEP WATER	Turbidite fan prograding over basinal shale; sequence generally composite	Proximal to medial submarine channels	Proximal, base-of-slope channels infilled by grain- and debris flows	Outer fan, distal turbidites

Facies transition of sand to mud

Basic log signatures and depositional processes in shallow and deep water (after Pettijohn and others, 1987, fig. 10-7).

Figure 50. Log signatures and depositional processes of the upper mixed-sandstone lithofacies from the Upper Kulthieth sandstone unit, OCS Y-0211 No. 1 well. The variety of log signatures indicates diverse bedding styles and depositional processes occurred in outer shelf to moderately deep-water environments.

North to northwesterly paleoflow trends in Kulthieth rocks have also been reported by Chisholm (1985), who suggested that the present-day counterclockwise marine gyre of the Gulf of Alaska region has persistently influenced coastal sedimentation on the Yakutat terrane since at least the early Eocene. He postulated that during deposition of the Kulthieth and Poul Creek Formations, rivers flowing from continental source areas to the east supplied sediment to paralic and marine environments which dispersed sediment to the north and northwest as a result of a prevailing counterclockwise marine system. The northwesterly paleocurrent trends reported by Chisholm (1985) are controversial because they apparently contradict the southwesterly to southerly paleocurrent trends of onshore data and because Chisholm (1985) provided no supporting data or references for his conclusions (Bruns, 1985a). However, his northwesterly trends are consistent with the OCS Y-0211 well data and with reconstructions of Paleogene oceanic surface-circulation patterns that indicate north to northwesterly flow along the Pacific Northwest coast of North America (Pickering and others, 1989, fig. 4.11).

In order for northwestern progradation of marine Kulthieth sandstone sequences at the OCS Y-0211 well site to have occurred there must have been substantial influxes of terrigenous sediment along the eastern end of the basin upcurrent and upslope from the well site. This suggests that Eocene fluvio-deltaic complexes represented by Kulthieth exposures on the mainland probably also were present along the segment of the Dangerous River zone that is currently offshore. These inferred deltaic or paralic deposits, like those represented by Kulthieth exposures onshore, probably also prograded southwestward down the slope of the western flank of the Dangerous River zone, but marine environments at the delta margins apparently dispersed the bulk of sediment northwestward along the basin axis.

Similarities in sediment dispersal patterns, areal distribution of lithofacies, and tectonic setting of the Tokun-Kulthieth Formations suggest that the modern Copper River delta may provide a crude depositional analogue for Eocene deltaic and marine sedimentation on the Yakutat terrane. Deltaic depositional systems are classified by the relative influence of fluvial sediment input versus wave and tide energy flux (fig. 53; Galloway, 1975). The Copper River delta, at least in its lower reaches, is a high-energy marine, mixed tidal and wave dominated deltaic depositional system (Galloway, 1975, 1976; Hayes, 1989). The Copper River delta progrades into an open-marine basin along a mesotidal coastline, a depositional setting similar to that inferred for the Tokun-Kulthieth depositional sequence. The continental shelf offshore of the Copper River delta is relatively deep (100 to 200 meters) and is comparable to the outer neritic to upper bathyal paleobathymetry (100 to 450 meters) inferred from Kulthieth marine microfaunas. The sediment dispersal pattern of the Copper River delta system consists of southwesterly trending distributaries and tidal channels that transport sediment to the delta margin, where the sediment is then diverted west-northwestward into the marine environment by longshore drift and marine currents (Galloway, 1976; Hayes, 1989). This pattern is similar to that inferred for the Kulthieth marine sandstone sequences from the dipmeter data of the OCS Y-0211 well. The high bed-load content of the Copper River and high marine energy combine to produce deltaic and deltaically derived marine sediments that are sand-rich (Galloway, 1976). Such an Eocene depositional system would have had the capacity to transport and deposit sand-rich sediments to the relatively deep-water marine basinal environments seen in the Kulthieth section of the OCS Y-0211 well.

To summarize, onshore and rather limited offshore data indicate that Tokun-Kulthieth sedimentation occurred in a moderately deep-marine basin along an active continental-oceanic margin. A schematic Eocene paleogeographic reconstruction is shown in figure 54. Terrigenous sediments including feldspathic-quartzose sands with varying admixtures of volcanic detritus were transported by rivers flowing from a continental, predominantly plutonic-metamorphic terrane to the northeast and east. The coastal plain complex consisted of coal-bearing alluvial plain, delta-plain, delta-front, and mesotidal barrier island–estuarine systems that prograded southwestward into marine prodelta, shelf, and basinal environments. Marine sedimentation was apparently influenced by a counterclockwise, coastal paleoflow pattern which resulted in northwestward dispersal of sediments along the basin axis. The Kulthieth section of the OCS Y-0211 well documents two major Eocene progradational cycles of subsea sand-rich sedimentation at about the early middle and late Eocene that are separated by a period of mud-rich sedimentation in the middle Eocene.

Stillwater and Haydon Peak Formations

The Stillwater and Haydon Peak Formations appear to be largely equivalent on the basis of probable age, lithologic similarities, and stratigraphic and structural relationships. These rock units probably represent shaly

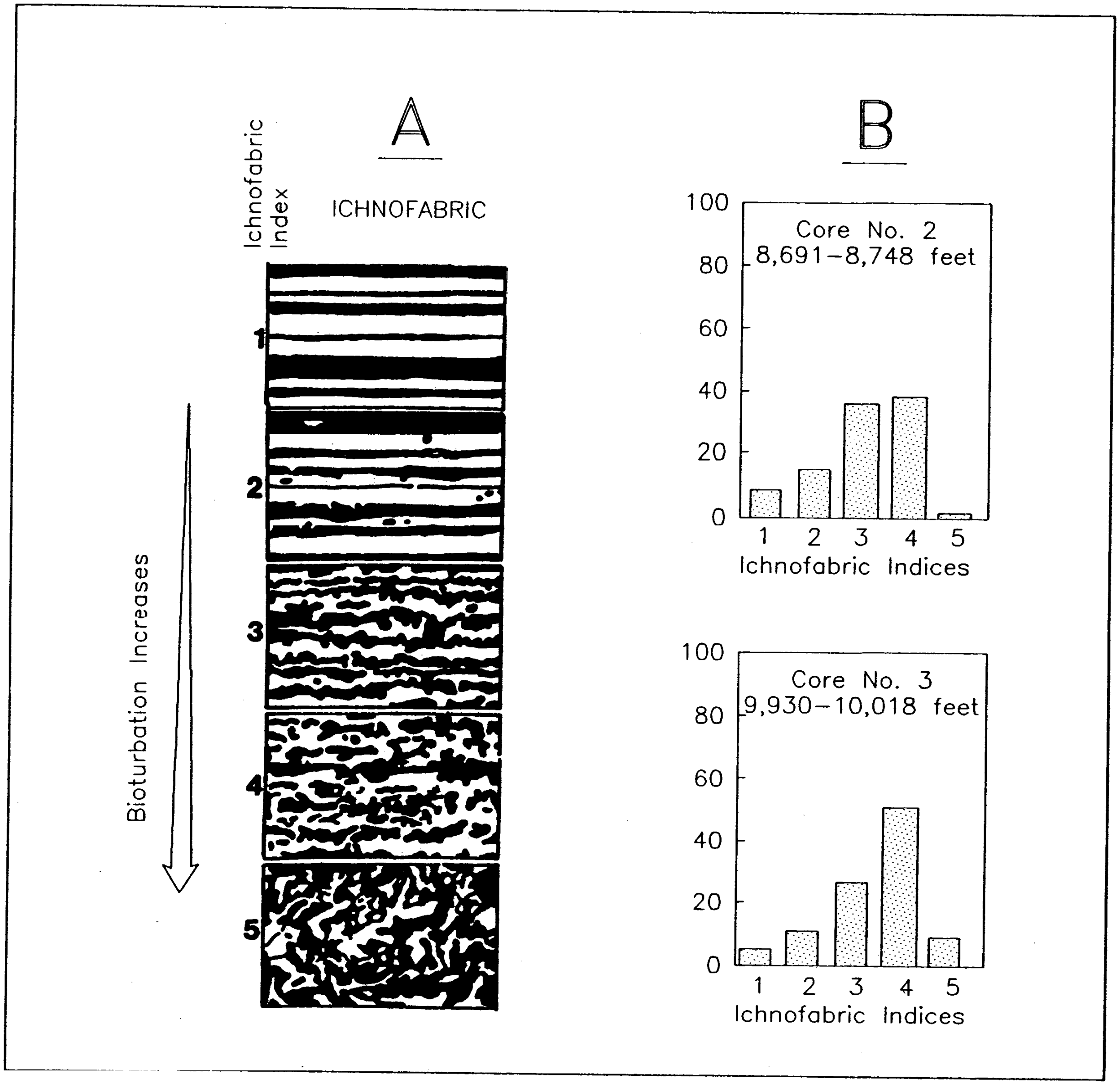


Figure 51. Evaluation of bioturbation in the upper Kulthieth sandstone unit from conventional cores, OCS Y-0211 No. 1 well. A) Schematic diagram showing a ranking of varying amounts of disruption of original sedimentary bedding by bioturbation, termed ichnofabric (after Droser and Bottjer, 1986; Bottjer and Droser, 1991). The ichnofabric indices are semi-quantitatively defined as follows: 1) no bioturbation; 2) up to 10% of bedding disturbed; 3) bedding 10–40% disturbed; 4) bedding 40–60% disturbed; 5) bedding completely disturbed, but sediment fabric not mixed; 6) homogenized sediment (not shown). B) Histograms, termed "ichnograms," of ichnofabric indices of cores 2 and 3 from the upper Kulthieth Formation. The ichnofabric indices were estimated visually from photographs of split cores utilizing diagram A. The ichnograms illustrate the extensive bioturbation that occurred in the sediments of the cores and indicate that the environment was characterized by well-oxygenated bottom waters and a dynamic benthic fauna.

prodelta and basinal marine equivalents of the Kulthieth Formation, as they appear to intertongue with the lower Kulthieth Formation (Plafker and others, 1978a; Plafker, 1987).

The Stillwater Formation (Martin, 1908) is exposed in the Katalla and Bering Glacier area (figs. 33 and 34a), where it consists of approximately 5,000 feet of hard, dense, dark-colored marine shaly siltstone that varies from carbonaceous to calcareous. The carbonaceous siltstone has a coaly appearance, and the calcareous

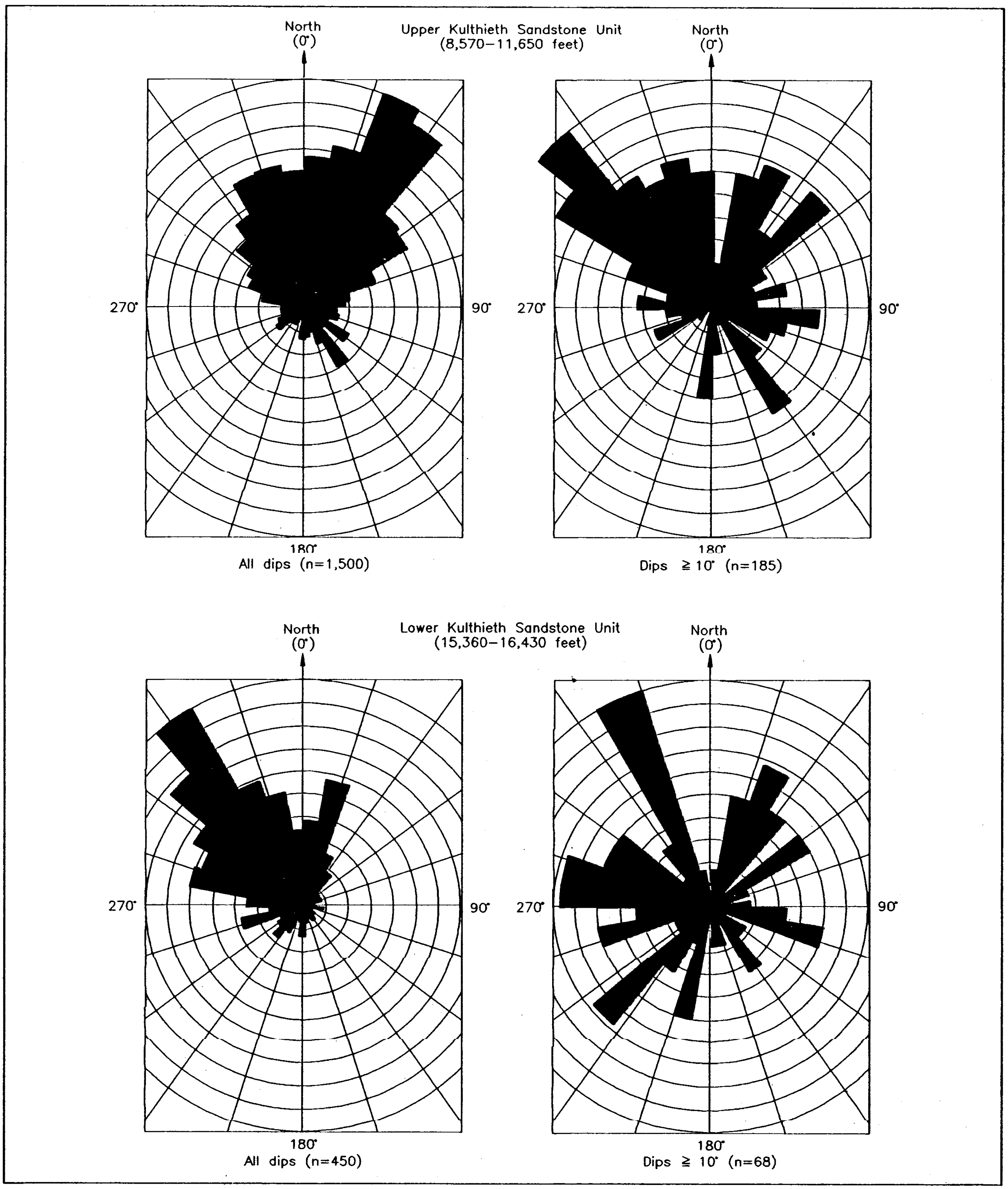


Figure 52. Rose diagrams (dip azimuth frequency plots) of dipmeter data from the upper and lower Kulthieth sandstone units in the OCS Y-0211 No. 1 well. Rose diagrams to the left are plots of all dips irrespective of inclination. The majority of dip inclinations in these diagrams are less than 5 or 6 degrees and indicate that the strata gently dip northwest to northeast. Rose diagrams to the right are plots of the more steeply inclined dips (≥ 10 degrees) that are interpreted to primarily reflect higher angle sedimentary features such as cross-bedding. The azimuths of higher angle dips are interpreted to indicate paleocurrent directional trends rather than the regional structural dip of the strata. Although these rose diagrams of higher angle dips exhibit greater scatter in dip directions, the predominant modes suggest that paleocurrent flow was predominantly northwest and secondarily northeast.

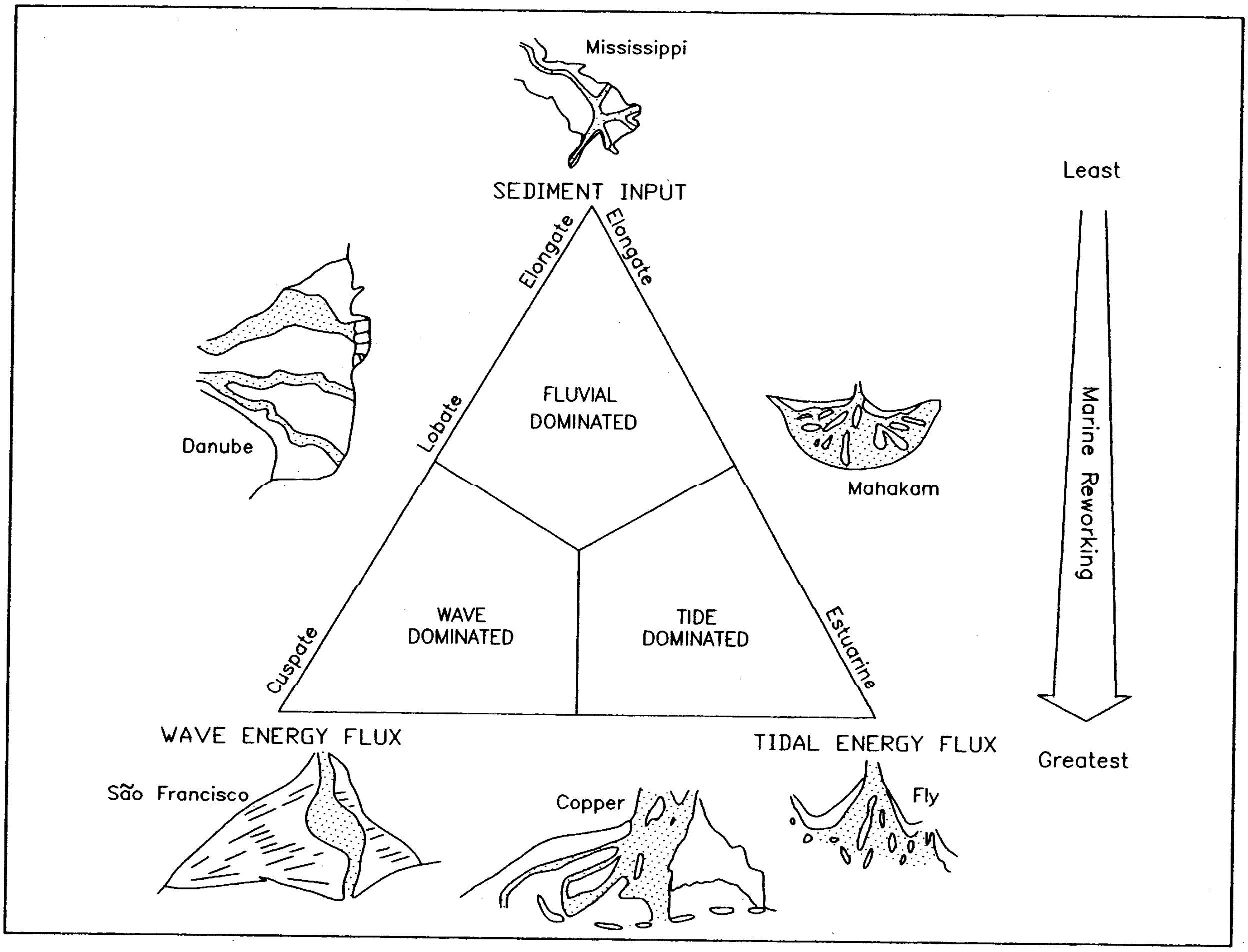


Figure 53. Triangular process classification of deltaic depositional systems (after Galloway, 1975). The Copper River delta in its lower reaches is a mixed wave-dominated and tidal-marine-dominated delta system. Tokun-Kulthieth deltaic depositional systems may have been similar to that of the Copper River delta system.

siltstone is variegated reddish-brown to pale green and usually contains foraminifera (Tysdal and others, 1976; Winkler and Plafker, 1981). Fossil data indicate ages ranging from Paleocene(?) or early Eocene to middle Eocene in older sections of the formation, and middle or early-late Eocene in younger parts (Tysdal and others, 1976). Stillwater strata are complexly folded and sheared and their relationships with underlying and overlying rock units are often obscured (Plafker, 1971). The Stillwater Formation appears to represent regressive deposition. Lower Stillwater strata were deposited in outer neritic to upper bathyal depths, and the upper part of the formation was deposited in shallower marine environments (Winkler and Plafker, 1981).

The Haydon Peak Formation (Winkler and others, 1976; Rodgers, 1987) is a 3,000-foot-thick sequence of marine siltstone and shale that crops out in a belt along the northern parts of the Yakataga and Malaspina districts. This siltstone and shale sequence, until recently unnamed, is thought to range from Paleocene to middle Eocene age on the basis of sparse, poorly preserved fossils and general stratigraphic and structural relationships (Miller, 1957, 1971; Plafker and Miller, 1957; Plafker, 1967; Addicott and Plafker, 1971; Winkler and others, 1976). Haydon Peak strata are predominantly dark-gray slaty siltstone and shale with thin interbeds of fine-grained sandstone. Subordinate lithologies include silty pebble conglomerate, basaltic(?) tuff, and tuffaceous sandstone (Plafker and Miller, 1957). Haydon Peak strata are relatively incompetent and are highly contorted and sheared in some areas (Addicott and Plafker, 1971). Tongues of coal-bearing nonmarine strata similar to the Kulthieth Formation occur locally in the upper part of the Haydon Peak Formation and suggest a gradational, interfingering relationship between the two formations (Miller, 1971). The Haydon Peak Formation rests with angular unconformity on the Yakutat Group in its easternmost exposures along Haydon Peak (Plafker and Miller, 1957). This area may mark the northwestern extension of the Dangerous River zone, as it lies along the trend of the zone from the Samovar Hills. East of the Dangerous River zone structural high, the Haydon Peak Formation and equivalent strata appear to be absent.

Stillwater and Haydon Peak strata have not been reported in onshore wells (Plafker, 1967; Rau and others, 1983; Larson and others, 1985a, 1985b). Offshore, only the Y-0211 well drilled deeply enough to encounter strata of this age, but the Eocene strata in the well have been correlated with the Kulthieth Formation and the Oily Lake siltstone (Plafker, 1987). However, stratigraphic relationships between the poorly dated Stillwater-Haydon Peak strata and the Oily Lake siltstone are uncertain, and it is possible that these rock units are equivalent.

Oily Lake Siltstone

The Oily Lake siltstone (Plafker, 1987) occurs in the Samovar Hills north of the Malaspina Glacier as isolated exposures near Oily Lake (plate 5). The rock unit consists of 300 to 600 feet of dark siltstone and thin, locally graded, very fine-grained sandstone beds and minor basaltic and vitric tuffs. The sediments contain a sparse fauna of middle Eocene marine foraminifers (Plafker, 1987). The large oil and gas seeps in the Oily Lake area appear to be associated with the outcrop distribution of these rocks, which have been interpreted to be their source (Plafker and Miller, 1957; Plafker, 1987). The upper and lower contacts of the siltstone unit are not exposed, but the outcrop distribution suggests that the Oily Lake siltstone is unconformably overlain by the Kulthieth Formation and conformably overlies the Hubbs Creek basalt (Plafker, 1987).

The Y-0211 well penetrated a 1,115-foot-thick section of deep-water marine (middle to lower bathyal), early to middle Eocene calcareous and tuffaceous shale and siltstone from 16,430 to 17,545 feet (plate 7) that Plafker (1987) tentatively correlated with the Oily Lake siltstone. Offshore dredging along the southern continental-slope edge of the Yakutat terrane between the Dangerous River and Pamplona zones recovered Paleocene(?) and Eocene outer shelf to bathyal marine sedimentary rocks (Plafker and others, 1980) that probably represent the Stillwater-Haydon Peak-Oily Lake section. These shaly rock units may represent most of the Eocene section along the distal southern to southwestern margins of the terrane.

Sitkalidak Formation

On the Prince William terrane, sedimentary rocks that are partly age-equivalent to the lower Tertiary sequence of the Yakutat terrane are included in the Eocene to early Oligocene Sitkalidak Formation that is exposed in the Kodiak Island area (Moore, 1969). The Sitkalidak strata consist of massive sandstone, conglomerate, siltstone, and mudstone that represent deformed trench-fill deposits and forearc-basin–subsea-fan sediments (Moore and Allwardt, 1980).

The Tenneco Middleton Island No. 1 well, located on the Prince William terrane (plate 6), drilled through an Eocene to early Oligocene section (fig. 58) that has previously been correlated with the Tokun Formation (Rau and others, 1983; Larson and others, 1985b). However, as previously discussed in the Sitkinak Formation section, strata encountered in this well that are older than middle Miocene were probably not contiguous with coeval strata on the Yakutat terrane. Consequently, these strata are interpreted as correlatives of the Sitkalidak Formation of the Kodiak Island area rather than the Tokun Formation. The Sitkalidak Formation was also drilled farther to the west on the Prince William terrane in the basal parts of the deeper Kodiak Shelf stratigraphic test wells (Turner and others, 1987), and can be correlated in the subsurface across the terrane to the exposures in the Kodiak Island area.

The section interpreted to be correlative with the Sitkalidak Formation in the Middleton Island No. 1 well (plate 6) is 5,220 feet thick and consists predominantly of fine- to very fine-grained silty sandstone and gray to varicolored, argillaceous siltstone or silty claystone that is occasionally bentonitic. Subordinate interbeds of siliceous shaly limestone and sandy conglomerate or conglomeratic sandstone containing pebbles of chert, quartzite, and metasiltstone are also present. The strata are interpreted as bathyal marine; a mix of occasional shallower water species with the predominant deep-marine microfossil assemblages suggests downslope transport of sediment from nearby slope and shelf regions (Keller and others, 1984, p. 486). The top of this section is poorly constrained biostratigraphically (Rau and others, 1983) and was picked from wireline logs at the top of a section that is sandier and more resistive than the overlying siltstones and shales of the Sitkinak Formation-equivalent section (plate 6).

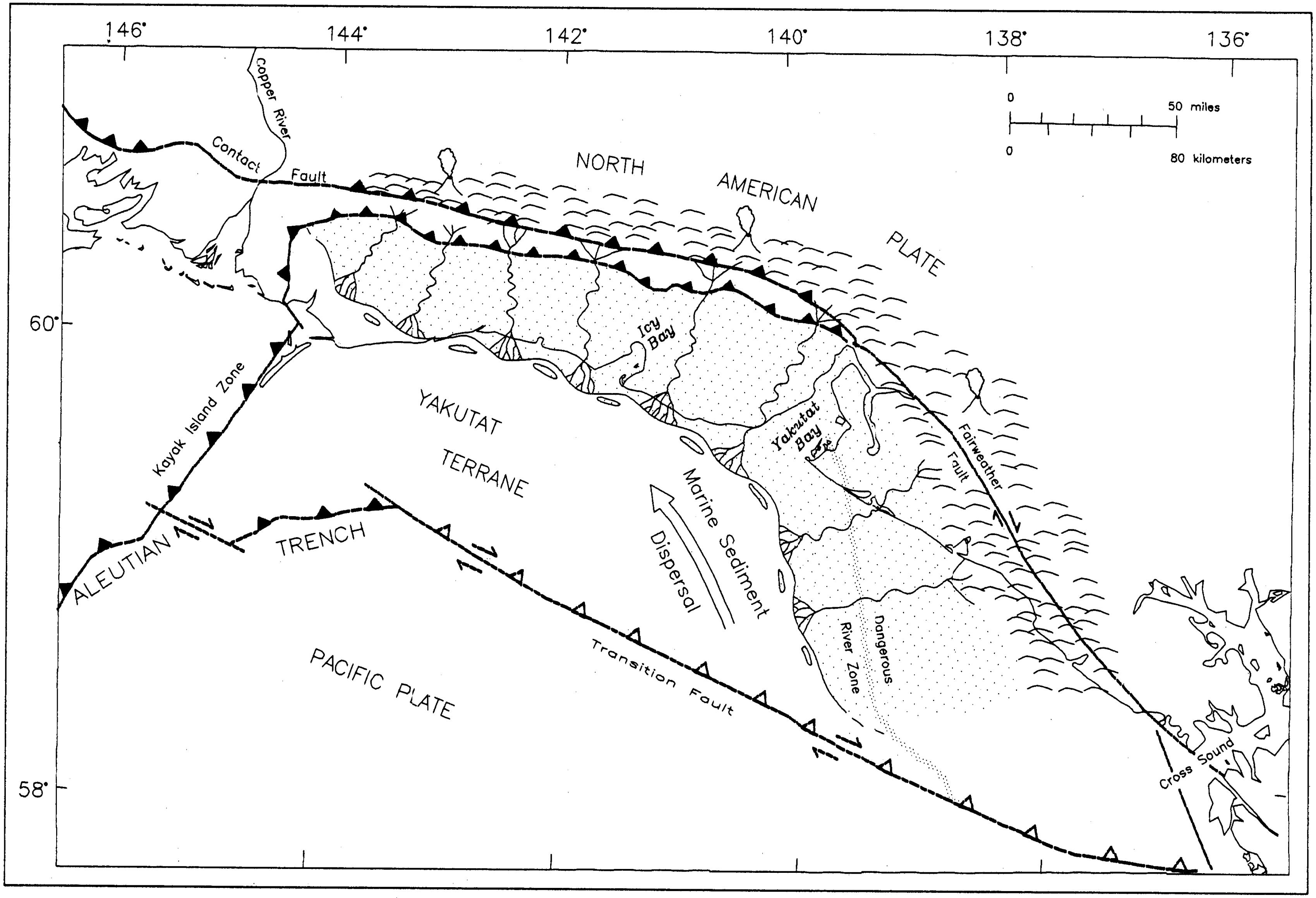


Figure 54. Schematic Eocene paleogeography of Tokun-Kulthieth sedimentation on the Yakutat terrane. Modern coastline and geographic features are shown for reference only; the actual position and orientation of the Yakutat terrane during the Paleogene is uncertain.

Lower Tertiary and Mesozoic basement rocks

Basalt of Hubbs Creek and offshore equivalents

Eocene oceanic basalts are thought to form the basement of the western segment of the Yakutat terrane between the Kayak Island zone and the Dangerous River zone (Plafker, 1983 and 1987; Davis and Plafker, 1986). The only onshore exposures of similar volcanics are in the Samovar Hills near exposures of the Oily Lake siltstone. The main outcrop consists of about 1,000 feet of volcanics exposed along Hubbs Creek in a fault-bounded block between the Kulthieth Formation and the Yakutat Group (Plafker and others, 1980, p. 40-42; Plafker, 1987, fig. 1). These rocks consist primarily of volcanic agglomerate with subordinate basalt flows and tuff, that are intruded by diabase sills and dikes (Plafker, 1987, p. 243). Potassium-argon radiometric age dates of about 50 Ma from the basalt flows indicate correlation with the oceanic volcanics that have been dredged from the present continental slope of the Yakutat terrane (Plafker and others, 1980; Plafker, 1987).

The oceanic basalt flows and pyroclastic rocks that were dredged from the continental slope are interbedded with marine sedimentary rocks of late Paleocene(?) to middle Eocene age (Plafker and others, 1980). Potassium-argon dates from the volcanics indicate an age of 50 to 55 millon years (Plafker and others, 1980). Seismic and offshore dredge data suggest that the basaltic unit underlying the western Yakutat terrane is over 4,200 feet thick (Bruns, 1983b; Plafker and others, 1980, p. 11). Petrologic and geochemical data suggest that these basalts erupted on mid-ocean ridge segments and seamounts of the Kula-Farallon spreading center, and, as a result, they may be correlative with coeval and geochemically similar basalts that occur in a linear belt from Vancouver Island to southern Oregon (Davis and Plafker, 1986).

The OCS Y-0211 and Malaspina No. 1A wells, which were drilled between the basalt outcrops of Hubbs Creek and the oceanic basalts dredged from the continental slope (fig. 33), both penetrated mafic igneous rock. The Y-0211 well bottomed in a 265-foot-thick section (17,545 to 17,810 feet) of mafic igneous rock intercalated with mudstone (plate 6). In the Yakutat Bay area, the Malaspina No. 1A well (fig. 66) drilled undated mafic volcanic or metavolcanic rock in the basal 500- to 600-foot section that overlies the metasedimentary rocks of the Yakutat Group. The mafic igneous rock in both of these wells is interpreted to be correlative with the Hubbs Creek basalt (Plafker, 1987, p. 243). The Dangerous River No. 1 well also drilled undated basaltic rocks that have been correlated with the Hubbs Creek basalt (Plafker, 1987). However, as previously discussed, this correlation is uncertain and stratigraphic relations suggest that the volcanics in the Dangerous River No. 1 well may be correlative with the Cenotaph Volcanics rather than the Hubbs Creek basalt.

Some of the lower and middle Eocene rocks dredged offshore consist of bioclastic sandstone that contains fossil debris characteristic of shallow-water tropical carbonate reefs (Plafker and others, 1980). Similar calcarenite clasts are contained in tuffs and volcaniclastic sandstones of the onshore Hubbs Creek basalt (Plafker, 1987, p. 243). Evidently carbonate reef formation occurred either during or just prior to the early stages of the deposition of the lower Tertiary stratigraphic sequence (Plafker, 1987, fig. 13).

Orca Group

The Orca group is exposed throughout the Prince William Sound region and represents the basement rock of the Prince William terrane west of the Kayak Island zone (fig. 34a). The Orca Group contains an aggregate thickness of over 20,000 feet of complexly folded and faulted, deep-sea fan sediments and interbedded oceanic volcanics of Paleocene to early middle Eocene age that have been metamorphosed to zeolite and greenschist facies (Tysdal and others, 1976; Helwig and Emmet, 1981; Winkler and Plafker, 1981).

In the Katalla area, the Orca Group consists of a lower volcanic unit made up of about 2,500 feet of marine tuff, tuff breccia, basalt and pillow basalt; a middle volcanic and sedimentary unit made up of about 1,000 feet of interbedded sandstone, siltstone, volcaniclastic sandstone, agglomerate, and tuff; and an upper sedimentary unit of about 5,000 feet of flyschoid sandstone, siltstone, and pebbly sandstone (Tysdal and others, 1976). Recent petrographic studies of sandstone from the Orca Group and the Upper Cretaceous Valdez Group of the adjacent Chugach terrane to the north suggest that the two groups may represent a single stratigraphic sequence (Dumoulin, 1988).

The Middleton Island No. 1 well is the only offshore test in the area that may have penetrated the Orca Group. In the basal section of the well (11,460 to 12,000 feet) (plate 6), high resistivity, density, and sonic-velocity well log responses are suggestive of highly compacted sedimentary rock approaching metamorphic grade. Drill cuttings from the interval consisted of pebbly sandstone, siltstone, and shale with abundant slickensided, mylonitized zones. Microfossils from the zone indicate a middle to possibly early Eocene age (Rau and others, 1983). Although this basal section of the well has been previously interpreted as probable Tokun Formation or equivalent (Rau and others, 1983; Larson and others, 1985b), it appears that it may correlate with the Orca Group on the basis of age, lithology, and induration.

Yakutat Group

The Yakutat Group forms the basement of the eastern continental segment of the Yakutat terrane between the Dangerous River zone and the Fairweather-Queen Charlotte fault (fig. 34a, b). The Yakutat Group consists of Jurassic(?) to Cretaceous flysch and melange metasediments (zeolite to lower greenschist facies) that are exposed in the coastal foothills of the St. Elias and Chugach mountain ranges between Icy Bay and Cross Sound (Hudson and others, 1977). The Yakutat Group is also exposed offshore on the continental shelf along the Fairweather Ground structural high and along the continental slope south and east of the Fairweather Ground (Plafker and others, 1980, fig. 3). The Yakutat Group is highly deformed and typically occurs in outcrop as fault-bounded slices that internally are steeply dipping, locally overturned, tightly folded, and highly sheared (Nilsen and others, 1984).

The Yakutat Group flysch facies consists of dense, hard, poorly sorted sandstone, black argillite, and pebble and cobble conglomerate and conglomeratic debris flows that represent turbidite and submarine-fan, forearc, or trench-fill deposits (Nilsen and Zuffa, 1982; Nilsen and others, 1984). The melange facies consists of greenstone, volcanic graywacke, and minor argillite, chert, and limestone, and contains blocks of mafic volcanics (Plafker, 1967; Plafker and others, 1977). The Yakutat Group sandstones contain abundant quartzofeldspathic detritus indicative of a dominantly plutonic provenance, whereas coeval sandstones of the Valdez Group of the Chugach terrane contain lithic detritus indicative of a volcanic provenance (Lull and Plafker, 1985; Dumoulin, 1988). The closest suitable provenance for the Yakutat Group sandstones is the plutonic and high-grade metamorphic crystalline complex of the Coast Mountains of British Columbia and southeastern Alaska (Plafker and others, 1980; Zuffa and others, 1980; Lull and Plafker, 1985).

The Yakutat Group was drilled in four of the onshore exploratory wells in the Malaspina and Yakutat districts. In three of the wells, the Colorado Malaspina No. 1A, Yakutat No. 2, and Dangerous River No. 1 (fig. 66), typical Yakutat Group flysch facies metaclastics were encountered. In the Colorado Yakutat No. 3 well, a carbonate section, possibly of the melange facies, was drilled in addition to metaclastics. The carbonate section, which was cored in the basal 580 feet of the well, consisted of hard, dense, locally highly fractured, sucrosic to cryptocrystalline limestone, that was locally oolitic and fossiliferous.

6. Biostratigraphy

Introduction

The Gulf of Alaska Planning Area (fig. 68) has been penetrated by 13 offshore wells (fig. 66, table 3, and plate 5). One of these, the Tenneco Middleton Island State No. 1 well, was drilled on a State lease less than 3 miles offshore from Middleton Island. Another, the ARCO COST No. 1 well, was a stratigraphic test well drilled to a total depth of 5,150 feet (Bolm and others, 1976). The remaining 11 wells were exploratory wells drilled on Federal leases on the Outer Continental Shelf (OCS).

Seven of the offshore wells encountered sediments at least as old as late Miocene and these wells were selected for detailed discussion in this report. One of these, the Shell OCS Y-0011 No. 1 well, bottomed in the lower portion of the glaciomarine Yakataga Formation. The other six wells drilled through the Yakataga Formation and penetrated underlying older sediments that had potential to provide more complete information about the geologic history and the petroleum potential of the area. These other wells include the Tenneco Middleton Island State No. 1, the Exxon OCS Y-0080 No. 1, the Shell OCS Y-0014 No. 1 and 2, the ARCO OCS Y-0007 No. 1, the Texaco OCS Y-0032 No. 1, and the ARCO OCS Y-0211 No. 1 wells (fig. 66, table 3, plate 5).

The strata encountered in these wells range in age from Holocene/Pleistocene to early to middle Eocene and are discussed in the order in which they were penetrated in each of the wells studied. The stratigraphic column east of Kayak Island where most of the wells were drilled (fig. 66, plate 5) includes, in descending order, the middle Miocene to Pleistocene glaciomarine Yakataga Formation, the late Eocene to Miocene Poul Creek Formation, the Eocene Tokun/Kulthieth/Stillwater Formation sequence, and older formations. The Yakataga Formation also lies at the top of the section west of Kayak Island, but the underlying section is similar to the sequence in the Kodiak Island area, which includes the Oligocene to Miocene Sitkinak Formation and the Eocene to Oligocene Sitkalidak Formation. The deepest section penetrated in the offshore area west of Kayak Island resembles outcrops of the Paleocene to late(?) Eocene (Plafker and others, 1985) Orca Group found along shore from Prince William Sound to the Katalla area (plate 5). The stratigraphy of the Gulf of Alaska area is discussed in detail in chapter 5 (Lithostratigraphy) and is summarized there in figures 33 and 34a.

The relative time scale used in this study is shown in figure 55, which also includes absolute ages of epoch boundaries. Because the ages of many of the benthic foraminifera occurring in the Gulf of Alaska section are inferred from their ranges in the California, Oregon, and Washington stratigraphic sections, figure 55 also shows the California Cenozoic stages and relates them to the standard time scale.

Several microfossil groups were used in the biostratigraphic analysis of these wells. Of primary importance were foraminifera, followed by calcareous nannofossils, dinoflagellates, and siliceous microfossils (diatoms, ebridians, and silicoflagellates). Pollen and spores were useful for paleoenvironmental analysis. Radiolaria and rare ostracodes were present but of limited biostratigraphic usefulness.

Benthic foraminifera are the most abundant and persistent microfossils present in all of the wells. Individual benthic species proved useful for determining some of the biostratigraphic tops, particularly in the Eocene section. The benthic foraminifera assemblages were of primary importance in determining paleobathymetry. The paleobathymetric divisions used in this report (fig. 56) are inner neritic (0 to 60 feet), middle neritic (60 to 300 feet), outer neritic (300 to 600 feet), upper bathyal (600 to 1,500 feet), middle bathyal (1,500 to 3,000 feet), and lower bathyal (3,000 to 6,000 feet).

Planktonic foraminifera assemblages in the Pleistocene section are characterized by abundant, low-diversity populations consisting primarily of *Neogloboquadrina pachyderma*. This species also dominates the Pliocene section, but in lesser abundance, and is present in the late Miocene section as well. Trends in the coiling directions of *Neogloboquadrina pachyderma* populations were used to establish the biostratigraphy of most of the Pliocene and Pleistocene sections. The coiling direction of the shell (test) of this species is either a clockwise, right-coiled trochospiral or a counter-clockwise, left-coiled trochospiral. The direction of coiling is related to the temperature of the water column in which the individual foraminifera lived. At temperatures above 7 to 9 degrees Centigrade (45 to 48 degrees Fahrenheit), right-coiled forms make up 90 percent or more of the population; below this temperature, left-coiled forms compose 90 percent or more of the population (Ericson, 1959; Bandy, 1960; Kennett, 1976). Through time, the history of coiling-ratio trends of medium- to high-latitude populations of this species track oceanic warm- and cold-water oscillations caused by late Miocene, Pliocene, and Pleistocene glacial–interglacial paleoclimate changes. Because of this, *Neogloboquadrina pachyderma* coiling-direction trends can generally be used to determine age by comparing them with a standardized coiling-trend curve (fig. 57), as was done for the Pliocene and Pleistocene sections of the Gulf of Alaska wells.

Although planktonic foraminifera in the Gulf of Alaska section are generally scarce below the Pliocene, they are more taxonomically diverse. They were important in subdividing the Miocene and Eocene sections, and were also used in determining the boundaries of the Oligocene section.

A listing of the foraminifera species observed in this study is provided in appendix A.

Dinoflagellates and calcareous nannofossils were the most useful microfossil groups in the Oligocene section. They were also useful in the Eocene and Miocene sections and, in some cases, the Pliocene section.

Siliceous microfossils (diatoms, silicoflagellates, and ebridians) are generally scarce in the offshore Gulf of Alaska wells studied except in the upper portions of the Shell OCS Y-0011 No. 1 well. They are also somewhat more abundant in the Gulf OCS Y-0059 No. 1 well (fig. 66, table 3, plate 5), which was not included in this study because at its total depth of 12,170 feet it was still in the Pliocene (Anderson, Warren, and Associates, Inc., 1977b; report provided by Gulf Oil Corporation). Siliceous microfossils were biostratigraphically significant only in the subdivision of the Pliocene and Pleistocene. They were of little significance below the Plio-Pleistocene because they were very scarce in the Miocene and, with the exception of

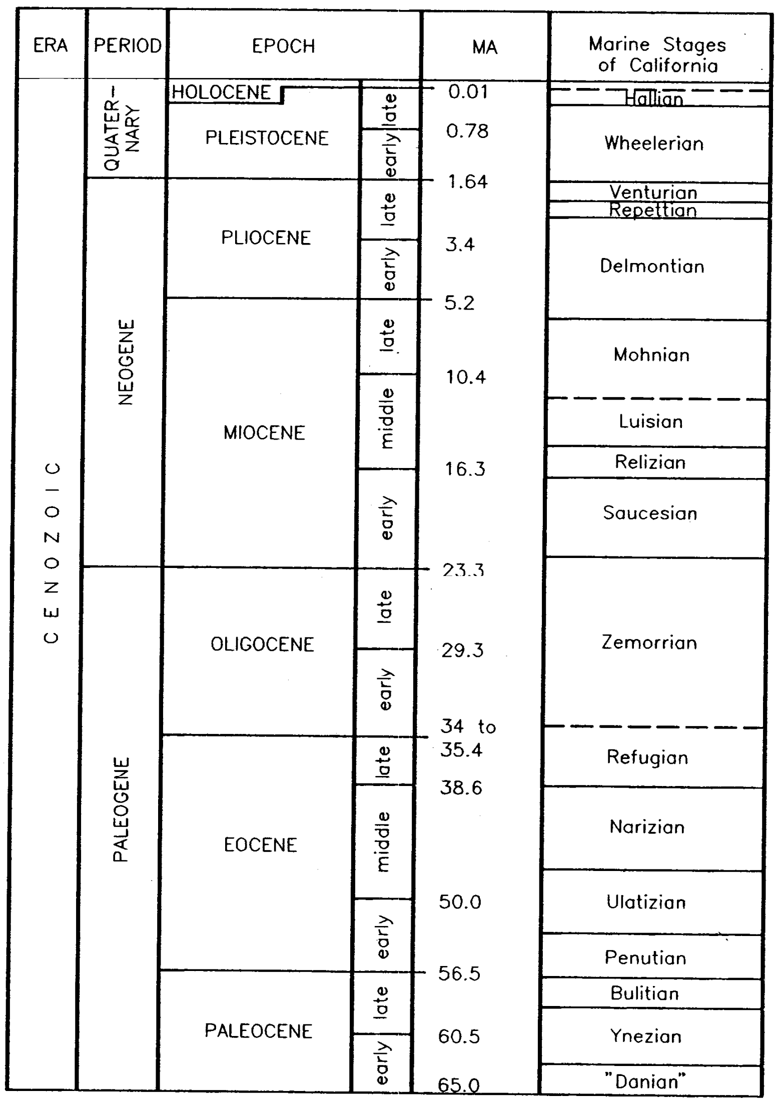


Figure 55. Cenozoic epochs related to California marine stages. Adapted from Kleinpell and others (1980), Harland and others (1990), and Prothero and others (1990).

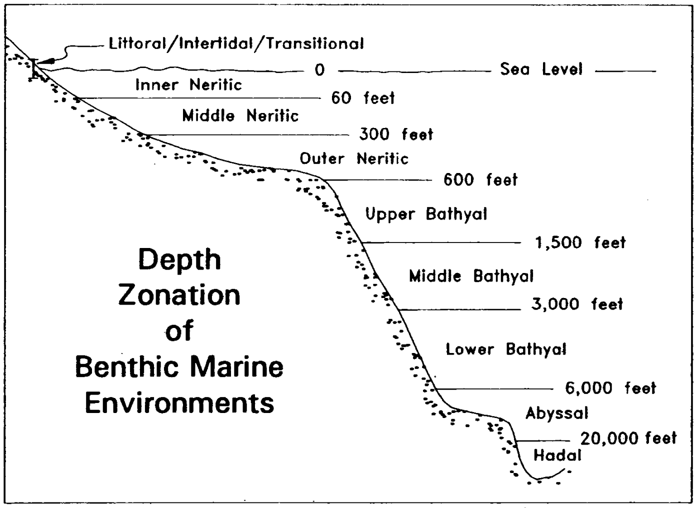
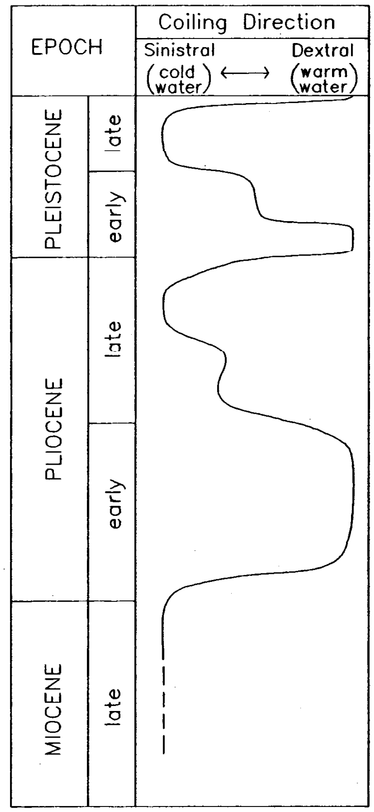


Figure 56 (left). Bathymetric zonation of the marine environment, including the paleodepth designations used in this report. Vertical distances are not to scale.

Figure 57(below). Idealized paleoclimatic curve showing the predominant coiling directions of *Neogloboquadrina pachyderma* through time in the North Pacific. Adapted from Keller and Ingle (1981) and Lagoe and Thompson (1988).



unidentifiable pyritized pseudomorphs, altogether absent deeper in the section.

The general scarcity of siliceous microfossils in the Gulf of Alaska section may be related to a variety of factors. Diatom productivity may have been relatively low throughout the Gulf of Alaska area during much of the deposition of the Yakataga Formation because of factors such as glacio-eustatic fluctuations of sea level, high turbidity, and the variable presence of ice cover over the continental shelf. In addition, the siliceous microfossils that are initially preserved in a glaciomarine environment such as this area of the Gulf of Alaska are probably volumetrically insignificant in the rapidly accumulating glaciomarine sediments. It also appears possible that some of the siliceous microfossils originally present in the lower parts of the Yakataga Formation and in underlying older rocks may have been lost as increasing burial depth resulted in heat- and pressure-related diagenesis that destroyed their opaline wall structure (Hein and others, 1978). This may have been what happened in the Miocene and older section in the Bering Sea (Turner and others, 1984).

Where noted in the text, the abundances of microfossil species observed in the well samples are referred to as absent (none), isolated (1 specimen of a given species per sample), rare (2 to 10 specimens per sample), frequent (11 to 32 specimens per sample), common (33 to 100 specimens per sample), abundant (101 to 320 specimens per sample), and very abundant (more than 320 specimens per sample).

Several types of well sample material were examined for micropaleontologic analysis. Aggregate samples of rotary drill bit cuttings (cuttings or ditch samples) recovered from circulating drilling mud were examined for each 30-foot interval in the OCS Y-0007 No. 1 and OCS Y-0032 No. 1 wells. Cuttings samples from the OCS Y-0080 No. 1, OCS Y-0014 No. 1 and 2, and OCS Y-0211 No. 1 wells were examined at 30- to 90-foot intervals. Cuttings samples from the Middleton Island State No. 1 well were examined at 60- to 180-foot intervals (Rau and others, 1983; Keller and others, 1984). Conventional core samples were also available for study in the OCS Y-0080 No. 1, OCS Y-0011 No. 1, and OCS Y-0211 No. 1 wells. Sidewall cores provided some micropaleontological data for the OCS Y-0011 No. 1 well.

The depths given for all samples were measured from the rotary kelly bushing on the drill rig floor. The depth at which a particular microfossil is first encountered in the course of drilling is termed its highest occurrence in the well; the deepest point at which it is encountered is termed its lowest occurrence. In cuttings samples, highest (also referred to as latest or last) occurrences are the most stratigraphically reliable because they are more likely to consist of material that was in place. Lowest occurrences, on the other hand, are less reliable because they may represent loose material that has fallen, or caved, from a point higher up in the hole to a well depth that is below its actual lowest stratigraphic (earliest or first) occurrence. Highest occurrences can also be unreliable, however, if specimens have been eroded from older rocks and re-deposited, thereby indicating an erroneous (older) age for the sediments in which they are now found. Such specimens are referred to as reworked. Specimens recovered from conventional cores, and to a slightly lesser degree from sidewall cores, are generally considered to be the most biostratigraphically reliable because their actual stratigraphic depth is known.

The top several hundred feet of each of the offshore wells was not sampled because of rapid drilling rates and caving of poorly consolidated material from the walls of the upper portions of the borehole. Collection of cuttings generally began at a depth where the upper part of the well was first stabilized by the insertion of a casing that reduced the possibility of sample contamination by caving.

Unprocessed material from the wells examined for this study, including cuttings samples, mud loggers' samples, and core samples, are stored at the State of Alaska Geologic Materials Center in Eagle River, Alaska. These samples are available by appointment for examination on the premises.

In this study, the Gulf of Alaska Pleistocene section is subdivided into early and late intervals only, as opposed to the early, middle, and late divisions of some authors (Harland and others, 1990). This is because the microflora taxa (diatoms, silicoflagellates, and calcareous nannofossils) needed to differentiate the middle Pleistocene section either were not recovered, or provided conflicting evidence because of caving or reworking. The early–late subdivision of the Gulf of Alaska Pleistocene section that is used here is principally derived from the coiling curves of the planktonic foraminifera *Neogloboquadrina pachyderma* (fig. 57). *Neogloboquadrina pachyderma* populations underwent a change of coiling directions from dextral (warm water) to sinistral (cold water) during a paleoclimatic transition in the mid-Pleistocene (fig. 57) near the top of the Matuyama magnetically reversed epoch, at approximately 0.8 million years before present (Lagoe and Thompson, 1988). This coiling change is apparent in the *Neogloboquadrina pachyderma* populations in the Gulf of Alaska wells and is used to divide the Gulf of Alaska Pleistocene section into early and late intervals.

This planktonic-foraminifera-based division roughly corresponds with mid-Pleistocene biostratigraphic divisions based on some of the other microfossil groups. In the zonation of calcareous nannofossils, it is approximately equivalent to the top of the *Crenalithus doronocoides* zone (Bukry, 1975) and the top of the *Pseudoemiliania lacunosa* zone (Perch-Nielsen, 1985a), possibly falling within the lowermost portion of the overlying *Gephyrocapsa oceanica* zone (Bukry, 1975; Perch-Nielsen, 1985a). In the diatom zonation, it is approximately equivalent to the top of the *Actinocyclus oculatus* zone, possibly falling within the lowermost portion of the overlying *Rhizosolenia curvirostris* zone (Barron, 1980, 1985). In the zonation of silicoflagellates, the planktonic-foraminifera-based division is approximately equivalent to the top of the *Distephanus speculum* zone of the North Sea (Martini and Muller, 1976) and the top of the *Mesocena quadrangula* zone (Perch-Nielsen, 1985b), or falls just within the lower portion of the overlying *Distephanus octangulatus* zone (Martini and Muller, 1976) or its equivalent, the *Dictyocha aculeata aculeata* zone (Perch-Nielsen, 1985b).

In addition to the information gained from examination of well samples and identification of benthic and planktonic foraminifera, bryozoans, and calcareous, siliceous, and phosphatic biotic fragments, data for this chapter were also gathered from Minerals Management Service reports, consultant reports, and a wide range of geological literature. Identification and primary interpretation of the foraminifera in the OCS Y-0007 No. 1 and OCS Y-0032 No. 1 wells was done by Ronald F. Turner (1977, 1978) of the Minerals Management Service, Alaska OCS Region. The identification of siliceous microfossils in the OCS Y-0080 No. 1, OCS Y-0007 No. 1, OCS Y-0032 No. 1, and OCS Y-0211 No. 1 wells was done by Donald L. Olson, also of the Minerals Management Service, Alaska OCS Region. Identifications of dinoflagellates and pollen in a large group of samples from the OCS Y-0080 No. 1 well were provided in a report done by the Bujak Davies Group (1988). Identifications of calcareous nannofossils from selected intervals in the OCS Y-0080 No. 1, OCS Y-0007 No. 1, and OCS Y-0032 No. 1 wells were provided in a report by W. H. Akers (1988). Jacobson and Akers (1985) provided identifications of dinoflagellates and calcareous nannofossils in a large suite of samples from the OCS Y-0007 No. 1, OCS Y-0032 No. 1, and OCS Y-0211 No. 1 wells and a smaller grouping of samples from the OCS Y-0080 No. 1 well (Jacobson Consulting, Inc., 1985). Identifications of foraminifera, siliceous microfossils, and calcareous nannofossils in the OCS Y-0011 No. 1 well were provided by Shell Oil Company in a report by Anderson, Warren, and Associates, Inc. (1977a). R. S. Boettcher of Micropaleo Consultants, Inc., provided identifications of foraminifera from selected intervals in the OCS Y-0080 No. 1 and OCS Y-0211 No. 1 wells (personal commun., 1990). Identifications of foraminifera and calcareous nannofossils in the Middleton Island State No. 1 well were taken from Rau and others (1983) and Keller and others (1984). The data from all of the supplementary sources were to some degree interpreted or reinterpreted by the author. A sizeable portion of the author's identification of foraminifera and other biotic constituents from the OCS Y-0211 No. 1 well was done from picked slides of foraminifera reposited at the Alaska State Geological Materials Center in Eagle River, Alaska.

The means for identification and determination of age ranges of microfossil species encountered in the offshore Gulf of Alaska well samples were provided by several principle references. Identifications and paleoenvironmental determinations of Oligocene to Recent Gulf of Alaska benthic foraminifera were dependent in part upon Bergren and O'Neil (1979), Echols and Armentrout (1980), and Lagoe (1983). Planktonic foraminifera identification and age determination was facilitated by reference to Postuma (1971), Stainforth and others (1975), Kennett and Srinivasan (1983), Bolli and Saunders (1985), Jenkins (1985), Toumarkine and Luterbacher (1985), and Hornibrook and others (1989). Ages for calcareous nannofossils were largely based on Bukry (1973, 1975) and Perch-Nielsen (1985a). Diatom age ranges were derived from Barron (1980, 1985), and age ranges of silicoflagellates were determined largely from Martini and Muller (1976) and Perch-Nielsen (1985b). Dinoflagellate age ranges were determined by referring to Bujak (1984), Williams and Bujak (1985), Matsuoka and Bujak (1988), Lentin and Williams (1989), and other literature sources.

Tenneco Middleton Island State No. 1 well

The Tenneco Middleton Island State No. 1 well is located in State of Alaska waters less than 3 miles offshore from Middleton Island on the Middleton shelf segment of the western part of the Gulf of Alaska study area (figs. 2 and 66, plate 5). It is the only offshore well in the western part of the area and is reviewed here to develop a better overview of the Middleton shelf subsurface stratigraphy for comparison with the Gulf of Alaska OCS wells farther to the east.

The Middleton Island State No. 1 well was drilled in 60 feet of water to a total depth (TD) of 12,000 feet. All well depths were measured from the kelly bushing (KB), 71 feet above mean sea level. The well encountered glaciomarine tillites, sandstones, and siltstones characteristic of the late Miocene to Pleistocene Yakataga Formation from the seafloor to 2,065 feet (fig. 58). Below this (figs. 34a and 58), the well penetrated strata that appear to be more related to the stratigraphic section of Kodiak Island and the Kodiak shelf COST wells (fig. 67 and table 2; Turner and others, 1987) than that of the central Gulf of Alaska section to the east (see chapters 5 and 3). Accordingly, Kodiak Island/Kodiak shelf stratigraphic nomenclature is used to describe the Middleton Island State No. 1 well stratigraphic section below 2,065 feet (fig. 58). From 2,065 to 6,240 feet, the well encountered Oligocene to Miocene sediments similar to those of the Sitkinak Formation; from 6,240 to 11,460 feet, lithologic, paleontologic, and well log data suggest the sediments of the Sitkalidak Formation. From 11,460 feet to 12,000 feet (TD), the well encountered well-indurated siltstones that appear to be equivalent to the early Paleogene Orca Group that forms the base of the Tertiary section throughout most of the Middleton shelf segment/Prince William Sound area of the Prince William terrane (fig. 2 and plate 5).

The Middleton Island State No. 1 well was drilled over 20 years ago and sample material from it was not available to the Minerals Management Service for examination. Because of this, the biostratigraphic interpretation shown here for this well is derived from data presented in Rau and others (1983) and Keller and others (1984). Most of the biostratigraphic tops are based on planktonic foraminifera and calcareous nannofossil data from Keller and others (1984), and most of the paleobathymetric interpretations are based on benthic foraminifera data from Rau and others

(1983). Paleobathymetric terms used and their depth-range equivalents are shown in figure 56.

On the basis of rare benthic foraminifera, Rau and others (1983) concluded that the well was Narizian (middle Eocene) from 8,590 to 10,560 feet, and Penutian(?) and Ulatizian (early to middle Eocene, fig. 55) from 10,560 to 12,000 feet (TD). Planktonic foraminifera and calcareous nannofossil assemblages identified by Keller and others (1984) indicate a younger age for the lower part of the well, however, and these assemblages are the provisional basis for our age interpretation. One other well in this study, the OCS Y-0211 No. 1 well, contained a planktonic foraminifera assemblage that was useful for the subdivision of the Paleogene section. There is little in common, however, between the Paleogene planktonic assemblages in the two wells: the Middleton Island State No. 1 well lacks an Oligocene fauna, the late Eocene species present in the OCS Y-0211 No. 1 well (*Globigerina* sp. cf. *G. eocaena* and *Globorotalia insolita*) are absent in the late Eocene section of the Middleton Island State No. 1 well, and the Middleton Island State No. 1 well did not penetrate the middle Eocene and early to middle Eocene sections that contained the most diverse planktonic assemblages in the OCS Y-0211 No. 1 well.

Late Miocene to Pleistocene

The unsampled interval from the seafloor to 720 feet in the Middleton Island State No. 1 well is late Miocene to Pleistocene in age based on the age of the underlying interval. From 720 to 2,065 feet, the section is late Miocene to Pleistocene in age based largely on the lithology (glaciomarine Yakataga Formation). Above 1,725 feet in this interval, the section is nearly barren of microfossils. Only rare benthic foraminifera, including *Cassidulina californica, Elphidium clavatum, Elphidiella oregonense, Epistominella pacifica*, and *Uvigerina yabei*, were described from 1,725 to 2,050 feet. These species are common in the Yakataga Formation throughout the study area.

The meager fauna from 720 to 1,725 feet suggests possible inner to middle neritic paleodepths (fig. 58). From 1,725 to 2,065 feet, paleodepths may have been outer neritic.

Probable Early to Middle Miocene

From 2,065 to 3,060 feet, the section is probably early to middle Miocene based on the occurrence of the planktonic foraminifera *Globorotalia pseudokugleri* (no younger than early early Miocene) at 2,920 feet, and on a benthic foraminifera fauna typical of the Saucesian to Relizian (early to early middle Miocene; see fig. 55 for California stage names and equivalent ages). This fauna includes species such as *Anomalina glabrata, Cassidulina* sp. cf. *C. crassa, C. crassipunctata, Cibicides* sp. cf. *C. elmaensis, Glandulina laevigata, Gyroidina soldanii, Melonis zaandamae, Oridorsalis umbonatus, Pullenia salisburyi*, and several arenaceous taxa (Rau and others, 1983). Also present is *Bulimina inflata alligata* (Keller and others, 1984).

Paleodepths for the interval were upper bathyal (fig. 58).

Oligocene

The section from 3,060 to 7,700 feet is undifferentiated Oligocene (Zemorrian, fig. 55). There were no age-diagnostic planktonic foraminifera or calcareous nannofossils recorded for the interval.

The benthic foraminifera fauna present is a long-ranging, deep-water, Refugian–Zemorrian (late Eocene to Oligocene, fig. 55) assemblage that includes *Anomalina californiensis, Buccella mansfieldi oregonensis, Buliminella subfusiformis, Cibicides* sp. cf. *C. elmaensis, C. hodgei, Elphidium* sp. cf. *E. minutum, Globobulimina* sp., *Globocassidulina globosa, Gyroidina orbicularis planata, Quinqueloculina* sp. cf. *Q. imperialis, Quinqueloculina* sp. cf. *Q. weaveri, Uvigerina garzaensis*, and several arenaceous species. Rau and others (1983) also noted the occurrence of *Cassidulina* sp. cf. *C. galvinensis* and *Uvigerina* sp. cf. *U. cocoaensis*. These latter species are normally associated with early to middle Refugian (late Eocene) sediments, although Rau and others (1983) contend that since a large number of the species in the assemblage were of Zemorrian (Oligocene) age, the section was most likely Zemorrian.

Paleodepths for the interval were upper to middle bathyal (fig. 58).

Late Eocene to Early Oligocene

The section from 7,700 to 10,520 feet is late Eocene to early Oligocene (Refugian to earliest Zemorrian) in age. The upper boundary is loosely based on the occurrence of a "bloom" of the calcareous nannofossil *Braarudosphaera* sp. reported by Keller and others (1984) at 7,700 feet. According to Keller (1983), this event has been noted in the early early Oligocene of deep-sea sequences and may be indicative of that part of the section. No additional age-diagnostic planktonic occurrences were noted within this section of the well.

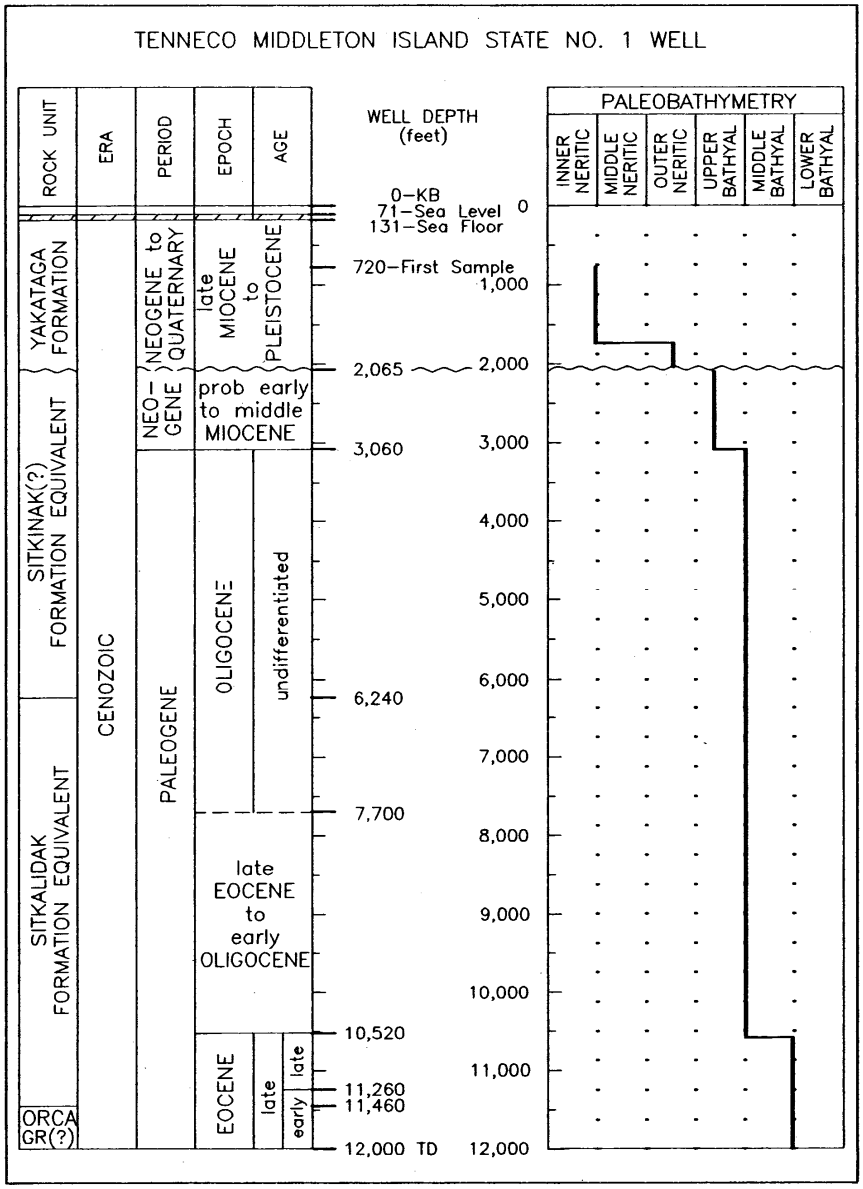


Figure 58. Biostratigraphy and paleodepth curve for the Tenneco Middleton Island State No. 1 well. All depths are measured from the kelly bushing (KB), 71 feet above mean sea level. Interpretation based on data published by Rau and others (1983), Keller and others (1984), and Plafker and others (1985). The well location is shown in figure 66.

Additional benthic foraminifera species in the interval include *Cibicides spiropunctatus*, *Spiroplectammina* sp. cf. *S. tejonensis*, and *Uvigerina churchi*, along with *Alabamina* sp., *Globobulimina* sp., *Gyroidina orbicularis planata*, *Oridorsalis umbonatus*, and *Uvigerina* sp. cf. *U. cocoaensis*, and several arenaceous species. Also present were the neritic species *Asterigerina crassiformis* and *Discorbis* sp., which were probably transported downslope (Rau and others, 1983). Below 8,770 feet, *Eggerella elongata*, *Praeglobobulimina pupoides*, *Sigmomorphina schenki*, and *Spiroplectammina directa* are also present (Keller and others, 1984).

Paleodepths for the interval were upper to middle bathyal (fig. 58).

Late Late Eocene

The section from 10,520 feet to 11,260 feet is late late Eocene (Refugian) in age based on the highest occurrence (10,520 feet) of the planktonic foraminifera *Globigerina linaperta*, which ranges no higher than the top of the Eocene. Other planktonic species in the interval include *Catapsydrax dissimilis*, *Globigerina angiporoides*, and *Globigerina praebulloides*. *Globigerina utilisindex*, a species that is restricted to the latest Eocene and early Oligocene (Keller, 1983), is also present.

Also occurring in the interval are the calcareous nannofossils *Dictyococcites bisectus* (10,600 feet) and *Reticulosphaera umbilica* (10,620 feet).

Several additional benthic foraminifera occur in this interval, including *Allomorphina* sp., *Ammodiscus incertus*, *Ammodiscus* sp. cf. *A. turbinatus*, *Anomalina* sp. cf. *A. danvillensis*, *Cibicides* sp. cf. *C. martinezensis*, *Eponides* sp. cf. *E. minuta*, *Glomospira charoides corona*, *Karreriella chapatoensis*, *K. monumentensis*, *Lenticulina* spp., *Pullenia* sp. cf. *P. bulloides*, *Pullenia* sp. cf. *P. eocenica*, *Spiroplectammina directa*, and *Valvulineria* sp. cf. *V. childsi*.

Paleodepths for the interval were upper to middle bathyal from 10,520 to 10,560 feet and middle to lower bathyal from 10,560 to 11,260 feet (fig. 58).

Early Late Eocene

The section from 11,260 feet to 12,000 feet (TD) is early late Eocene (early Refugian) in age based on the highest occurrences of the planktonic foraminifera *Globorotaloides carcoselleensis* (11,260 feet), which ranges no higher than the early late Eocene. Also present is *Globigerinatheka semiinvoluta* (11,950 feet), which is restricted to the early late Eocene. Other planktonic foraminifera in the interval include *Catapsydrax dissimilis*, *Globigerina angiporoides*, *G. linaperta*, *G. praebulloides*, *G. utilisindex* (caved?), and *Globorotalia opima nana*.

The calcareous nannofossil *Chiasmolithus grandis* at 11,940 feet ranges no higher than the early late Eocene. *Discoaster barbadiensis* (11,920 feet), which is restricted to the late Eocene, also supports an age no older than early late Eocene. Other calcareous nannofossils in the interval include *Dictyococcites bisectus*, *D. scrippsae*, and *Reticulosphaera umbilica*.

The benthic foraminifera assemblage is similar to that of the overlying interval.

Paleodepths for the interval (fig. 58) were middle to lower bathyal from 11,260 to 12,000 feet (TD).

According to Rau and others (1983), the benthic foraminifera fauna of the interval from 10,520 to 12,000 feet (TD) indicates a possible early to middle Eocene age (Penutian to Narizian, fig. 55). However, the presence of planktonic species with published age ranges that are no older than the late Eocene, such as the foraminifera *Globigerina angiporoides*, or that are restricted to the late Eocene, such as the foraminifera *Globigerinatheka semiinvoluta* and the calcareous nannofossil *Discoaster barbadiensis* (Keller and others, 1984), indicates a late Eocene age for the interval.

The section from 11,460 to 12,000 feet (TD) appears to be part of the Orca Group based on lithology (see chapter 5). Paleontologic and radiometric age data from onshore outcrops show the age of the Orca Group to be Paleocene to early middle Eocene (Plafker and others, 1985). However, radiolarians and calcareous nannofossils from various onshore outcrops assigned to the Orca Group have indicated ages as young as late Eocene and possible Oligocene (Plafker and others, 1985), which is compatible with the age of the section in the lower part of the Middleton Island State No. 1 well. These onshore outcrops and the early late Eocene "Orca Group" section in the well may be part of a younger Orca Group facies or an as yet undescribed late Eocene (to possible Oligocene) sequence.

Exxon OCS Y-0080 No. 1 well

The Exxon OCS Y-0080 No. 1 well was drilled in 448 feet of water to a TD of 13,507 feet. All depths were measured from the kelly bushing (KB), 82 feet above mean sea level. The well encountered the Yakataga Formation from the seafloor to 8,470 feet, and penetrated the Poul Creek Formation from 8,470 feet to TD (fig. 59).

Pleistocene

From the seafloor to 6,120 feet the section is Pleistocene in age, with the late Pleistocene section extending from the seafloor to 4,560 feet and the early Pleistocene section extending from 4,560 to 6,120 feet. Ages for the Pliocene and Pleistocene sections in this well are based on diatom occurrences and on coiling-direction trends of the planktonic foraminifera *Neogloboquadrina pachyderma*.

Late Pleistocene

No samples were recovered in the interval from the seafloor to 2,090 feet, which is assigned to the late Pleistocene on the basis of its stratigraphic position above the underlying interval. From 2,090 to 4,560 feet, the section is late Pleistocene in age based on 98 to 100 percent sinistrally coiled populations of *Neogloboquadrina pachyderma* that indicate the cold-water conditions of the late Pleistocene (fig. 57). The planktonic foraminifera assemblage of this interval also includes frequent to abundant *Globigerina bulloides* and rare occurrences of *Neogloboquadrina dutertrei*, *Globigerinoides conglobatus*, and *Globigerina quinqueloba*.

Two diatom species within this interval, *Thalassiosira* sp. cf. *T. nidulus* at 2,400 feet and *Rhizosolenia* sp. cf. *R. curvirostris* at 3,120 feet, range only as high as the early late Pleistocene (Barron, 1980, 1985). These occurrences are used to subdivide the late Pleistocene interval into early and late segments at 2,400 feet. With the exception of these diatom species, the Pleistocene section contains no age-diagnostic microflora. Rare to common discoidal (spongodiscid) and spheroidal (cenosphaerid) radiolarians are also present in the late Pleistocene.

Benthic foraminifera in the late Pleistocene section include *Bolivina interjuncta*, *B. spissa*, *Buccella frigida*, *Buccella* sp. cf. *B. inusitata*, *B. tenerrima*, *Cassidulina californica*, *C. cushmani*, *C. delicata*, *C. islandica*, *C. limbata*, *C. minuta*, *C. norcrossi*, *C. reflexa*, *C. teretis*, *Cibicides fletcheri*, *C. lobatulus*, *Cibicides* sp. cf. *C. mckannai*, *Cyclammina cancellata*, *Cyclammina* sp. cf. *C. pacifica*, *Dentalina californica*, *D. frobisherensis*, *D. baggi*, *Eggerella* sp., *Elphidium bartletti*, *E. clavatum*, *E. frigidum*, *E. incertum*, *Elphidiella arctica*, *E. oregonense*, *E. sibirica*, *Epistominella pacifica*, *Eponides subtener*, *Globobulimina pacifica*, *Gyroidina* sp. cf. *G. soldanii*, *Haplophragmoides* spp., *Hyperammina* sp., *Karreriella* sp., *Lagena sulcata*, *Martinottiella communis*, *Nonionella auricula*, *N. labradorica*, *Protelphidium orbiculare*, *Quinqueloculina* sp. cf. *Q. akneriana*, *Q. seminula*, *Trifarina fluens*, *Triloculina trihedra*, *Uvigerina* sp. cf. *U. auberiana*, *U. cushmani*, *U. juncea*, *U. peregrina*, and *Valvulineria glabra*. Also present in the assemblage near the base of the late Pleistocene interval are *Bulimina* sp. cf. *B. subacuminata*, *B. tenuata*, *Cassidulina lomitensis*, *Elphidium* sp. aff. *E. incertum*, *Elphidiella groenlandica*, and *Lenticulina* sp. cf. *L. cultratus*.

Benthic foraminifera did not serve as the basis for any of the biostratigraphic tops in the Pliocene and Pleistocene sections of the well, although they were useful for paleobathymetric determinations.

Dinoflagellates are sparse throughout the Pleistocene section, with rare occurrences of *Achomosphaera ramulifera*, *Filisphaera filifera*, *Impagidinium japonicum*, *Operculodinium* sp. cf. *O. centrocarpum*, *Spiniferites membranaceous*, and *S. ramosus ramosus*.

Molluscan shell fragments, echinoid spines and fragments, and rare barnacle plate fragments are also present in the late Pleistocene section. Fragments of the erect bryozoan *Myriozoum subgracile*, a neritic to upper bathyal species that has been reported from Recent sediments on Albatross Bank east of Kodiak Island (Cuffey and Turner, 1987), were also found at 3,210 and 3,750 feet.

Paleodepths in the late Pleistocene section were outer neritic to upper bathyal from 2,090 to 3,090 feet, and outer neritic to upper bathyal, upper to middle bathyal, and upper bathyal between 3,090 and 4,560 feet (fig. 59).

Cool temperate, possibly humid terrestrial climates during vegetated intervals in the late Pleistocene section are indicated by the presence of pollen from birch (*Betulaceoipollenites* or *Trivestibulopollenites*), spruce (*Piceapollenites*), pine (*Pinuspollenites*), and hemlock (*Tsugaepollenites*).

Early Pleistocene

From 4,560 to 6,120 feet, populations of frequent to abundant *Neogloboquadrina pachyderma* generally include 10 to 20 percent dextrally coiled forms, possibly indicating warmer water. Because this is the only interval in the well that consistently contains elevated proportions of dextrally coiled *Neogloboquadrina pachyderma* it is assigned an early Pleistocene age (fig. 57). Although the assemblages in this interval do not contain the 90 percent or greater proportion of dextrally coiled forms observed in temperate waters of modern oceans (Ericson, 1959; Bandy, 1960; Kennett, 1976), it is possible that they reflect sporadic encroachments of early Pleistocene warmer water masses into the Gulf of Alaska area along a fluctuating warm water–cold water front.

The remainder of the planktonic foraminifera assemblage in the early Pleistocene interval is similar to that of the late Pleistocene, along with isolated occurrences of *Globorotalia humerosa humerosa*. A specimen morphologically transitional between the *Globorotalia* sp. cf. *G. pseudopima* and *Neogloboquadrina dutertrei* is also present at 5,640 feet.

The benthic foraminifera assemblage in the early Pleistocene section is also similar to that of the late Pleistocene, but includes the additional species *Bulimina* sp. cf. *B. exilis*, *B. mexicana*, *Cassidulina* sp. cf. *C. laevigata carinata*, *C. subglobosa*, *Cibicides* sp. aff. *C. conoideus*, *Elphidium* sp. cf. *E. discoidale*, *Gyroidina* sp. cf. *G. condoni*, *Melonis barleeanum*, *Melonis* sp. cf.

M. zaandamae, *Nonion* sp. cf. *N. incrassitas*, *Nonionella basispinata*, *N. fimbriata*, *Oolina* sp. cf. *O. apliopleura*, *Oolina melo*, *Planulina* sp. cf. *P. alaskense*, *Pseudoglandulina laevigata*, *Pullenia bulloides*, *P. salisburyi*, and *Trifarina hughesi*.

Rare diatoms and rare spongodiscid and cenosphaerid radiolarians are also present.

Paleodepths in the early Pleistocene were mainly outer neritic to upper bathyal, with shorter intervals of upper to middle bathyal (fig. 59).

Below 4,650 feet in the early Pleistocene interval, the addition of *Sequoia* group pollen (*Taxodiaceaepollenites*), blue beech (*Carpinipites* sp. cf. *C. spackmaniana*), and *Quercoidites microhenrici* to the assemblage indicates a somewhat milder climate.

Pliocene

The interval from 6,120 to 8,470 feet is Pliocene in age on the basis of coiling-direction trends in populations of the planktonic foraminifera *Neogloboquadrina pachyderma*, with the division between early and late Pliocene placed at 8,400 feet.

Late Pliocene

The section from 6,120 to 8,400 feet is late Pliocene in age on the basis of predominantly sinistrally coiled, cold-water populations of *Neogloboquadrina pachyderma* (fig. 57) that are common to abundant from 6,120 to 6,570 feet and sparse from 6,570 to 8,400 feet. Additional planktonic foraminifera present in the late Pliocene section include *Globorotalia* sp. cf. *G. pseudopima* at 8,280 feet, and *Neogloboquadrina* sp. cf. *N. asanoi* at 7,560 feet. The latter species ranges no higher than the Pliocene in the Ventura Basin section of California (Lagoe and Thompson, 1988).

Additional benthic foraminifera appearing in the Pliocene section include *Cassidulina* sp. cf. *C. quadrata*, *Cribrononion* sp., *Cribrostomoides* sp., *Epistominella* sp. cf. *E. pulchella*, *E. smithi*, *Fissurina pelucida*, *Haplophragmoides* spp., *Pullenia malkinae*, *Quinqueloculina* sp. cf. *Q. arctica*, *Uvigerina* sp. aff. *U. hootsi*, and *Uvigerina juncea*. *Elphidiella simplex*, a species noted by Voloshinova and others (1970) in the Miocene section of Sakhalin Island (eastern Russia), was found at 8,280 feet, along with *Cribroelphidium crassum*, *Elphidiella* sp. cf. *E. arctica*, and *Nonionella* sp. cf. *N. stellata*.

The pollen assemblage in the Pliocene section is similar to the early Pleistocene assemblage, with the addition of rare specimens of elm (*Ulmipollenites undulosus*), *Pachysandra* sp., and willow (*Salixpollenites discoloripites*), along with decreased populations of hemlock (*Tsugaepollenites*) and the *Sequoia* group (*Taxodiaceaepollenites*).

Paleodepths in the late Pliocene section were mostly outer neritic to upper bathyal, with middle to outer neritic conditions at 7,020 to 7,290 feet and 7,920 to 8,100 feet (fig. 59).

Early Pliocene

The interval from 8,400 to 8,470 feet may be late early Pliocene on the basis of rare dextrally coiled *Neogloboquadrina pachyderma* (fig. 57). Lattanzi (1981) reported dextrally coiled populations in the interval from 8,400 to 8,470 feet, and the only planktonic foraminifera recovered from MMS samples in the interval, single specimens of *Neogloboquadrina pachyderma* at 8,430 and 8,460 feet, were also dextrally coiled. Dextral coiling at this depth suggests the warmer water conditions prevalent in the early Pliocene (fig. 57). On this basis, the division between late and early Pliocene is placed at 8,400 feet. Because of its unconformable base, possibly indicating a missing early Pliocene section, the short interval from 8,400 to 8,470 feet is assigned to late early Pliocene.

Paleodepths in the late early Pliocene section were outer neritic to upper bathyal (fig. 59).

Miocene

Well-log curves and rotary drill bit cuttings at 8,470 feet and below indicate a lithologic change from the sandstones, siltstones, and glaciomarine diamictites of the Yakataga Formation to the marine glauconitic siltstones and sandstones of the Poul Creek Formation. The contact at 8,470 feet marks an unconformity at the base of the Yakataga Formation (see chapter 5). The section is late Miocene from 8,470 to 9,660 feet and middle Miocene from 9,660 to 11,360 feet. The late Miocene section is fault-repeated from 11,360 to 12,210 feet. From this depth to TD, the well remained in a Poul Creek section interpreted to be Miocene in age, with middle to late Miocene section from 12,210 to 12,960 feet, and middle Miocene from 12,960 to TD at 13,507 feet (fig. 59).

Lattanzi (1981) described the Yakataga–Poul Creek Formation contact at 8,470 feet, but concluded that the

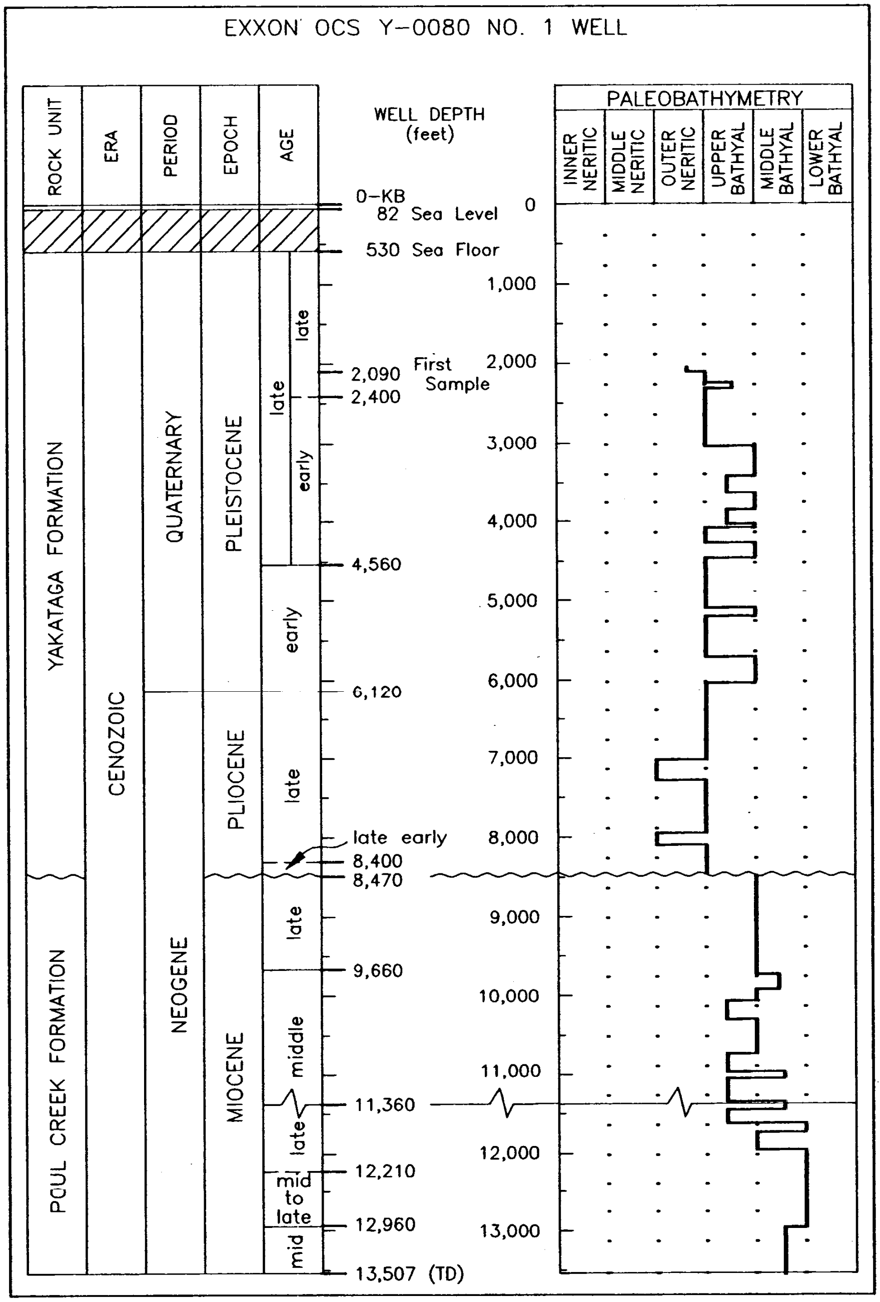


Figure 59. Biostratigraphy and paleodepth curve for the Exxon OCS Y-0080 No. 1 well. All depths are measured from the kelly bushing (KB), 82 feet above mean sea level. The well location is shown on figure 66.

underlying section was Pliocene in age because of its stratigraphic position beneath a very thin section of early Pliocene Yakataga Formation, and because it contained scattered specimens of *Neogloboquadrina pachyderma*, which ranges from late Miocene to Recent. A Pliocene age determination for the Poul Creek Formation is at variance with the late Eocene to early Miocene age of Rau and others (1983) and the up-to-late Miocene age Lagoe (1983) observed for the Poul Creek Formation in onshore wells and stratigraphic sections. Although rare specimens of *Neogloboquadrina pachyderma* recovered from MMS samples below 8,470 feet were brownish and weathered like other planktonic and benthic foraminifera present, most of the specimens of *Neogloboquadrina pachyderma* from this deeper section had a fresh, white crystalline appearance similar to specimens found above 8,470 feet. Such "fresh" specimens were interpreted as caved from the Pliocene–Pleistocene section uphole. Ample opportunity for caving existed in this part of the well because the well bore was uncased throughout the process of drilling from 4,098 to 11,610 feet.

Late Miocene

The section from 8,470 to 9,660 feet is late Miocene in age on the basis of dinoflagellate occurrences and the age of the subjacent interval. The abrupt change in lithology, paleodepth, and the foraminiferal assemblage at 8,470 feet support this interpretation (fig. 59).

Dinoflagellates present in this section include *Systematophora ancyrea* at 8,580 feet and *Achomosphaera spongiosa* at 8,670 feet, both indicating an age no younger than late Miocene, and *Impagidinium* sp. cf. *I. patulum* at 8,580 feet, which indicates an age no older than late early Miocene. Core samples taken from 9,021 to 9,045 feet (conventional core 2, Appendix E-3) also contain several dinoflagellates that are characteristic of the late Miocene *Hystrichosphaeropsis variabile* zone of Bujak (1984) and Matsuoka and Bujak (1988) and range no higher than that interval. These species include *Hystrichosphaeropsis obscura, Litosphaeridium parvum, Reticulosphaera actinocoronata,* and *Tuberculodinium rossignoliae*. Also recovered from the core were *Spiniferites hexatypicus, Spiniferites ramosus,* and *Tuberculodinium vancampoae*, which have slightly less restricted individual ranges but are also representative of the *Hystrichosphaeropsis variabile* zone.

The monolete spore *Polypodiisporonites* sp. at 8,580 feet indicates an age of late Miocene or older. The angiosperm pollen ?*Ericipites* also occurs at 8,580 feet.

The lowest stratigraphic occurrence of the diatom species *Thalassiosira antiqua* at 8,940 feet also supports a late Miocene age for this interval.

Most of the rare planktonic foraminifera present in the late Miocene section (8,470 to 9,660 feet), including *Globigerina bulloides* and *G. venezuelana*, are not age diagnostic. Three sinistrally coiled specimens of *Neogloboquadrina pachyderma* found in the interval had a brownish, weathered appearance and were judged to be in place, supporting a late Miocene age.

The late Miocene section (8,470 to 9,660 feet) contains an abundant assemblage of light-colored arenaceous benthic foraminifera, along with many additional species of calcareous benthic foraminifera. The arenaceous assemblage is similar to that recovered from the Poul Creek Formation section onshore and in the OCS Y-0007 No. 1, OCS Y-0014 No. 1 and 2, OCS Y-0032 No. 1, and OCS Y-0211 No. 1 wells. Arenaceous species include *Alveolophragmium rotundidorsata, Bathysiphon arenacea, Bathysiphon* spp., *Budashaevella* sp., *Cornuspira byramensis, Cribrostomoides* spp., *Cyclammina cancellata, C. pacifica, C. incisa, Dorothia* sp., *Gaudryina* sp., *Haplophragmoides trullisata, Martinottiella* sp., *M. communis, Reophax* sp., *Rhabdammina* sp., *Spirosigmoilinella* sp., *Spirosigmoilinella* sp. cf. *S. compressa, Trochammina globigeriniformis*, and a conically coiled species resembling *Arenoturrispirillina* sp.

Also present are rare specimens of *Liebusella* sp., an arenaceous species that begins with triserial trochospiral coiling and ultimately becomes a relatively large uniserial form. Several broken specimens of *Liebusella* sp. revealed the characteristic cross-sectional internal structure of 8 to 16 radially arranged, regularly shaped alveolar cavities per chamber (Sieglie and others, 1986). Lattanzi (1981) identified this species as *Liebusella pliocenica*, which is restricted to the Pliocene in the California section (Wissler, 1943). Our late Miocene age assignment conflicts with this age. Because the genus *Liebusella* ranges from late Eocene to Recent (Sieglie and others, 1986), the specimens in the OCS Y-0080 No. 1 well could be compared with other species within this range. One comparable species is *Liebusella laevigata* from the middle and upper Miocene section of Sakhalin Island (Voloshinova and others, 1970). We refer the form present in the OCS Y-0080 well to *Liebusella* sp. because we lack specimens good enough for specific identification and lack comparative material. In addition, some of the *Liebusella*-like specimens in the interval may belong to the genus *Alveovalvulinella*, which has a more irregularly alveolar internal structure and ranges from the Oligocene to the Miocene (Loeblich and Tappan, 1964). Both *Liebusella laevigata* and *Alveovalvulinella* sp. are compatible with the Miocene age interpretation for the section below 8,470 feet. Anderson, Warren, and Associates, Inc., (1977a) also describe occurrences of both *Alveovalvulinella* sp. and the related, higher-ranging *Alveovalvulina* sp. (early Miocene to mid-Pliocene; Sieglie and others, 1986) in the probable late Miocene section of the OCS Y-0011 well.

Calcareous benthic foraminifera present in the late Miocene section include *Anomalina glabrata, Asterigerina crassiformis, Cassidulina* sp. cf. *C. crassa, Chilostomella* sp. cf. *C. cylindroides, Cibicides* sp. cf. *C. elmaensis, Cibicides* sp. cf. *C. perlucida, Elphidium* sp. aff. *E. californicum, Elphidium* sp. cf. *E. minutum, Epistominella pacifica, E. pulchella, Gyroidina* sp. cf. *G. condoni, G. soldanii, Lagena strumosa, Lenticulina inornata, Marginulina* sp. cf. *M. adunca* (reworked early Miocene?), *Melonis* sp. cf. *M. pacificum*, *Nodogenerina* sp. aff. *N. sanctaecrucis*, *Nodosaria* sp. cf. *N. longiscata*, *Nonionella* sp. cf. *N. costiferum*, *Oolina melo*, *Oridorsalis umbonatus*, *Pullenia miocenica*, *Quinqueloculina* sp. cf. *Q. weaveri*, *Uvigerina auberiana*, *Uvigerina* sp. cf. *U. hannai*, *Uvigerina* sp. cf. *U. gallowayi* (reworked late Eocene to earliest Miocene?), and *Uvigerina* sp. cf. *U. obesa*.

A species of *Uvigerina* that is present throughout the Miocene section of the well posed several problems in identification. It was initially assigned to *Uvigerina* sp. cf. *U. subperegrina* because it is similar to a specimen with that name from the lower Yakataga Formation figured by Lagoe (1983, plate 2 and figure 16). Although many of the specimens in the OCS Y-0080 No. 1 well resemble this species in ornamentation, subsequent study showed most specimens to be slimmer, with more chambers. Rare individuals have subdued surface ornamentation resembling that of *Uvigerina juncea*. The species also bears a strong resemblance to *Uvigerina yabei*, a species originally described from the Pliocene of Japan (Asano, 1938) and more recently reported from the Middleton Island State No. 1 well (Rau and others, 1983), but the specimens in the OCS Y-0080 well appear to have more costae per chamber than are shown on the specimens in the type illustration. On the whole, most of the specimens bear a stronger resemblance to *Uvigerina cushmani*, a species originally described from Recent ocean sediments from neritic to upper bathyal depths off the coast of southern California (Todd, 1948). Accordingly, the specimens from the well are referred to as *Uvigerina* sp. cf. *U. cushmani*. This species is present throughout the Miocene section of the well, but is rare in the late Miocene interval.

Several worn specimens of reworked Eocene to early Oligocene benthic foraminifera were found in samples near the top of the late Miocene section, including *Quinqueloculina* sp. cf. *Q. goodspeedi* at 8,470 feet, *Plectofrondicularia packardi* at 8,520 feet, and *Cibicides spiropunctatis* at 8,640 feet. In addition, a small assemblage of reworked Eocene dinoflagellates is present in the upper part of the interval, including *Deflandria eocenica*, *D. heterophlycta*, *D. phosphoratica*, *Hafniasphaera septata*, and *Impagidinium californiense*. These elements indicate that some of the sediments of the upper Poul Creek Formation in the well were derived from the erosion of Eocene marine strata.

Paleodepositional environments for this interval were upper to middle bathyal (fig. 59). Fragments of light brown micritic limestone at 8,520 feet suggest a pelagic carbonate ooze, or perhaps a distal facies of fringing carbonate sediments shed from a positive open-marine feature such as a seamount that has since collided and subducted along the southern Alaska margin.

The late Miocene interval also contains small shark and teleost fish teeth, common triaxon and fused-desmid-form sponge spicules, and pyritized cenosphaerid radiolaria. Shark teeth and and sponge spicules are particularly numerous in conventional core samples of dark-brown siltstones taken from 9,024 to 9,045 feet (core 2, Appendix E-3). The foraminifera recovered from the core are almost exclusively arenaceous and include rare to frequent occurrences of *Spirosigmoilinella* sp. cf. *S. compressa*.

According to geochemical analysis (Tybor, 1979), cuttings from thermally immature sediments between 9,100 and 9,160 feet have the most favorable hydrocarbon source rock potential in the well. Total organic carbon (TOC) in this sample interval was recorded at 1.97 percent, and total bituminous extract measured 1,897 ppm (with estimated 488 ppm extractable hydrocarbon). In addition, amorphous-herbaceous organic components exceeded woody components, a condition that could favor liquid hydrocarbon generation if the thermal maturity of the section were greater. The predominance of arenaceous foraminifera and sponge spicules, along with the preservation of numerous phosphatic vertebrate elements (shark teeth, teleost fish teeth) in an organically rich siltstone suggests a depositional environment resembling the silled, organic-rich, sediment-starved basin paradigm postulated by Armentrout (1983a) for the dark shales of the upper Poul Creek Formation onshore.

Middle Miocene

The section from 9,660 to 11,360 feet is middle Miocene in age based on planktonic foraminifera. This interval, a middle Miocene section in the OCS Y-0014 No. 1 and 2 well, and an early to middle Miocene section in the OCS Y-0211 No. 1 well (this chapter) are the first middle Miocene sediments described from the Poul Creek Formation onshore or offshore. However, unpublished data (R. S. Boettcher, personal commun., 1991) have indicated that a deep-water section of late early to early middle Miocene (Relizian to possible Luisian, fig. 55) Poul Creek Formation exists onshore on Kayak Island, 22 miles to the northwest (fig. 66 and plate 5). This age is based on the presence of the middle early to early middle Miocene planktonic foraminifera

Globorotalia archaeomenardii and the benthic foraminifera *Siphogenerina* sp. cf. *S. branneri* and *Siphogenerina* sp. cf. *S. kleinpelli.*

Planktonic foraminifera species indicating a middle Miocene age for this section of the OCS Y-0080 No. 1 well include *Globorotalia* sp. cf. *G. continuosa* at 9,660 feet and below, *Globorotalia* sp. cf. *G. conica* at 9,840 and 10,260 feet, and *Globorotalia* sp. cf. *G. obesa* at 11,040 feet. Other planktonic species present include *Globigerina bulloides, Globigerina* sp. cf. *G. venezuelana, Globigerina* sp. cf. *G. woodi, Globigerinoides* sp. cf. *G. bolli, Globigerinoides* sp. cf. *G. trilobus, Globoquadrina dehiscens*, and *Globorotalia conoidea.*

Also present from 9,750 feet downward are rare to frequent *Orbulina universa.* The typical spherical form is dominant, but rare bilobate and trilobate forms occur in the lower part of the interval. *Orbulina universa* ranges from middle Miocene to Recent and is most common in temperate and warmer water. *Orbulina universa* has been described from the uppermost (late Miocene) Poul Creek Formation and the lower Yakataga Formation onshore at the Yakataga Reef section (Lagoe, 1983), but has not been recorded previously in other offshore wells. A single specimen of *Orbulina universa* also occurs at 13,510 feet in the middle Miocene section of the OCS Y-0014 No. 1 and 2 well.

The dinoflagellate *Dapsilidinium pastielsi* is also present from 10,020 to 10,500 feet in the middle Miocene section. This species has not been observed above the early Miocene in the Bering Sea stratigraphic section (Matsuoka and Bujak, 1988), but its world-wide range extends into the middle Miocene (Bujak-Davies Group, 1988). Reworked specimens of the Oligocene dinoflagellates *Deflandria phosphoritica* and *Trinovantedinium boreale* also occur in the interval.

Additional benthic foraminifera in the middle Miocene section include *Anomalina* sp. cf. *A. californiciensis, Bulimina* sp. cf. *B. alsatica, B. ovata, B. subcalva, Cassidulina* sp. cf. *C. laevigata, Cibicides* sp. cf. *C. perlucidus, Eponides* sp. cf. *E. subtener, Globobulimina pacifica, Hoeglundina elegans, Karreriella* sp. cf. *K. baccata, Lagena laevis, Pseudoglandulina inflata, Sphaeroidina variabilis, Triloculina tricarinata, Uvigerina* sp. cf. *U. hispida, U. senticosa*, and *Uvigerina* sp. cf. *U. senticosa adiposa. Uvigerina* sp. cf. *U. cushmani*, which was present but rare in the overlying late Miocene section, is common to abundant at the top of the thick sandy sequence that begins at 9,750 feet and remains plentiful down to 10,740 feet. *Liebusella* sp. is rare to absent throughout the middle Miocene interval. Also present in the interval are sponge spicules, shark teeth, pyritized cenosphaerid radiolaria, and ostracodes.

Paleodepths in this interval were upper to middle bathyal (fig. 59).

Late Miocene: Repeated Section

The interval from 11,360 to 12,210 feet is late Miocene in age and is part of a fault-repeated Miocene section that extends to the bottom of the well. The lithology changes from a predominantly sandstone sequence to an underlying siltstone sequence at 11,360 feet. This lithologic change may mark a thrust fault that has displaced and repeated the stratigraphic sequence. The steep dips seen on dipmeter logs throughout the underlying Miocene section indicate significant structural deformation and support the possibility of a fault. Several instances of stuck drilling pipe were reported in the interval, where the well was sidetracked three times. Such problems are often encountered in fault zones, although these operational difficulties may have had other causes.

A late Miocene age for the section from 11,360 to 12,210 feet is indicated by the occurrence of in-place, brownish-colored specimens of *Neogloboquadrina pachyderma* (which ranges no older than late Miocene) at 11,430, 11,580, and 11,610 feet. Occurrences of other planktonic foraminifera, including *Globorotalia acostaensis* at 11,970 feet, *Globorotalia* sp. cf. *G. sphericomiozea* at 12,090 feet, and *Globorotalia* sp. aff. *G. pseudopima* at 11,580 feet, further support this age. Also present in the section are *Globorotalia* sp. cf. *G. conoidea, Globigerina bulloides*, and *Orbulina universa.* A late Miocene age is also indicated by the presence at 12,150 feet of the benthic foraminifera *Rotalia* sp. cf. *R. garveyensis*, a species that is characteristically found in the Mohnian stage (late Miocene, fig. 55) of the California section.

?*Arenoturrispirillina* sp., *Spirosigmoilinella* sp. cf. *S. compressa*, and *Uvigerina* sp. cf. *U. hannai*, benthic foraminifera that were present in the late Miocene section above the fault, reappear in the repeated interval. *Liebusella* sp. also reappears and is common in some samples. Benthic foraminifera new to the assemblage include *Anomalina* sp. cf. *A. salinasensis, Bulimina* sp. cf. *B. alligata, Cassidulina pulchella, Cibicides* sp. cf. *C. conoideus, Conicospirillina* sp., *Epistominella* sp. cf.

E. peruviana, *Gyroidina* sp. cf. *G. healdi*, *G. soldanii altiformis*, *Marginulina* sp. cf. *M. subbullata*, and *Oolina globosa*. *Uvigerina* sp. cf. *U. cushmani* was frequent to common in the interval.

Other elements in the fauna include rare ophiuroid fragments, fish bones, and barnacle plate fragments, along with rare sponge spicules and pyritized cenosphaerid radiolaria.

The monolete spore *Polypodiisporonites* sp. and the angiosperm pollen ?*Ericipites* sp., present in the late Miocene section above the fault, were also noted in this interval at 12,120 feet.

Paleodepths were upper to middle bathyal from 11,360 to 11,520 feet, deepening to include middle to lower bathyal intervals from 11,520 to 12,210 feet (fig. 59).

Middle to Late Miocene

The section from 12,210 to 12,960 feet is considered to be middle to late Miocene in age primarily on the basis of its stratigraphic position. Poorly preserved specimens of planktonic foraminifera such as *Globorotalia* sp. aff. *G. conica* at 12,210 feet and *Globorotalia* sp. aff. *G. continuosa* at 12,390 feet suggest a possible middle Miocene age. Other planktonic foraminifera within the interval include *Globorotalia* sp. cf. *G. scitula*, *Globorotalia* sp. cf. *G. conoidea*, *Globigerina bulloides*, *Globigerina* sp. cf. *G. venezuelana*, *Globigerinoides* sp. aff. *G. bolli*, *Globigerinoides* sp. cf. *G. trilobus*, *Globigerinita uvula*, and *Orbulina universa*.

Additions to the benthic foraminifera fauna in this interval include *Cassidulina laevigata carinata*, *Cornuspira byramensis*, *Fissurina marginata*, *Pullenia bulloides*, *P. salisburyi*, *Quinqueloculina* sp. cf. *Q. lamarckiana*, *Spiroplectammina* sp. aff. *S. directa*, and *Uvigerina* sp. cf. *U. hispidocostata*. Also present are *Liebusella* sp., which is very rare in the interval, and frequent to abundant *Uvigerina* sp. cf. *U. cushmani*. Similar abundance trends were observed for these latter two species in the middle Miocene section above the fault.

Other faunal elements include fish bone fragments, ostracodes, and pyritized cenosphaerid radiolaria.

Paleodepths for the interval were middle to lower bathyal (fig. 59).

Middle Miocene

The interval from 12,960 to 13,507 feet (TD) is middle Miocene. This age is indicated by the planktonic foraminifera *Globorotalia* sp. cf. *G. conica* at 12,960, 12,990 and 13,500 feet, and *Globorotalia* sp. aff. *G. lata* (as figured in Lipps, 1964) at 13,020 and 13,200 feet. Other planktonic species in the interval include *Globigerina bulloides*, *Globigerina* sp. cf. *G. nepenthes*, *Globigerinoides* sp. cf. *G. trilobus*, *Globorotalia* sp. aff. *G. conoidea*, *Orbulina suturalis*, and *Orbulina universa*, including spherical, bilobate, and trilobate forms.

Additional benthic foraminifera in the interval include *Nonion goudkoffi*, *Uvigerina* sp. cf. *U. modeloensis*, and *Uvigerina senticosa* ssp. cf. *U. senticosa adiposa*.

Other faunal elements include pyritized cenosphaerid radiolaria and rare ostracodes.

Paleodepths for the interval were middle bathyal (fig. 59).

Shell OCS Y-0011 No. 1 well

The Shell OCS Y-0011 No. 1 well was drilled in 541 feet of water to a TD of 13,565 feet. All well depths were measured from the kelly bushing (KB), 85 feet above mean sea level. The well penetrated the Yakataga Formation from just below the seafloor to TD (fig. 60).

Pleistocene

The interval from the seafloor to 8,940 feet is Pleistocene in age on the basis of coiling-direction trends in populations of the planktonic foraminifera *Neogloboquadrina pachyderma* and diatom occurrences. The section from the seafloor to 5,700 feet is late Pleistocene in age, and is further divided into late late and early late Pleistocene intervals at 2,910 feet. The section from 5,700 to 8,940 is early Pleistocene.

Late Pleistocene

The interval from the seafloor to the first sample at 1,650 feet is late Pleistocene in age based on the age of the underlying section. From 1,650 to 5,700 feet the section is also late Pleistocene, based on predominantly sinistrally coiled populations of the planktonic foraminifera *Neogloboquadrina pachyderma* (fig. 57). Population coiling ratios approach 100 percent sinistral between 1,650 and 3,840 feet, and are 90 percent or more sinistral from 3,840 feet to the base of the interval at 5,700 feet.

Siliceous microfossils are rare but relatively continuous throughout this section. The highest occurrence of the diatom *Rhizosolenia curvirostris* at 2,910 feet marks the top of the early late Pleistocene and is used to divide the late Pleistocene section into late and early intervals. Other siliceous microfossils appearing in the late late Pleistocene interval include the diatom species *Chaetoceros* sp., *Coscinodiscus excentricus*, *C. marginatus*, *C. lineatus*, *C. oculis iridis*, *Denticulopsis seminae*, *D. seminae fossilis*, *Navicula* sp., *N. optima*, *Rhizosolenia hebetata*, *Stephanopyxis dimorpha*, *S. turris*, *Thalassiosira decipiens*, *T. excentrica*, *T. gravida*, *T. oestrupii*, *Thalassiothrix longissima*, and *Xanthiopyxis* sp. Also present are the silicoflagellate *Distephanus octangulatus* and the radiolarians *Spongodiscus* sp. and *Spongotrochus glacialis*.

The early part of the late Pleistocene interval includes the additional diatom species *Actinocyclus* sp. cf. *A. curvatulus*, *A. divisus*, *A. ochotensis*, *Actinoptychus splendens*, *A. undulatus*, *Arachnoidiscus ehrenbergii*, *Biddulphia aurita*, *Cocconeis costata*, *C. scutulum*, *Coscinodiscus nodulifer*, *Melosira sulcata*, *Roperia tesselata*, *Rhabdonema* sp., *Rhaphoneis amphiceros*, *Thalassionema nitzschioides*, and *Thalassiosira* sp. aff. *T. antiqua* (reworked late Pliocene), and the silicoflagellate species *Distephanus octonarius* and *D. speculum* at 3,990 feet. *Dictyocha aculeata* and *Distephanus boliviensis* at 5,660 feet (sidewall core) support an earliest late Pleistocene age for the base of the late Pleistocene interval. *Distephanus stauracanthus* (reworked middle Miocene) is also present at 5,660 feet (sidewall core).

The siliceous endoskeletal dinoflagellate(?) *Actiniscus pentasterias* also occurs in the late Pleistocene at 4,440 and 4,578 feet (sidewall core).

The late Pleistocene section also contains a sparse but persistent population of calcareous nannofossils. The late late Pleistocene portion of the interval includes *Coccolithus carteri*, *C. pelagicus*, *C. pliopelagicus*, *Cycloccolithina leptopora*, and *Gephyrocapsa caribbeanica*. The early late Pleistocene portion of the interval also contains *Braarudosphaera bigelowi*. *Coccolithus* (*Crenalithus*) *doronicoides* occurs at 3,540 feet (reworked?), 4,530 feet, and 4,578 feet (sidewall core).

Several reworked specimens of calcareous nannofossils are found in the Pleistocene section, including the Mesozoic species *Watznaueria barnesae*; the Eocene to Oligocene species *Dictyococcites scrippsae*, *Reticulofenestra hillae*, and *R. umbilica*; and the Paleogene to middle Miocene species *Coccolithus miopelagicus*, *Dictyococcites bisectus*, and *Helicopontosphaera euphratis*. Reworked specimens of *Cyclicocargolithus floridanus* (Eocene to late Miocene) are found from 2,370 feet to a sample from conventional core 1 at 9,375 feet, and reworked specimens of *Reticulofenestra* sp. cf. *R. pseudoumbilica* (middle Miocene to middle Pliocene) occur in the upper parts of the well.

The late Pleistocene section of the OCS Y-0011 No. 1 well contains a boreal foraminiferal assemblage very similar to that seen in the Pliocene-Pleistocene section of the OCS Y-0080 No. 1 well and the Pliocene section of the OCS Y-0211 No. 1 well (see appendix A). Planktonic foraminifera present in the late Pleistocene include *Globigerina bulloides* and *Neogloboquadrina pachyderma*. *Globigerina quinqueloba* occurs at 3,150 feet and *Globigerina woodi* var. (reworked middle Miocene?) at 4,079 feet in the early late Pleistocene section.

Some additional benthic foraminifera species occurring in the late late Pleistocene section include *Astrononion gallowayi*, *Cassidulina nakamurai*, *Rotalia subcorpulenta*, *R. umbonata teneris*, and *Silicosigmoilina groenlandica*. *Epistominella exigua* and *Virgulina complanata* are present in the early late Pleistocene section at 3,840 feet.

Paleodepths in the late Pleistocene were middle to outer neritic from 1,650 to 2,070 feet, outer neritic to upper bathyal from 2,070 to 2,340 feet, middle to outer neritic from 2,340 to 3,840 feet, and outer neritic to upper bathyal from 3,840 to 5,700 feet (fig. 60).

Early Pleistocene

The section from 5,700 to 8,940 feet is early Pleistocene based on the highest occurrence of the diatom *Actinocyclus oculatus* and on coiling ratios of the planktonic foraminifera *Neogloboquadrina pachyderma*. Populations of *Neogloboquadrina pachyderma* from 5,700 to 6,570 feet are 10 percent or more dextrally coiled, similar to the proportion observed in the early Pleistocene section of the OCS Y-0080 No. 1 well. This proportion increases downward in the section to 20 to 30 percent dextrally coiled from 6,570 to 8,550 feet,

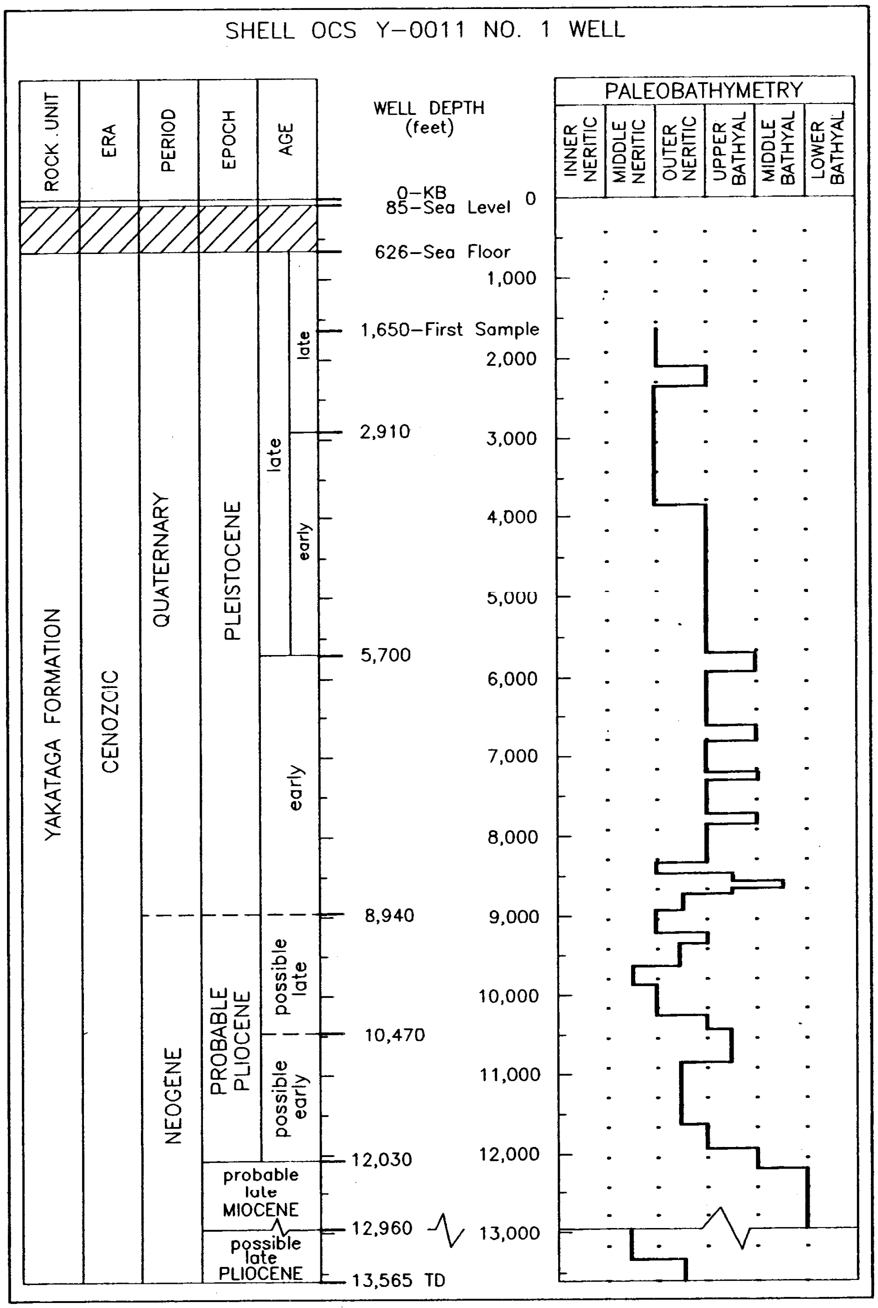


Figure 60. Biostratigraphy and paleodepth curve for the Shell OCS Y-0011 No. 1 well. All depths are measured from the kelly bushing (KB), 85 feet above mean sea level. The well location is shown in figure 66.

and 50 percent dextrally coiled from 8,550 to 8,940 feet, further supporting an early Pleistocene age (fig. 57).

The diatom *Nitzschia* sp. cf. *N. reinholdii* and the silicoflagellate *Dictyocha* sp. cf. *D. subarctios* are both present at 6,420 feet, supporting an early Pleistocene age. Additional diatoms include *Actinocyclus ehrenbergii*, *Asteromphalus decorus*, *Biddulphia aurita*, and *Porosira glacialis*. The silicoflagellate *Distephanus speculum* is also present.

The radiolarian species *Sphaeropyle langii* and *Xiphosira circularis* occur between 5,700 and 5,790 feet. *Acanthodesmia* sp. occurs at 7,250 feet (sidewall core), and *Cenosphaera* sp., *Sphaeropyle* sp. cf. *S. robusta*, and *Spongaster* sp. cf. *S. pentas* (reworked mid-Pliocene) occur between 8,580 and 8,670 feet.

Siliceous microfossils are rare below 8,670 feet, and no additional species were found below this depth.

Several additional calcareous nannofossil species occur in the early Pleistocene section. Among these are

Helicopontosphaera sp. cf. *H. sellii* at 5,716 feet (sidewall core), *Discolithina* sp. cf. *D. japonica* (5,880 feet), and *Coccolithus* sp. cf. *C.* (*Dictyococcites*?) *productus* (6,600 feet). *Emiliania* sp. cf. *E. annula* (*Pseudoemiliania lacunosa*, round form) at 6,440 feet (sidewall core) ranges no higher than early early Pleistocene. *Cyclococcolithina* sp. cf. *C.* (*Calcidiscus*?) *macintyrei* at 7,250 feet (sidewall core) and 7,680 feet also supports an early Pleistocene age.

Calcareous nannofossils are scarce below 7,250 feet. No additional unreworked species are found below that point.

Additional planktonic foraminifera occurring in the early Pleistocene section include *Globigerina quadrilatera* (equivalent to *Globigerina bulloides* according to Kennett and Srinivasan, 1983) at 5,970 feet and *Globigerina* sp. cf. *G. parabulloides* at 6,180 feet. *Globigerinita uvula* occurs at 8,550 feet.

Additional benthic foraminifera present in the early Pleistocene section include *Bolivina interjuncta*, *Bolivina* sp. aff. *B. numerosa*, *B. spissa*, *B. subadvena*, *Bolivinita* sp., *Bulimina exilis*, *Cibicides* (*Planularia*) *wuellerstorfi*, *Elphidium* sp. cf. *E. discoidale*, *Gyroidina* sp. cf. *G. soldanii*, and *Uvigerina hispidocostata*. Also present at 8,550 feet are *Eponides* sp. cf. *E. tener* and *Valvulineria auracana*.

Other faunal elements present include shell fragments, unidentified radiolaria, and sponge spicules. Unidentified ostracodes were recovered between 8,550 and 8,670 feet.

Paleodepths alternated between outer neritic to upper bathyal and upper to middle bathyal from 5,700 to 8,370 feet (fig. 60). Middle to outer neritic conditions prevailed from 8,370 to 8,490 feet. Below this, the paleodepth curve fluctuates from upper bathyal (8,490 to 8,550 feet) to middle bathyal (8,550 to 8,670 feet), back to upper bathyal (8,670 to 8,730 feet) and outer neritic (8,730 to 8,940 feet).

Probable Pliocene

The section from 8,940 to 12,030 feet is probable Pliocene, and is further subdivided into early and late intervals at 10,470 feet. *Neogloboquadrina pachyderma* is rare from the top of the section down to 10,830 feet, and very rare to absent below that, providing little evidence of Pliocene paleoclimate trends or biostratigraphy (fig. 57). No other age-diagnostic planktonic foraminifera and no additional species of siliceous microfossils or calcareous nannofossils were recovered from this section. Because other Gulf of Alaska OCS wells have shown a decrease in planktonic species abundances in the Pliocene section, the sparseness of planktonic microfossils in this interval is the basis for placing the upper boundary of the probable Pliocene section in the OCS Y-0011 No. 1 well at 8,940 feet (fig. 60).

Possible Late Pliocene

The section from 8,940 to 10,470 feet is possible late Pliocene in age. The lower boundary of the interval is arbitrarily placed at the midpoint of the probable Pliocene section.

Benthic foraminifera in the interval include *Buccella frigida*, *B. tenerrima*, *Cassidulina californica*, *C. islandica*, *C. minuta*, *Cibicides fletcheri*, *Elphidium bartletti*, *E. clavatum*, *E. discoidale*, *E. frigidum*, *Epistominella pacifica*, *Glandulina laevigata*, *Globobulimina auriculata*, *Haplophragmoides deformes*, *Nonionella auricula*, *N. digitata*, *N. labradorica*, *Protelphidium* sp. cf. *P. orbiculare*, *Quinqueloculina* sp., and *Uvigerina cushmani*.

Planktonic foraminifera include rare *Globigerina bulloides*, *G. quinqueloba*, and sinistral *Neogloboquadrina pachyderma*.

Additional faunal elements in the interval include shell fragments and unidentified ostracodes and radiolaria.

Paleodepths for the possible late Pliocene interval average some of the shallowest in the well (fig. 60), varying between middle to outer neritic (8,940 to 9,240 feet), outer neritic to upper bathyal (9,240 to 9,390 feet), outer neritic (9,390 to 9,630 feet), middle neritic (9,630 to 9,810 feet), middle to outer neritic (9,810 to 10,260 feet), and outer neritic to upper bathyal (10,260 to 10,470 feet).

Possible Early Pliocene

The section from 10,470 to 12,030 feet is possible early Pliocene, with the top of the interval arbitrarily placed midway in the probable Pliocene section. Generally outer neritic to bathyal paleodepths are encountered, in contrast with the shallower paleodepths of the overlying possible late Pliocene interval (fig. 60). The top of the interval also marks the highest occurrence of the benthic foraminifera *Haplophragmoides trullissata* (10,470 feet).

The planktonic foraminifera assemblage includes rare to very rare *Globigerina bulloides* and *Neogloboquadrina pachyderma*. *Globorotalia* sp. cf. *G. crassaformis ronda* (early Pliocene to Recent) and *Globorotalia pseudopima* (latest Miocene to Recent) occur at 11,940 feet.

Additional benthic foraminifera species in the interval include *Bulimina subacuminata*, *Cassidulina* sp. cf. *C. transluscens*, *Elphidium* sp. cf. *E. poeyanum*, *Martinottiella communis*, and *Pullenia* sp. cf. *P. salisburyi*.

Additional faunal elements include shell fragments, sponge spicules, and unidentified ostracodes and radiolaria.

Paleodepths were upper bathyal from 10,470 to 10,830 feet, outer neritic from 10,830 to 11,610 feet, outer neritic to upper bathyal from 11,610 to 11,940 feet, and upper to middle bathyal from 11,940 to 12,030 feet (fig. 60).

Probable Late Miocene

The section from 12,030 to 12,960 feet is probable late Miocene, based on occurrences of the planktonic foraminifera *Globorotalia* sp. cf. *G. sphericomiozea* from 12,030 to 12,420 feet. *Globorotalia sphericomiozea* is thought to be restricted to the late late Miocene (Jenkins, 1985; Hornibrook and others, 1989), although others mention its possible occurrence in the earliest Pliocene (Keller, 1978). Other planktonic foraminifera present include *Globorotalia pseudopima* (latest Miocene to Recent) at 12,030 and 12,890 feet, *Globorotalia acostaensis* (late Miocene to Recent) at 12,670 feet, *Globorotalia* sp. aff. *G. conoidea* (late middle Miocene to earliest Pliocene) at 12,830 feet, and *Globorotalia* sp. cf. *G. humerosa* (late late Miocene to Recent) at 12,950 feet. All support, or are compatible with, a late Miocene age. *Globorotalia* sp. cf. *G. crassaformis ronda* at 12,240 feet and a deformed specimen of *Globigerinoides* sp. aff. *G. conglobatus* (12,670 feet) may be caved from uphole. Brown, weathered specimens of other planktonic species present, including *Globorotalia* sp. aff. *G. opima* and *Globorotalia* sp. cf. *G. continuosa*, appear to be reworked.

The benthic foraminifera species *Alveovalvulina* sp. and *Alveovalvulinella* sp. at 12,420 feet also support a Miocene age (Loeblich and Tappan, 1964), although some species of *Alveovalvulina* have been reported in the Pliocene (Sieglie and others, 1986). *Liebusella* sp., a similar-appearing species with a somewhat different internal structure, and possible *Alveovalvulinella* sp. occur also in the late Miocene section of the OCS Y-0080 No. 1 well.

Additional benthic species in the interval include *Bulimina* sp. cf. *B. inflata*, *Cassidulina subglobosa*, *Eponides* sp. cf. *E. healdi*, *Eponides* sp. aff. *E. subtener*, *Haplophragmoides* sp., *Lenticulina* sp. cf. *L. strongi*, *Melonis barleeanum*, *M. pompiliodes*, *Uvigerina* sp. cf. *U. hispidocostata*, and *Virgulina* sp.

Other faunal elements present include sponge spicules and unidentified radiolaria and ostracodes.

Paleodepths for the interval were probable upper to middle bathyal from 12,030 to 12,210 feet and middle to lower bathyal from 12,210 to 12,960 feet (fig. 60).

Faulted(?) Section–Possible Late Pliocene

From 12,960 to 13,565 feet (TD), the well may have penetrated a late Pliocene section that was overthrust by an older (late Miocene) section (fig. 60). The sparse assemblages of indigenous foraminifera from cuttings samples and from conventional core 2 (12,998 to 13,023 feet; Anderson, Warren, and Associates, Inc., 1977a) suggest that paleodepths were much shallower below 12,960 feet (fig. 60). Middle neritic depths are indicated from 12,960 to 13,320 feet, and possible outer neritic depths from 13,320 to 13,565 feet (TD). The sparse foraminifera assemblage includes the benthic species *Buccella frigida*, *B. tenerrima*, *Cassidulina californica*, *Cassidulina* sp. cf. *C. limbata*, *C. nakamurai*, *Cassidulina* sp. cf. *C. transluscens*, *Cibicides fletcheri*, *Elphidium* sp. cf. *E. bartletti*, *E. clavatum*, *Elphidium* sp. cf. *E. discoidale*, *Elphidiella oregonense*, *Epistominella pacifica*, *Glandulina laevigata*, *Nonionella labrodorica*, and *Protelphidium* sp. aff. *P. orbiculare*.

The neritic depths are a marked departure from the downhole deepening trend in the early Pliocene and Miocene sections of this well (fig. 60), the OCS Y-0080 No. 1 well (fig. 59), and other Gulf of Alaska OCS wells. The bathymetric change (1,500 to 2,000 feet or more) seems too large to be related to late Miocene shoaling events. There is no evidence of older sediments below 12,960 feet, which should be the case if this were an unconformity. Indeed, the foraminifera assemblage and paleobathymetric trends present in the interval do not resemble those of other Miocene sequences in the Gulf of Alaska area, but are reminiscent of those seen higher in the well in the late Pliocene interval. It appears most likely that the interval from 12,960 to 13,565 feet (TD) is a deeper repetition of the late Pliocene, lying beneath an overthrust late Miocene section.

Shell OCS Y-0014 No. 1 and 2 (redrill) well

The Shell OCS Y-0014 No. 1 and 2 (redrill) well was drilled in 485 feet of water to a combined TD of 15,390 feet. All well depths were measured from the kelly bushing (KB), 90 feet above mean sea level. The well encountered the Yakataga Formation from just below the seafloor to 12,250 feet, and penetrated the Poul Creek Formation from 12,250 feet to TD (fig. 61).

The OCS Y-0014 well was drilled in two segments: the OCS Y-0014 No. 1 well was drilled to a depth of approximately 11,900 feet, where the hole collapsed and the drill stem was stuck, whereupon the OCS Y-0014 No. 2 (redrill) well was kicked out laterally from the original hole at approximately 8,700 feet. It was drilled essentially vertically and parallel to the OCS Y-0014 No. 1 well to a total depth of 15,390 feet. Because they share the same hole down to 8,700 feet and are proximal and parallel below that, the two wells are treated together here as a single continuous entity, with samples down to the arbitrary depth of 8,910 feet coming from the No. 1 well, and samples below that depth coming from the No. 2 well.

Pleistocene

The section from the seafloor to 6,480 feet is Pleistocene on the basis of planktonic foraminifera. The late Pleistocene section extends to a depth of 4,440 feet. From 4,440 to 6,840 feet, the section is early Pleistocene.

Late Pleistocene

The upper portion of the well from the seafloor to the first sample at 2,220 feet is considered to be late Pleistocene in age on the basis of its stratigraphic position above the subjacent late Pleistocene interval. The interval from 2,220 to 4,440 feet is late Pleistocene in age based on the presence of a planktonic foraminifera population consisting predominantly of sinistrally coiled *Neogloboquadrina pachyderma*. This probably represents the late Pleistocene cold-water interval (fig. 57). *Globigerina bulloides* is also common throughout this section. Other planktonic species present include *Globigerina quinqueloba*, *Globigerinita* sp. cf. *G. naparimaensis*, *Globigerinita* sp. cf. *G. uvula*, and *Neoglogoquadrina dutertrei*.

The boreal benthic foraminifera assemblage is very similar to that found in the Pliocene and Pleistocene of the Exxon OCS Y-0080 No. 1 well and the Pliocene of the OCS Y-0211 No. 1 well (see appendix A). Additional species present in the late Pleistocene section of the OCS Y-0014 No. 1 and 2 well include *Bolivina* sp. cf. *B. beyrichi*, *Buliminella elegantissima*, *Frondicularia* sp. cf. *F. gigas*, *Lenticulina* sp. cf. *L. strongi*, *Saidovella* sp. cf. *S. okhotica*, and *Trichohyalis ornatissima* (small form). *Rotalia columbiensis* appears at 3,060 feet.

Other faunal elements in the section include cenosphaerid and spongodiscid radiolaria, ostracodes, decapod fragments, fish bone fragments, teleost fish teeth, bivalve and gastropod fragments, barnacle fragments, and sponge spicules. *Myriozoum subgracile*, an erect bryozoan that occurs today in outer neritic environments on the Albatross Shelf off the coast of Kodiak Island (Cuffey and Turner, 1987), was found from 2,220 to 2,520 feet, and again at 4,260 feet.

Calcareous nannofossils are sparse and generally not biostratigraphically useful in the well. Several samples throughout the well were analyzed for dinoflagellate content, but either yielded no dinoflagellate material or contained reworked or caved specimens. There were no samples processed for diatoms and silicoflagellates.

Paleodepths for the late Pleistocene interval were middle to outer neritic from 2,220 to 2,820 feet, and outer neritic to upper bathyal from 2,820 to 4,440 feet (fig. 61).

Early Pleistocene

The interval from 4,440 to 6,480 feet is early Pleistocene in age based on the occurrence of dextrally coiled populations of *Neogloboquadrina pachyderma* (fig. 57). *Globigerina bulloides* was also common in the interval. Deformed specimens of one additional planktonic species, *Globigerinoides* sp. cf. *G. conglobatus*, were found at 5,940 and 6,030 feet.

Additional benthic foraminifera in the interval include *Cyclammina cancellata*, *Dentalina* sp. cf. *D. decepta*, *Elphidiella groenlandica*, *Lenticulina* sp. cf. *L. occidentalis*, *Nonion* sp. cf. *N. goudkoffi*, *Nonionella* sp. cf. *N. auricula*, *N. basispinatum*, and *Triloculina tricarinata*. A large form of *Trichohyalis ornatissima* occurs at 4,440 and 4,620 feet. Poorly preserved pyritized diatoms are present, in addition to ostracodes and other faunal elements similar to those present in the late Pleistocene.

Paleodepths for the early Pleistocene interval were middle to outer neritic from 4,440 to 5,670 feet and outer neritic to upper bathyal from 5,670 to 6,480 feet (fig. 61). These conditions are shallower than in the overlying late Pleistocene section.

Early Pleistocene warm-water conditions should have resulted in deeper water depths due to global melting and the resulting eustatic sea level rise during a relatively warmer interval (fig. 57). The fact that paleodepths appear to have been shallower in the warmer water early Pleistocene interval of the OCS Y-0014 No. 1 and 2 well than during the more glaciated late Pleistocene interval presents an interesting problem. The lack of a direct correspondence between water depth and paleotemperature changes in the Gulf of Alaska was also noted by Zellers (1989, 1990) in a study of outcrops of the middle and upper Pliocene section of the Yakataga Formation onshore at Icy Bay (fig. 66 and plate 5). Zellers suggests several possible reasons for the discrepancy, some of which might be acting together. Tectonic uplift and subsidence of the continental shelf may have produced paleodepth changes that were superimposed on eustatic sea level changes. Such changes in turn may have been locally overprinted by glacial loading and post-glacial isostatic rebound. Glacial scour and reworking of diamictite on the continental shelf during glacial stages may also have transported and mixed the faunal assemblages used in paleobathymetric interpretations. An additional possibility, not mentioned by Zellers, is that large increases in runoff and sediment supply during warm-cycle glacial melting phases may have covered portions of the continental shelf with sediments rapidly enough to maintain shallow water depths as eustatic sea level rose.

Although the OCS Y-0007 No. 1 well (fig. 62) also shows a shallowing trend in the early Pleistocene, similar trends are not readily apparent in the Pleistocene section of other Gulf of Alaska OCS wells. Contra-eustatic trends are not obvious in the Gulf of Alaska OCS Pliocene section, although they may be reflected by slight shallowing in the early Pliocene section of some wells (OCS Y-0011 No. 1, OCS Y-0032 No. 1, and OCS Y-0211 No. 1). The poor correlation of these events across the Gulf of Alaska OCS suggests that local tectonic movements and perhaps local depositional factors may have been the principal elements in generating contra-eustatic paleobathymetric trends.

Pliocene

From 6,480 to 10,410 feet, the section is Pliocene in age, based principally on planktonic foraminifera. The late Pliocene extends from 6,480 to 8,820 feet. The section from 8,820 to 10,410 feet is early Pliocene.

Late Pliocene

The interval from 6,480 to 8,820 feet is late Pliocene in age based on sparse planktonic foraminifera populations containing sinistrally coiled *Neogloboquadrina pachyderma*. Additional planktonic species present include *Globorotalia* sp. cf. *G. acostaensis* at 6,480 feet, *Globorotalia* sp. cf. *G. crassaformis* at 7,200 feet, and *Globorotalia* sp. cf. *G. puncticulata* at 8,100 feet. *Globigerina bulloides* is present throughout the interval, along with intermittent occurrences of *Globigerinita uvula*.

Additions to the late Pliocene benthic foraminifera assemblage include *Astacolus* sp., *Bulimina* sp. cf. *B. subacuminata*, *Cibicides conoideus*, *Cibicides* sp. aff. *C. perlucida*, *Cibicides* sp. cf. *C. refulgens*, *Elphidiella* sp. aff. *E. simplex*, *Guttulina* sp., *Melonis barleeanum*, *Melonis* sp. cf. *M. pacifica*, *Melonis* sp. cf. *M. zaandamae*, *Nonionella basispinatum*, *Nonionella* sp. cf. *N. miocenica*, *Planularia* sp., *Plectina* sp., *Protelphidium orbiculare*, *Sigmomorphina* sp., and *Sigmomorphina* sp. cf. *S. fenestrata*. *Rotalia columbiensis*, *Buccella inusitata* (large), and *Buccella* sp. aff. *B. mansfieldi* are present at 6,840 feet. Benthic foraminifera were slightly more worn and corroded below 7,200 feet.

Other faunal elements in the interval include teleost fish teeth and bone fragments, echinoid and molluscan fragments, and sponge spicules. The bryozoan *Microporina* sp., an articulated upright form that occurs today in inner and middle neritic environments on Albatross Bank off Kodiak Island (Cuffey and Turner, 1987), is present at 7,920 and 8,010 feet. This zoarial form is typical of environments characterized by moderate to high currents.

Paleodepths for the late Pliocene section were outer neritic to upper bathyal, with a middle to outer neritic interval from 7,830 to 8,100 feet (fig. 61).

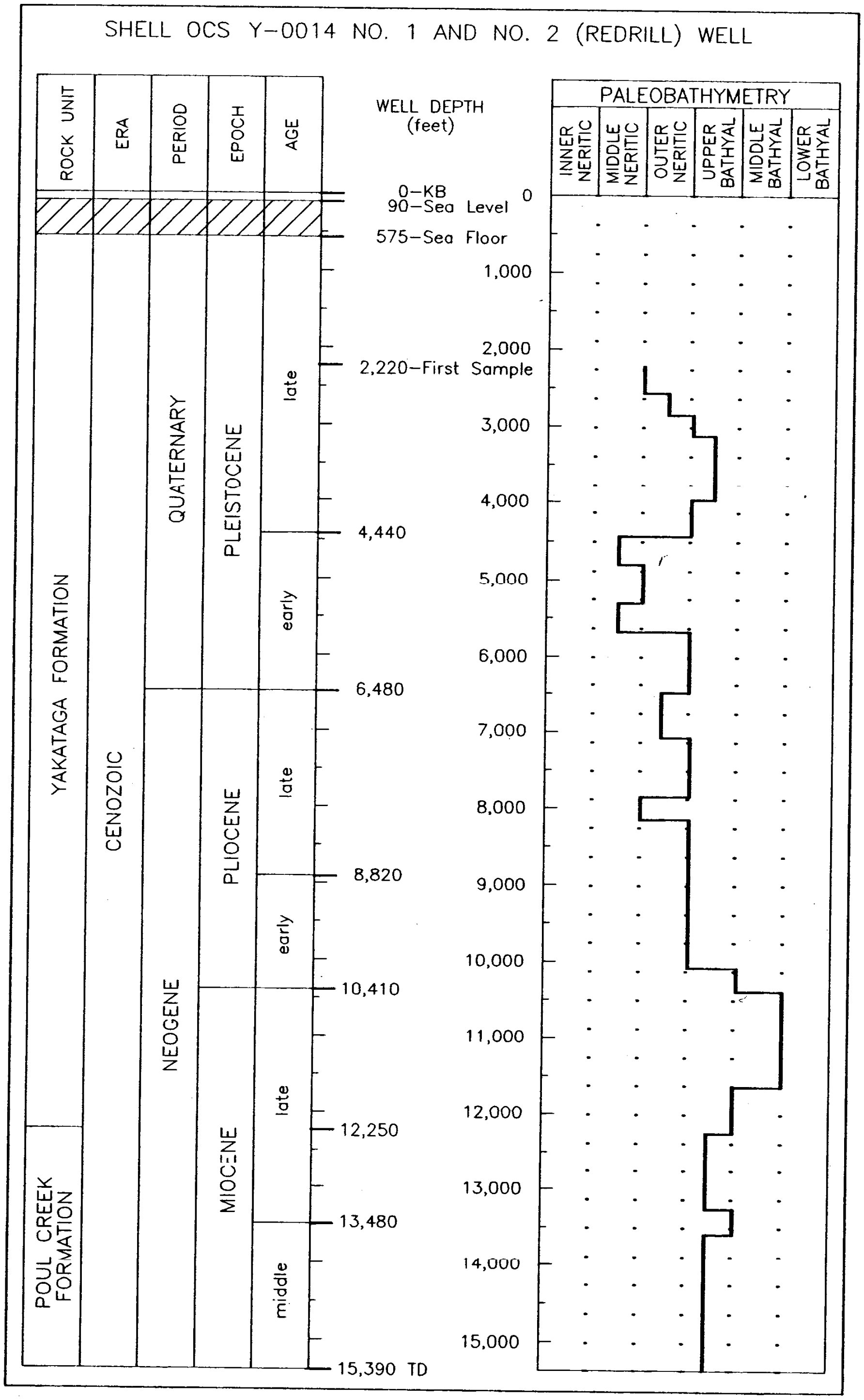


Figure 61. Biostratigraphy and paleodepth curve for the Shell OCS Y-0014 No. 1 and No. 2 (redrill) well. All depths are measured from the kelly bushing (KB), 90 feet above mean sea level. The well location is shown in figure 66.

Early Pliocene

The section from 8,820 to 10,410 feet is early Pliocene in age as indicated by sparse, dextrally coiled, warm-water populations of *Neogloboquadrina pachyderma* (fig. 57). Other planktonic species present include *Globigerina bulloides*, *Globigerina* sp. cf. *G. venezuelana*, *Globigerinoides* sp. cf. *G. conglobatus*, *Globigerinita* sp. cf. *G. naparimaensis*, and poorly preserved specimens of *Globorotalia* spp.

Additional benthic foraminifera present include *Lenticulina* sp. cf. *L. simplex* and *Sphaeroidina* sp. cf. *S. variabilis*. Other faunal elements present include teleost fish teeth and molluscan and echinoid fragments.

Paleodepths in the interval were outer neritic to upper bathyal from 8,820 to 10,050 feet and upper to middle bathyal from 10,050 to 10,410 feet (fig. 61).

Miocene

The section from 10,410 to 15,390 feet (TD) is Miocene in age, on the basis of planktonic foraminifera. The late Miocene section extends from 10,410 to 13,480 feet, while the section from 13,480 to 15,390 feet (TD) is middle Miocene.

Late Miocene

The section from 10,410 to 13,480 feet is late Miocene based on sparse populations of sinistrally coiled *Neogloboquadrina pachyderma* and occurrences of *Globorotalia* sp. cf. *G. juanai* (12,220 feet) and *Globorotalia acostaensis* (12,280 feet). Other planktonic foraminifera present include *Globigerina bulloides* and *Globigerinita* sp. cf. *G. naparimaensis* (13,290 feet).

Late Miocene–Yakataga Formation

The base of the Yakataga Formation at 12,250 feet is within the late Miocene section. Additions to the benthic foraminifera fauna in the late Miocene section of the Yakataga Formation include *Anomalina* sp. cf. *A. glabrata, Bulimina subacuminata, Cassidulina* sp. cf. *C. laticamerata, Cibicides* sp., and *Uvigerina* sp. cf. *U. hannai. Cribroelphidium* sp. cf. *C. crassum*, which is known from the Mohnian and Delmontian (late Miocene and early Pliocene, fig. 55) of California (Kleinpell and others, 1980), occurs at the top of the interval (10,410 feet).

Other faunal elements present include ostracodes and molluscan and echinoid fragments. A specimen of the early Miocene to Recent diatom *Actinocyclus* sp. cf. *A. ehrenbergii* occurs at 12,160 feet.

Paleodepths in the interval were middle to lower bathyal from 10,410 to 11,610 feet, and upper to middle bathyal from 11,610 to 12,250 feet (fig. 61).

Late Miocene–Poul Creek Formation

The top of the Poul Creek Formation is at 12,250 feet, within the late Miocene section. The formation boundary is marked by a change from mixed-lithology, coarse- to medium-grained Yakataga Formation sandstones, to the gray siltstones typical of the Poul Creek Formation. This contact is also identified on electric-well-log data (see chapter 5). It appears to be conformable at this location, similar to the late Miocene contact between the two formations at the Yakataga Reef section onshore (Lagoe, 1983).

Additions to the benthic foraminifera fauna in the late Miocene portion of the Poul Creek Formation include *Anomalina* sp. cf. *A. californiensis, Anomalina glabrata, Anomalina* sp. cf. *A. salinasensis, Bulimina* sp. cf. *B. alligata, Bulimina* sp. cf. *B. subcalva, Dorothia* sp., *Epistominella parva, Pullenia malkinae, Trochammina* sp., *Uvigerina* sp. cf. *U. hootsi, Uvigerina peregrina hispidocostata*, and *Valvulineria* sp. cf. *V. auracana*. Arenaceous species, including *Cyclammina* spp., *Haplophragmoides* spp., *Cribrostomoides* sp., and others, are abundant below 13,260 feet.

Other faunal elements present include bivalve and echinoid fragments, teleost fish bone fragments and teeth, and ostracode fragments.

Paleodepths in the late Miocene section of the Poul Creek Formation were upper bathyal from 12,250 to 13,260 feet, and upper to middle bathyal from 13,260 to 13,480 feet (fig. 61).

Between 13,200 and 14,250 feet, the well encountered a medium- to coarse-grained sandstone unit containing lithic clasts of varying lithologies. Below 14,250 feet, the lithology is indurated gray siltstone more typical of the Poul Creek Formation. Although the sandstone unit could be a section of Yakataga Formation that has been overthrust by Poul Creek Formation, we interpret it to be a (submarine fan?) sand facies within the Poul Creek Formation on the basis of the gray siltstone (Poul Creek Formation lithology) immediately above and below it, and its middle to early late Miocene age.

Middle Miocene

The section from 13,480 to 15,390 feet (TD) is middle Miocene based on the highest occurrence of the early to middle Miocene planktonic foraminifera *Globorotalia* sp. cf. *G. continuosa*. This species appears at 13,480 feet and occurs sporadically below this throughout the interval. A single specimen of *Orbulina universa* (middle Miocene to Recent) at 13,510 feet and *Globorotalia* sp. cf. *G. mayeri* (late Oligocene to late middle Miocene) at 15,010 feet also support a middle Miocene age. *Globigerina* sp. aff. *G. nepenthes* at 15,160 feet indicates an age no older than middle Miocene. Other planktonic species in the interval include *Globigerina bulloides, Globigerina* sp. cf. *G. venezuelana*, and *Globigerina quadrilobatus triloba. Globigerinita* sp. aff. *G. uvula* is present at 14,200 feet.

Additional benthic foraminifera present include *Cassidulina* sp. cf. *C. crassaformis*, *Cibicides perlucida*, *Dentalina* sp. cf. *D. pauperata*, *Dorothia* sp. cf. *D. bulletta*, *Plectina* sp., and *Sigmoilina* sp. *Spirosigmoilinella* sp. cf. *S. compressa*, which was present in the late Miocene section of the OCS Y-0080 No. 1 well, occurs in the middle Miocene of the OCS Y-0014 No. 1 and 2 well at 13,900 feet. *Anomalina glabrata* and *Anomalina* sp. cf. *A. salinasensis*, which were both observed in the late Miocene interval, are also present in the middle Miocene section.

Other faunal elements present in the middle Miocene section consist of bivalve fragments, including prismatic shell layer fragments at 13,510 and 13,540 feet, echinoid spines, and ostracodes. A barren interval from 13,560 to 13,590 feet contains nothing but small siderite nodules and may represent an interval of slow sedimentation or nondeposition.

Paleodepths in the middle Miocene interval were upper to middle bathyal from 13,480 to 13,590 feet and upper bathyal from 13,590 feet to 15,390 feet (TD) (fig. 61).

ARCO OCS Y-0007 No. 1 well

The ARCO OCS Y-0007 No. 1 well was drilled in 250 feet of water to a TD of 17,920 feet. All well depths were measured from the kelly bushing (KB), 95 feet above mean sea level. The well penetrated the Yakataga Formation from the seafloor to 11,580 feet, and encountered the Poul Creek Formation from 11,580 feet to TD (fig. 62).

Pleistocene

The interval from the seafloor to 5,370 feet is Pleistocene in age based on planktonic foraminifera and diatoms. The section is subdivided into late Pleistocene from the seafloor to 2,770 feet and early Pleistocene from 2,770 to 5,370 feet.

Late Pleistocene

The unsampled interval from the seafloor to 1,410 feet and the sampled interval from 1,410 to 2,380 feet, where no planktonic foraminifera were found, are late Pleistocene based on the age of the underlying interval. From 2,380 to 2,770 feet, the section is late Pleistocene in age based on the occurrence of sinistrally coiled populations of the planktonic foraminifera *Neogloboquadrina pachyderma* (fig. 57). *Globigerina bulloides* is present in the planktonic population below 2,380 feet, occurring throughout the remainder of the Neogene section.

The benthic foraminifera assemblage present is similar to the boreal assemblage in the Plio-Pleistocene of the OCS Y-0080 No. 1 well and the Pliocene of the OCS Y-0211 No. 1 well (see appendix A).

Other faunal constituents include bivalve and gastropod fragments, echinoid spines and fragments, bryozoan fragments, and rare shark teeth, salmonid teeth, pyritized diatoms, and ostracodes.

Paleodepths in the late Pleistocene were inner to middle neritic from 1,410 to 2,380 feet, middle to outer neritic from 2,380 to 2,740 feet, and outer neritic to upper bathyal from 2,740 to 2,770 feet (fig. 62).

Early Pleistocene

The interval from 2,770 to 5,370 feet is early Pleistocene based on the highest occurrence of the diatom *Actinocyclus oculatus* at 2,770 feet. The presence of dextrally coiled populations of the planktonic foraminifera *Neogloboquadrina pachyderma* at 2,860 feet and below also indicate an early Pleistocene age (fig. 57). Other planktonic foraminifera in the interval include *Globigerinita glutinata* at 2,770 feet and *Globigerinoides trilobus* at 4,780 and 5,310 feet.

Warmer water early Pleistocene conditions are also suggested by a small, broken delphinid (porpoise) tooth at 2,920 feet. The tooth is conical in shape and circular in cross section. It apparently comes from a warm-water species that lives today off the coast of California and does not range any farther north than Point Conception (D. Calkins, Alaska State Department of Fish and Game, personal commun.).

Additional benthic foraminifera in the early Pleistocene interval include *Buccella subperuviana*, *Rosalina ornatissima*, *Silicosigmoilina groenlandica*, *Trichohyalis bartletti*, *Trifarina* sp. cf. *T. baggi*, and *Uvigerina cushmani*. *Rotalia columbiensis* occurs from 5,190 to 5,310 feet.

Additional faunal elements present include molluscan fragments, ostracodes, echinoid spines, and rare ophiuroid fragments.

Paleodepths were outer neritic to upper bathyal from 2,770 to 3,490 feet, middle to outer neritic from

3,490 to 5,310 feet, and outer neritic to upper bathyal from 5,310 to 5,370 feet (fig. 62).

Pliocene

The interval from 5,370 to 11,580 feet is Pliocene in age based on planktonic foraminifera. The section is subdivided into late Pliocene from 5,370 to 7,290 feet and early Pliocene from 7,290 to 11,580 feet.

Late Pliocene

The section from 5,370 to 7,290 feet is late Pliocene based on the presence of colder water, predominantly sinistrally coiled *Neogloboquadrina pachyderma* (fig. 57) throughout the interval. Minor warming episodes or incursions of warmer water are indicated by short intervals containing dominantly dextrally coiled populations. Other planktonic species include *Globigerinoides trilobus* at 5,370 feet and *Globorotalia* sp. cf. *G. inflata* at 5,670 feet.

The benthic foraminifera assemblage is similar to that of the Pleistocene with the addition of *Epistominella pulchella, E. smithi, Pyrgo vespertilio, Quinqueloculina agglutinata, Q. seminula*, and *Quinqueloculina* sp. cf. *Q. stalkeri. Rotalia columbiensis* occurs at 5,880 feet.

Additional faunal elements include molluscan fragments, echinoid spines and fragments, and rare ophiuroid fragments, crustacean fragments, and ostracodes.

Paleodepths were outer neritic to upper bathyal throughout the interval (fig. 62).

Early Pliocene

The section from 7,290 to 11,580 feet is early Pliocene based on the presence of predominantly dextrally coiled populations of *Neogloboquadrina pachyderma* (fig. 57). Other planktonic species in the interval include rare *Globigerina quinqueloba* and *Neogloboquadrina dutertrei.*

Additional benthic species appearing in this interval include *Cyclammina pusilla, Melonis barleeanum*, and *Nonionella miocenica stella. Nonion* sp. aff. *N. goudkoffi* appears at 8,460 feet, while *Uvigerina hootsi* appears at 8,640 feet and *U. excellens* appears at 8,760 feet.

Other faunal elements present in the interval include molluscan fragments, echinoid spines and fragments, and rare ostracodes and pyritized diatoms.

Paleodepths for the entire interval were probably upper bathyal (fig. 62).

Miocene

The entire Miocene section appears to be missing in the OCS Y-0007 No. 1 well. There is no indication of late Miocene sinistrally coiled, cold-water populations of *Neogloboquadrina pachyderma* in the section above 11,580 feet. Below 11,580 feet, there is a long-ranging, typically late Eocene (Refugian, fig. 55) to early Miocene (Saucesian) benthic foraminifera assemblage present. However, none of the species typical of the early Miocene section onshore are present.

Oligocene

The section from 11,580 to 15,950 feet is Oligocene (Zemorrian, fig. 55) based on benthic foraminifera. The Oligocene age, along with lithologic and electric-well-log analyses (see chapter 5), indicates that the interval probably corresponds to the middle part of the Poul Creek Formation.

The benthic foraminifera assemblage in the top part of the interval (11,580 to 12,000 feet) contains several species (including *Cassidulina margareta, Cibicides elmaensis, Gyroidina orbicularis planata*, and *Valvulineria menloensis*) that have been recorded as high as the early Miocene Saucesian stage, but are much more commonly found in the Oligocene and late Eocene in Washington and California. Species characteristic of the early Miocene section were absent. Below 12,000 feet, the assemblage does not contain species ranging higher than the Oligocene (Zemorrian stage, fig. 55).

Rare, poorly preserved calcareous nannofossils are present in the lower part of the Oligocene section. A single occurrence of *Reticulofenestra hillae* (late middle Eocene to mid-early Oligocene) at 15,530 feet suggests an age no younger than early Oligocene. Also present are rare *Cyclococcolithus neogammation* (equivalent to *Cyclicargolithus floridanus*) at 15,574 feet (conventional core 8, appendix B-9), and *Dictyococcites bisectus* at 15,710 feet. The former species ranges from latest Eocene to middle Miocene, the latter from middle Eocene to late Oligocene.

There is also an occurrence of frequent specimens of calcareous nannofossils identified as *Coccolithus* sp. cf. *C. orangensis* at 15,710 feet (Jacobson and Akers, 1985). This species, which is now referred to *Pyrocyclus* sp. cf. *P. orangensis*, ranges from late

Oligocene to middle Miocene. The poorly preserved specimens do not appear to be caved (none were found anywhere higher in the well). If the identification of this species is correct, the interval (11,580 to 15,950 feet) may be no older than late Oligocene, conflicting with the early Oligocene age of *Reticulofenestra hillae* mentioned above, and implying that *R. hillae* is reworked. This would suggest that much of the early Oligocene section could be missing, and that there could be an unconformity at 15,950 feet between the late Oligocene section and the late Eocene section. However, because the preservation of *Pyrocyclus* sp. cf. *P. orangensis* was poor, this species may have been misidentified, and the species present may be a related form such as *Pyrocyclus hermosus* (early Oligocene to early Pliocene). If the species at 15,710 feet is *Pyrocyclus hermosus*, then a more complete early(?) to late Oligocene section is probably present, *R. hillae* is probably in place, and an unconformity between the Eocene and Oligocene sections is less likely. This is the interpretation that is depicted in figure 62, where the possibility of an unconformity at 15,950 feet is noted with question marks. Possible faults were noted on dipmeter logs at approximately 14,000 feet and at the base of the interval at 15,950 feet (see chapter 5), but they could not be detected with the biostratigraphic data. Lithologic and well log data revealed no evidence supporting an unconformity at 15,950 feet.

Several dinoflagellate species common in the late Eocene and Oligocene are also present in the section. These include *Lejeunecysta hyalina* (Eocene to early Miocene) at 12,540 feet, *Cordosphaeridium microtriainum* (Eocene to Oligocene) at 15,389 feet (conventional core 8, appendix B-9) and 15,710 feet, and *Deflandria phosphoritica* (Eocene to Oligocene) at 15,710 feet. The longer-ranging *Hystrichokolpoma rigaudiae* (Eocene to Pleistocene) occurs at 13,389 feet in a sample from conventional core 5 (appendix B-6).

Numerous additional benthic foraminifera species occur in the Oligocene section. These include *Cibicides elmaensis* (11,580 feet), *Cassidulina crassipunctata*, *Cassidulina* sp. cf. *C. margareta* and *Gyroidina orbicularis planata* (11,610 feet), *Elphidium minutum* and *Valvulineria* sp. cf. *V. menloensis* (11,700 feet), *Epistomina* sp. cf. *E. eocenica* and *Uvigerinella obesa impolita* at 12,000 feet, *Cassidulina galvinensis* (12,420 feet), *Nonion blakeleyensis* (12,510 feet), *Cibicides pseudoungerianus* (12,240 feet), *Ellipsonodosaria* sp. aff. *E. cocoaensis* (fragments) at 15,000 feet, *Gaudryina alazanensis* (15,380 feet), and *Anomalina californiensis* (15,470 feet). Other species present include *Anomalina* sp. cf. *A. loweryi*, *Bathysiphon* sp. cf. *B. eocenica*, *Bathysiphon* sp. cf. *B. sanctaecrucis*, *Biloculina* sp. aff. *B. cowlitzensis*, *Bulimina* sp. cf. *B. ovata*, *Cassidulina* sp. cf. *C. californica*, *Cassidulina* sp. cf. *C. modeloensis*, *Ceratobulimina washburnensis*, *Cornuspira byramensis*, *Cyclammina* sp. cf. *C. clarki*, *C. incisa*, *C. pacifica*, *C. pacifica obesa*, *Dentalina* sp. cf. *D. nasuata*, *Eggerella* sp., *Elphidium* sp. aff. *E. californicum* (fragments), *Elphidium* sp. cf. *E. clavatum*, *Epistomina* sp. cf. *E. ramonensis*, *Epistominella parva*, *Eponides minimus*, *Glandulina* sp. cf. *G. laevigata*, *Guttulina franki*, *G. irregularis*, *Haplophragmoides obliquicamerata*, *H. trullissata*, *Hyperammina* sp. cf. *H. elongata*, *Karreriella washingtonensis*, *Lagena* sp. cf. *L. substriata*, *Lenticulina becki*, *Lenticulina* sp. aff. *L. budensis*, *L. inornata*, *L. limbosa hockleyensis*, *L. miocenica*, *L. nickobarensis*, *Lenticulina* sp. aff. *L. welchi*, *Martinottiella communis*, *Nodosaria* sp., *N. longiscata*, *Nonion* sp. cf. *N. planatum*, *Oridorsalis umbonatus*, *Plectofrondicularia*? sp., *Pseudoglandulina inflata*, *P. nallpeensis*, *Pyrgo lupheri*, *Quinqueloculina goodspeedi*, *Q. imperialis porterensis*, *Q. weaveri*, *Sigmoilina tenuis*, *Sigmomorphina* sp. aff. *S. schenki*, *Siphonodosaria* sp. (fragments), *Textularia* sp. cf. *T. adalta*, *Trochammina globigeriniformis*, *T. parva*, and *Verneuilina*? sp. Planktonic foraminifera were not found in the section.

Other faunal elements present include molluscan fragments, echinoid fragments, ophiuroid ossicles, pyritized diatoms, and rare ostracodes and radiolarians.

Paleodepths in the Oligocene section were upper to middle bathyal and middle bathyal from 11,580 to 12,600 feet. Middle bathyal conditions probably prevailed from 12,600 to 15,950 feet (fig. 62).

Late Eocene

The section from 15,950 to 17,920 feet (TD) is late Eocene. The top of the interval is based on the highest occurrences of *Eponides kleinpelli*, *Uvigerina cocoaensis*, and other species characteristic of the lower Refugian stage (late Eocene, fig. 55) of California, Oregon, and Washington. Also occurring in the top sample of the interval (15,950 feet) are *Uvigerina* sp. cf. *U. gallowayi*, *Uvigerina* sp. cf. *U. vicksburgensis*, and *Valvulineria willapaensis*. Other benthic species in the late Eocene section include *Anomalina californiensis*, *Bathysiphon* spp., *Bathysiphon* sp. cf. *B. eocenica*, *Cassidulina crassipunctata*, *C. galvinensis*, *C. modeloensis*, *Ceratobulimina washburni*, *Cibicides*

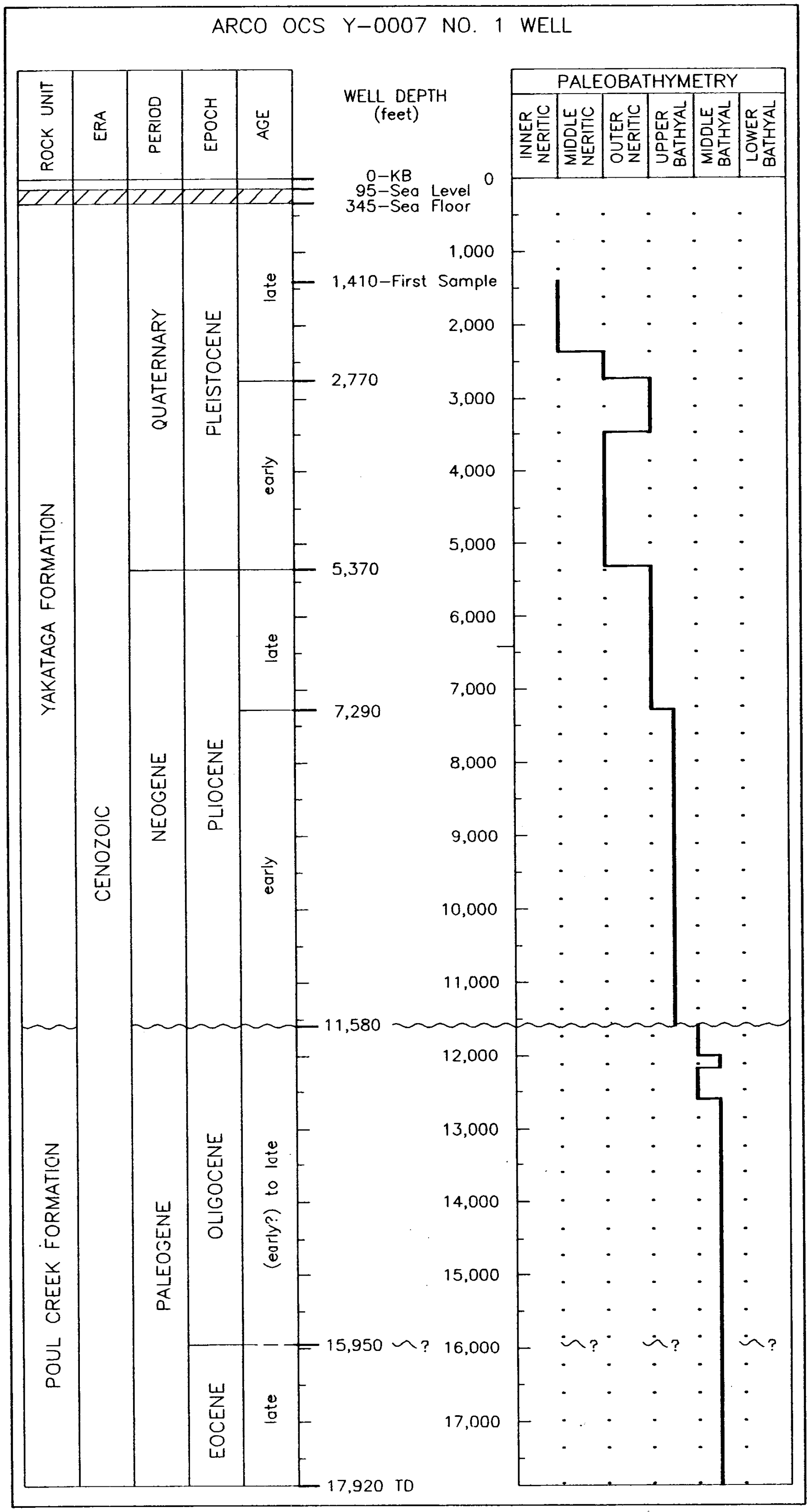


Figure 62. Biostratigraphy and paleodepth curve for the ARCO OCS Y-0007 No. 1 well. All depths are measured from the kelly bushing (KB), 95 feet above mean sea level. The well location is shown in figure 66.

elmaensis, *C. pseudoungerianus*, *Cyclammina cancellata*, *C. cancellata obesa*, *C. clarki*, *C. incisa*, *C. pacifica*, *Dentalina communis*, *Ellipsonodosaria* sp. cf. *E. cocoaensis*, *Epistomina eocenica*, *Gyroidina orbicularis planata*, *Haplophragmoides obliquecamerata*, *H. trullissata*, *Karreriella washingtonensis*, *Lagena strumosa*, *Lagena* sp. cf. *L. vulgaris*, *Sigmoilina tenuis*, *Sigmomorphina schencki*, *Siphogenerina*? sp. aff. *S. smithi*, *Sphaeroidina variabilis*, *Uvigerina* sp. cf. *U. churchi*, and *Verneulina*? sp. *Allomorphina* sp. cf. *A. macrostoma* and *Uvigerina atwilli* occur at 16,140 feet. Planktonic foraminifera in the interval were scarce, poorly preserved, and problematic.

A late Eocene age for this section is also supported by dinoflagellate occurrences. *Impletosphaeridium implicatum* (17,600 feet) indicates an age no younger than Eocene. Other dinoflagellates present, including the Eocene to Oligocene species *Cordosphaeridium microtriainum* and *Deflandria phosphoritica*, and the longer ranging *Paralecaniella indentata*, are all compatible with a late Eocene age.

An assemblage of calcareous nannofossils indicating a late Eocene to Oligocene age range also occurs in the interval. It includes *Chiasmolithus altus*, *Coccolithus eopelagicus*, *Dictyococcites bisectus*, *D. scrippsae*, *Reticulofenestra hillae*, and *Sphenolithus moriformis*. Also present are *Discolithina vigintiforata*, *Transversopontis pulcher*, and *Cyclococcolithus* sp. cf. *C. neogammation* (*Cyclicargolithus floridanus*).

Other faunal elements present include molluscan and echinoid fragments. Glauconite is an important accessory mineral.

Paleodepths in the late Eocene interval were probably middle bathyal (fig. 62) based on frequent to common occurrences of arenaceous foraminifera such as *Cornuspira byramensis* and various species of *Cyclammina* and *Bathysiphon*, and on calcareous species such as carinate forms of *Cassidulina*, costate species of *Uvigerina*, and large specimens of *Epistomina*, *Gyroidina*, and *Anomalina*.

Texaco OCS Y-0032 No. 1 well

The Texaco OCS Y-0032 No. 1 well was drilled in 240 feet of water to a TD of 15,638 feet. All well depths were measured from the kelly bushing (KB), 86 feet above mean sea level. The well encountered the Yakataga Formation from just below the seafloor to 13,580 feet, and penetrated the Poul Creek Formation from 13,580 feet to TD (fig. 63).

Pleistocene

The interval from the seafloor to 6,380 feet is Pleistocene based on planktonic foraminifera. The section is divided into late Pleistocene from the seafloor to 3,590 feet and early Pleistocene from 3,590 to 6,380 feet.

Late Pleistocene

The interval from the seafloor to the first sample at 475 feet is late Pleistocene based on the age of the underlying interval. From 475 to 3,590 feet the sediments are late Pleistocene based on the presence of predominantly sinistrally coiled populations of the planktonic foraminifera *Neogloboquadrina pachyderma* (fig. 57) and a boreal assemblage of benthic foraminifera. This cold-water assemblage is very similar to that encountered in the Plio-Pleistocene section of the OCS Y-0080 No. 1 well and the Pleistocene section of the OCS Y-0211 No. 1 well (see appendix A), with the addition of *Rotalia columbiensis* at 2,090 feet and *Polymorphina charlottensis* at 3,020 feet. *Globigerina bulloides* was also present in the planktonic foraminifera assemblage.

Paleobathymetry in the late Pleistocene interval was inner to middle neritic from 475 to 590 feet, middle to outer neritic from 590 to 1,130 feet, outer neritic to upper bathyal from 1,130 to 2,300 feet, middle to outer neritic from 2,300 to 2,900 feet, and outer neritic to upper bathyal from 2,900 to 3,590 feet (fig. 63).

Early Pleistocene

An early Pleistocene age is indicated by warmer water populations of predominantly dextrally coiled *Neogloboquadrina pachyderma* (fig. 57) from 3,590 to 6,380 feet. Also present are *Globorotalia*? sp. and *Globigerina bulloides*. *Globorotalia* sp. cf. *G. puncticulata* (reworked late early to early late Pliocene) is present at 5,720 feet, and *Globigerinita humilis* is present at 5,990 feet.

The benthic foraminifera assemblage is very similar to that in the late Pleistocene section.

The paleobathymetry of this interval was outer neritic to upper bathyal, with short intervals of middle to outer neritic from 3,920 to 4,130 feet and from 4,700 to 4,970 feet (fig. 63).

Pliocene

The interval from 6,380 to 13,460 feet is Pliocene in age based on planktonic foraminifera and siliceous nannofossils. The section is divided into late Pliocene from 6,380 to 8,000 feet, and early Pliocene from 8,000 to 13,460 feet.

Late Pliocene

Cold-water conditions characteristic of the Late Pliocene are indicated by the recurrence of predominantly sinistrally coiled populations of *Neogloboquadrina pachyderma* (fig. 57) from 6,380 to 8,000 feet. *Globigerina bulloides* is also present. *Globorotalia* sp. cf. *G. puncticulata* at 7,640 and 7,850 feet supports an early late Pliocene age for the lower part of the interval.

Additional benthic foraminifera found in the late Pliocene interval include *Elphidiella arctica*, *Haplophragmoides* sp. cf. *H. trullisata*, *Trifarina angulosa*, *T. fluens*, and *Uvigerina hootsi*.

Paleodepths were middle to outer neritic from 6,380 to 7,640 feet, and probably upper bathyal from 7,640 to 8,000 feet (fig. 63).

Early Pliocene

Early Pliocene warm-water faunas characterized by predominantly dextrally coiled populations of *Neogloboquadrina pachyderma* (fig. 57) are present from 8,000 to 13,460 feet. Other planktonic species present include *Neogloboquadrina dutertrei* and *Globigerina quinqueloba*. Specimens of *Globigerinita glutinata* and *G. uvula* occur at 8,570 feet, and *Globorotalia* sp. cf. *G. inflata* occurs at 8,660 and 10,250 feet.

Additional benthic foraminifera species occurring in this interval include *Cribrostomoides veleronis*, *Cyclammina cancellata*, and *Dentalina ittai* at 8,420 feet and below; *Dentalina frobisherensis*, *D. pauperata*, *Elphidium incertum*, *Lagena laevis*, *Oolina lineata*, *O. squamata*, *O. striatopunctata* at 10,460 feet and below; and *Anomalina* sp. cf. *A. californiensis*, *Marinottiella communis*, *Uvigerina auberiana*, and *U. peregrina* at 13,160 feet and below. *Polymorphina charlottensis* is once again present at 10,280 feet.

The silicoflagellates *Dictyocha* sp. cf. *D. fibula* and *Distephanus speculum*, which are known from the early Pliocene (Perch-Nielsen, 1985b), occur at 8,990 feet. The diatom *Denticulopsis kamtschatica*, also characteristically present in the early Pliocene (Barron, 1980), occurs at the same level.

Paleodepths were outer neritic to upper bathyal from 8,000 to 10,250 feet, and probably upper bathyal from 10,250 to 10,880 feet. From 10,880 to 11,060 feet, paleodepths were outer neritic to upper bathyal. Sparser faunas with decreased planktonics from 11,060 to 13,160 feet suggest possible middle to outer neritic conditions. From 13,160 to 13,460 feet conditions were outer neritic to upper bathyal (fig. 63).

Miocene

The interval from 13,460 to 13,760 feet is Miocene is age. The section is divided into possible late Miocene and possible early Miocene segments by an unconformity surface at 13,580 feet.

Possible Late Miocene

Rare occurrences of sinistrally coiled *Neogloboquadrina pachyderma* in the interval from 13,460 to 13,580 feet, if not caved, indicate the cold-water conditions characteristic of the late Miocene (fig. 57). Also present are *Globigerina bulloides* and *Globigerinoides* sp. cf. *G. trilobus*. The benthic foraminifera assemblage was similar to that of the overlying section.

Paleodepths were outer neritic to upper bathyal (fig. 63).

Possible Early Miocene–Poul Creek Formation

The top of the Poul Creek Formation is placed at 13,580 feet based on well log data and lithology (see chapter 5). The age of the uppermost part of this interval is uncertain, but the presence of a broken specimen of the benthic foraminifera *Siphogenerina* sp. aff. *S. kleinpelli* at 13,640 feet suggests a Saucesian age (early Miocene, fig. 55) from 13,580 feet to the top of the underlying interval at 13,760 feet. *Siphogenerina kleinpelli* has been described in Saucesian sediments onshore in the Gulf of Alaska area, where it occurs in a stratigraphic section on the north and west side of Kayak Island and (*Siphogenerina* sp. cf. *S. kleinpelli*) in the White River No. 3 well (Rau and others, 1983; fig. 66 and table 1).

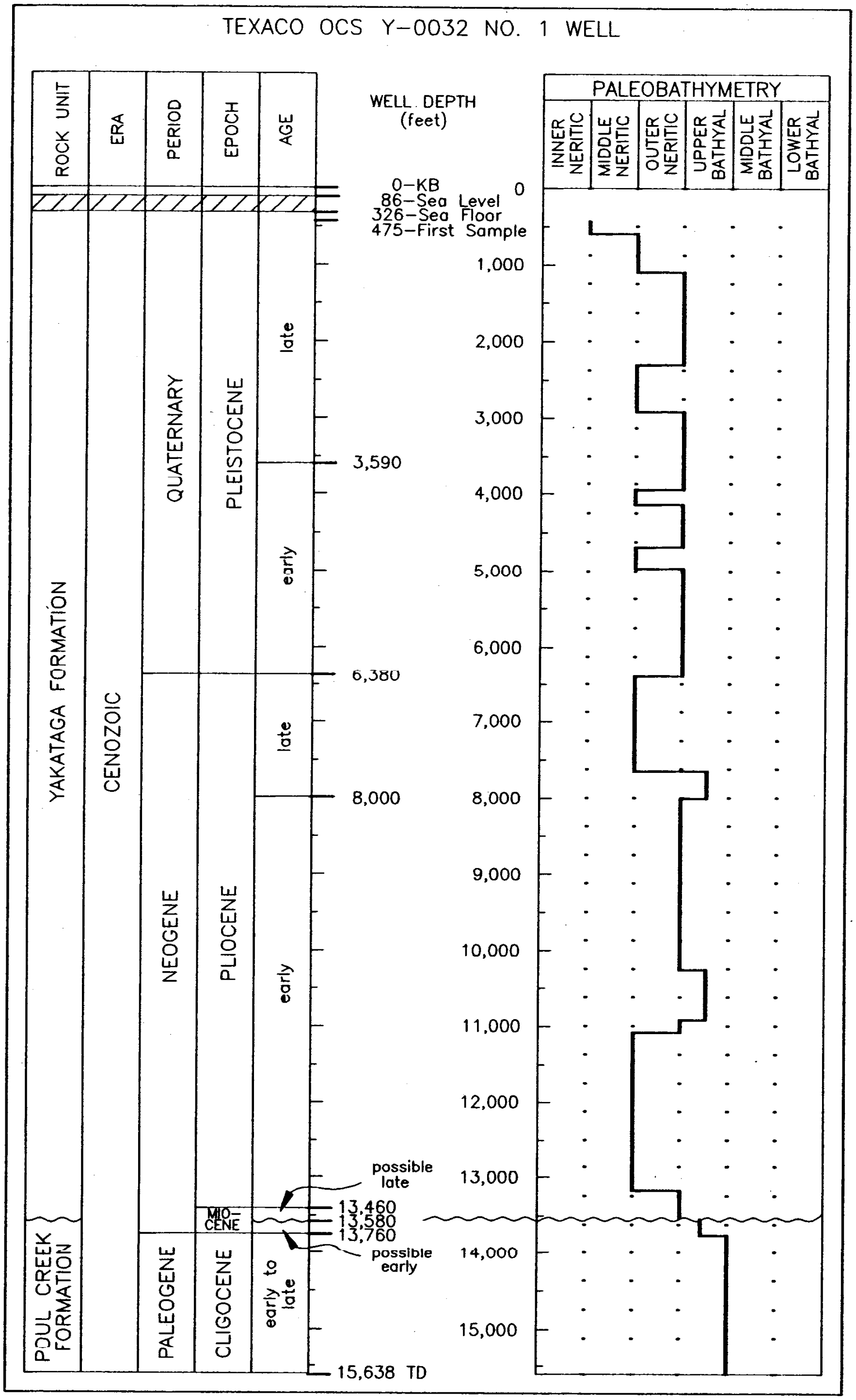


Figure 63. Biostratigraphy and paleodepth curve for the Texaco OCS Y-0032 No. 1 well. All depths are measured from the kelly bushing (KB), 86 feet above mean sea level. The well location is shown in figure 66.

The apparent absence of middle Miocene sediments in the well suggests that the contact at the top of the Poul Creek Formation (13,580 feet) is unconformable.

Planktonic foraminifera in the interval include *Globigerina* sp. and *G. bulloides*. Additional benthic foraminifera in the interval include *Bulimina* sp., *Cassidulina laevigata carinata, C. margareta, C. pulchella, Epistominella parva, Nodosaria*? sp., *Sphaeroidina*? sp., *Textularia*? sp., and *Uvigerina montesanensis*.

Paleodepths for the possible early Miocene section were upper bathyal (fig. 63).

Oligocene

The section from 13,760 to 15,638 feet (TD) is Oligocene in age based on the presence of deep-water calcareous foraminifera (species of *Gyroidina, Anomalina, Cibicides,* and *Cassidulina*) and arenaceous foraminifera typical of Oligocene (Zemorrian) and older sediments of California, Oregon, and Washington (fig. 55). The planktonic foraminifera *Globigerina* sp. cf. *G. sellii* at 14,210 feet and below also supports an Oligocene age. Other planktonic foraminifera include *Globigerina* sp. and *Globigerina* sp. cf. *G. bulloides.*

The benthic foraminifera assemblage includes *Allomorphina macrostoma, Anomalina californiensis, Anomalina* sp. cf. *A. loweryi, Bathysiphon eocenica, Bulimina alligata, B. blakelyensis, B. ovata, B. pupoides, B. pyrula, B. rinconensis, Buliminella subfusiformis, Cassidulina* sp. cf. *C. galvinensis, C. kernensis, C. modeloensis, Cassidulinoides* sp., *Cibicides elmaensis, C. pseudoungerianus, Cornuspira byramensis, Cyclammina clarki, C. incisa, C. obesa, C. pacifica, Dentalina* spp., *D. communis, D. consorbina, Discammina eocenica, Eggerella* sp., *Elphidium* sp. cf. *E. californicum, E. minutum, Epistomina eocenica, Eponides gaviotaensis, E. healdi, E. minimus, Gaudryina* sp., *G. alazanensis, Globobulimina* sp. cf. *G. hannai, Guttulina irregularis, Gyroidina condoni, G. orbicularis planata, G. soldanii, Haplophragmoides deflata, Hyperammina elongata, Karreriella washingtonensis, Lagena strumosa, L. vulgaris, Lenticulina crassa, Lenticulina* sp. cf. *L. chehalensis, Lenticulina* sp. cf. *L. texanus, Martinottiella eocenica, Nodosaria sanctaecrucis, Nonion blakleyensis, Nonion* sp. cf. *N. californiensis, N. incisum, Oridorsalis umbonatus, Plectina garzaensis, Pseudoglandulina inflata, Pseudoglandulina* sp. cf. *P. nallpeensis, Pseudopolymorphina* sp., *Pullenia eocenica, P. multilobata, Pullenia* sp. cf. *P. quinqueloba, Pyrgo cowlitzensis* (large), *P. lupheri, Quinqueloculina imperialis, Q. imperialis porterensis, Quinqueloculina* sp. cf. *Q. goodspeedi, Quinqueloculina weaveri, Rhabdammina eocenica, Trochammina* sp. cf. *T. globigeriniformis, Trochammina* sp. cf. *T. parva, Sigmoilina tenuis, Sigmomorphina undulata, Sphaeroidina variabilis, Uvigerina* sp. cf. *U. carmeloensis, Uvigerina* sp. cf. *U. garzaensis, Uvigerinella obesa impolita, Vaginulinopsis saundersi,* and *Verneuilina* sp. aff. *V. compressa. Ellipsonodosaria* sp. aff. *E. cocoaensis* (fragment) occurs at 14,000 feet.

The late Eocene to middle Miocene calcareous nannofossil *Cyclococcolithus* sp. cf. *C. neogammation* (equivalent to *Cyclicargolithus floridanus*) was noted at 15,070 feet. No age-diagnostic dinoflagellates were identified.

Other faunal elements in the section include molluscan fragments, gastropods, ostracodes, echinoid spines and fragments, and pyritized radiolaria. Glauconitic sandstone is present from 14,030 to 14,120 feet.

Paleodepths for the Oligocene section were upper to middle bathyal (fig. 63).

ARCO OCS Y-0211 No. 1 well

The ARCO OCS Y-0211 No. 1 well was drilled in 450 feet of water to a TD of 17,810 feet (fig. 64). All well depths were measured from the kelly bushing (KB), 86 feet above mean sea level. The well encountered the Yakataga Formation from the seafloor to 4,805 feet, the Poul Creek Formation from 4,805 to 8,570 feet, the Kulthieth Formation from 8,570 to 16,430 feet, sediments equivalent to the Oily Lake siltstone (Plafker, 1987) from 16,430 to 17,545 feet (see chapter 5), and volcanics and minor amounts of shale and siltstone that are possibly equivalent to the Hubbs Creek basalt (see chapter 5) from 17,545 feet to TD.

Late Pliocene to Pleistocene

The upper 4,805 feet of the ARCO OCS Y-0211 No. 1 well consists of glaciomarine siltstones, conglomerates, and sandstones of the Yakataga Formation. The boreal foraminifera assemblage in this section of the well is similar to the assemblage in the Plio-Pleistocene section of the OCS Y-0080 No. 1 well and other OCS wells in the Gulf of Alaska (see appendix A), and is only broadly age diagnostic. The interval from the seafloor (536 feet below KB) to 1,580 feet in the well was not sampled for microfossils, but is probably late Pliocene to Pleistocene in age based on the age of the underlying interval (fig. 64) and the cross-sectional geometry of the continental shelf structure. Seismic evidence suggests that the Pleistocene sequence in the vicinity of the OCS Y-0211 well is thin. Seismic profiles show that shelf edge uplift centered in the Fairweather Ground area (fig. 28) has tilted the shelf landward, causing the Pleistocene section to be thicker nearshore and to thin seaward in the direction of the well (see chapter 4 and plate 3A, lines YT-1 and YT-2). As a result of this uplift, the upper part of the tilted section is truncated at the seafloor landward of the OCS Y-0211 No. 1 well, and a significant portion of the Pleistocene section has probably been removed at the well site.

Pliocene

The section from 1,580 to 4,805 feet is Pliocene in age. The section is divided into late Pliocene from 1,580 to 2,120 feet and early Pliocene from 2,120 to 4,805 feet. The age of the interval and its division into early and late Pliocene are based primarily upon the coiling-direction trends of sparse populations of the planktonic foraminifera *Neogloboquadrina pachyderma* (fig. 57), and on siliceous microfossil occurrences.

Late Pliocene

From 1,580 to 2,120 feet, scant but persistent populations of *Neogloboquadrina pachyderma* are composed entirely of sinistrally coiled forms, indicating cold water. From 2,120 to 4,805 feet, the sparse populations of *Neogloboquadrina pachyderma* range from 25 to 100 percent dextrally coiled, indicating warmer water. When compared to the generalized *Neogloboquadrina pachyderma* coiling curve (fig. 57), this sequence resembles the pattern of either the early and late Pleistocene warm and cold intervals or the early and late Pliocene warm and cold intervals. Because of the probable truncation of the Pleistocene section mentioned above, this is most likely the Pliocene section, with the change in *Neogloboquadrina pachyderma* coiling ratios at 2,120 feet marking the division between early and late Pliocene.

Other planktonic foraminifera in the late Pliocene section include *Globigerina bulloides*, *G. quinqueloba*, and *Neogloboquadrina dutertrei*.

A late Pliocene age for the upper portion of the well is supported by rare occurrences of the diatoms *Thalassiosira usatschevii* (which ranges no higher than late Pliocene) and *Denticulopsis seminae* (late Pliocene to Recent) at 1,760 feet. Additional siliceous microfossils in the late Pliocene section include the diatoms *Thalassiosira gravida* (1,760 feet and below) and *T. nidulus* (1,910 feet and below).

Benthic foraminifera in the late Pliocene section include *Buccella frigida*, *B. inusitata*, *B. tenerrima*, *Cassidulina californica*, *C. cushmani*, *C. islandica*, *C. limbata*, *C. norcrossi*, *C. reflexa*, *C. subglobosa*, *C. teretis*, *C. transluscens*, *Cibicides fletcheri*, *C. lobatulus*, *C. mckannai*, *Dentalina baggi*, *D. decepta*, *D. frobisherensis*, *Elphidium bartletti*, *E. clavatum*, *E. frigidum*, *E. hughesi*, *E. incertum*, *Elphidiella* sp. cf. *E. arctica*, *E. oregonense*, *Epistominella* sp. cf. *E. narai*, *Fissurina lucida*, *Glandulina* sp., *Karreriella baccata*, *Lagena sulcata*, *Lenticulina* sp. cf. *L. occidentalis*, *L.* sp., *Nonionella labradorica*, *Oolina costata*, *O. globosa*, *Pyrgo lucernula*, *P. murrhina*, *P. rotalaria*, *Quinqueloculina akneriana*, *Q. seminulum*, *Triloculina tricarinata*, *T. trihedra*, *Trifarina angulosa*, *T. fluens*, *Uvigerina cushmani*, *U. juncea*, and *U. peregrina*. Also present are *Elphidiella nitida* and *Marginulina* sp. cf. *M. glabra* (1,730 feet), *Polymorphina charlottenensis* (1,760 feet), and *Rotalia columbiensis* (1,880 feet).

Other faunal elements in the late Pliocene section include barnacle fragments, bivalve and gastropod fragments, echinoid spines and plates, ostracodes, and serpulid worm tube fragments. A shark skin denticle was found at 2,030 feet. Bryozoan fragments are also present, including the erect bryozoan *Myriozoum subgracile* at 1,820 feet. This species is known from Recent neritic environments on Albatross Bank, near Kodiak Island (Cuffey and Turner, 1987).

Paleodepths in the late Pliocene interval were middle to outer neritic (fig. 64). Sinistrally coiling *Neogloboquadrina pachyderma* indicate cold-water conditions.

Early Pliocene

The section from 2,120 to 4,805 feet is early Pliocene in age. The top of this interval is marked by the highest occurrence of elevated percentages of dextrally coiled *Neogloboquadrina pachyderma*, indicating early Pliocene warmer water conditions (fig. 57). Other planktonic foraminifera in the early Pliocene section include *Globigerina bulloides*, *G. quinqueloba*, and *Neogloboquadrina dutertrei*, with the addition of *Globigerinoides*? sp. cf. *G. trilobus* at 3,350 feet, *Globorotalia* sp. cf. *G. acostaensis* at 4,450 feet, and very rare to rare occurrences of 50 to 100 percent dextrally coiled *Neogloboquadrina pachyderma* variety "*incompta*" (Kennett and Srinivasan, 1980) at 2,930, 3,820, and 4,780 feet.

The silicoflagellate *Mesocena diodon*, which ranges no higher than the early Pliocene *Distephanus boliviensis* zone (Martini and Muller, 1976), occurs several times between 2,120 and 2,870 feet, supporting an early Pliocene age for the section below 2,120 feet. Additional siliceous microfossils in the early Pliocene section include the diatom *Actinocyclus oculatus* at 2,660 feet, and the silicoflagellate *Stephanopyxis horridus* at 3,560 feet. Specimens of the diatoms *Rhizosolenia curvirostris*, *Denticulopsis seminae*, *D. seminae* var. *fossilis*, and the silicoflagellate *Distephanus octonarius* are also present in the early Pliocene section, but these are considered to be caved from uphole or to represent contaminants from recirculated drilling mud.

Additional benthic foraminifera species appearing in the early Pliocene section include *Cassidulina* sp. cf. *C. laevigata, Cribroelphidium* sp. cf. *C. paromaense, Elphidiella* sp. cf. *E. arctica, E. groenlandica, Epistominella pacifica, E. pulchella, Fissurina marginata, Glandulina laevigata, Haplophragmoides* sp., Lagena sp. cf. *L. striata, Protelphidium orbiculare, Pullenia malkinae, P. salisburyi, Quinqueloculina lamarckiana, Quinqueloculina* sp. cf. *Q. oblonga, Quinqueloculina* sp. cf. *Q. subrotunda, Trifarina* sp. cf. *T. hughesi, Trochammina* sp. cf. *T. globigerinoides, Uvigerina* sp. cf. *U. hootsi*, and *Uvigerina* sp. cf. *U. subperegrina.*

Additional faunal elements appearing in the early Pliocene section include barnacle fragments, bivalve and gastropod fragments, echinoid spines and plates, bryozoan fragments, and serpulid worm tube fragments, plus siliceous sponge spicules and additional species of ostracodes. Also present is the erect, articulated bryozoan *Microporina articulata* (4,430 feet), a species that also occurs in littoral to neritic, moderate- to strong-current environments in Recent sediments on Albatross Bank (Cuffey and Turner, 1987).

Paleodepths for the early Pliocene were middle to outer neritic, deepening to outer neritic to upper bathyal conditions from 4,250 to 4,805 feet (fig. 64).

Early to Middle Miocene

Changes in well log characteristics at 4,805 feet (SP, resistivity, and dipmeter curves) and the presence of glauconitic sand at 4,820 feet are used to define the top of the Poul Creek Formation (see chapter 5). An early to middle Miocene age (Saucesian to Relizian, possibly Luisian, fig. 55) for the interval from 4,805 to 5,360 feet is suggested by the presence of the benthic foraminifera *Siphogenerina* sp. cf. *S. branneri* at 4,910 feet. There is also an occurrence of *Siphogenerina* sp. cf. *S. branneri*? in a late early to early middle Miocene section on Kayak Island (R. S. Boettcher, personal commun., 1991; see also the discussion of the middle Miocene section in the OCS Y-0080 No. 1 well, this chapter). *Sphaeroidina bulloides* is present at 4,820 feet.

Paleodepths in this interval were probably upper to middle bathyal (fig. 64) based on a foraminiferal fauna that includes *Gyroidina soldanii, Melonis pompilioides, Pullenia salisburyi, Siphogenerina* sp. cf. *S. branneri, Sphaeroidina bulloides, Uvigerina* sp. cf. *U. peregrina*, and several arenaceous taxa including *Cyclammina cancellata, Cyclammina* sp. cf. *C. pacifica, Haplophragmoides* spp., *Karreriella* sp. cf. *K. baccata, Martinottiella communis*, and *Psammosphaera* sp.

Oligocene

The interval from 5,360 to 7,250 feet is Oligocene in age. The section is divided into late Oligocene from 5,360 to 6,800 feet and early Oligocene from 6,800 to 7,250 feet.

Late Oligocene

The interval from 5,360 to 6,800 feet is late Oligocene (late Zemorrian, fig. 55). The top of the interval is in part based on the lowest occurrence of Miocene microfauna and microflora, including pollen of the group Compositae at 5,180 feet and the foraminifera *Siphogenerina* sp. cf. *S. branneri* at 5,276 feet. The top of the Oligocene section coincides with a transition to middle to lower bathyal paleodepths (fig. 64). This depth (5,360 feet) also marks the highest occurrence of the planktonic foraminifera *Globigerina* sp. cf. *G. euapertura*, a species that is characteristic of the Oligocene, but also ranges into the early Miocene (Bolli and Saunders, 1985). Additional planktonic foraminifera include the long-ranging species *Globigerina praebulloides* and *Globigerina* sp. cf. *G. venezuelana*.

Isolated specimens of the calcareous nannofossil *Reticulofenestra hillae* occur at 5,630 feet. This species is generally considered to be early Oligocene, and may be reworked.

Benthic foraminifera in the section include *Adercotryma* sp., *Anomalina glabrata, Buccella mansfieldi oregonensis, Buccella* sp. cf. *B. parkerae, Bulimina ovata, Cassidulina* sp. cf. *C. crassipunctata, C. galvinensis, Cassidulina* sp. cf. *C. modeloensis, Cibicides* sp. aff. *C. elmaensis, C. floridanus, C. mckannai, Cibicides* sp. cf. *C. perlucida, Cribroelphidium* sp. cf. *C. vulgare, Cyclammina cancellata, C. pacifica, Elphidiella* sp. cf. *E. californica, Globobulimina pacifica, Glomospirella* sp., *Gyroidina* sp. cf. *G. condoni, Gyroidina orbicularis planata, G. soldanii, Haplophragmoides obliquecamerata, H. trullissata, Melonis pompilioides, Oridorsalis* sp. cf. *O. umbonatus, Quinqueloculina* sp. cf. *Q. imperialis*, and *Quinqueloculina* sp. cf. *Q. weaveri.*

Other faunal elements present include echinoid spines and fragments, teleost fish tooth fragments, ostracodes, and cenosphaerid radiolaria.

Paleodepths for the late Oligocene were probably middle to lower bathyal (fig. 64).

Early Oligocene

The section from 6,800 to 7,250 feet is early Oligocene (early Zemorrian), with the top of the interval being placed at the highest occurrence of the dinocyst species *Spiniferites* sp. cf. *S. membranaceous*. The Oligocene calcareous nannofossil *Dictyococcites bisectus* is present at 6,800 feet.

Planktonic foraminifera present include *Globigerina* sp. and *Globigerina* sp. cf. *G. bulloides*. The benthic foraminifera assemblage is similar to that in the section above, with the addition of *Ellipsonodosaria* sp., *Guttulina* sp., *Lenticulina* sp., *Marginulina*? sp., *Pseudoglandulina* sp. cf. *P. laevigata*, *Sphaeroidina variabilis*, *Trochammina* sp. cf. *T. globigeriniformis*, *Uvigerina* sp. cf. *U. subperegrina*, and *Valvulineria* sp.

Spongodiscid and cenosphaerid radiolaria and pyritized diatoms are also present.

Paleodepths were probably middle to lower bathyal (fig. 64).

Late Eocene to Early Oligocene

The interval from 7,250 to 8,270 feet is late Refugian in age (probable latest Eocene to earliest Oligocene, fig. 55). The top of the interval is based on the highest occurrence of the benthic foraminifera *Epistomina eocenica*. Other benthic foraminifera such as *Uvigerina cocoaensis* (7,880 feet) and *U. atwilli* and *Uvigerina* sp. cf. *U. jacksonensis* (8,150 feet) support a Refugian age. *Alabamina* sp. cf. *A. wilcoxensis* occurs at 7,700 feet.

Calcareous nannofossils, including *Dictyococcites bisectus* (late middle Eocene to early late Oligocene) below 7,250 feet and *Discolithina vigintiforata* below 7,550 feet, are relatively common. Consistent populations of *Cyclococcolithus neogammation* (equivalent to *Cyclicargolithus floridanus*, late Eocene to middle Miocene) occur below 7,640 feet. The late Eocene to early Oligocene species *Reticulofenestra hillae* is present at 7,730 and 7,910 feet. Also present at 7,910 feet are *Chiasmolithus oamaruensis* (late Eocene to early Oligocene), *Zygrhablithus bijugatus* (late Eocene to late Oligocene), and common *Dictyococcites scrippsae* (middle Eocene to late Oligocene). A worn fragment of *Polycladolithus operosus* (early to late Eocene) at 7,910 feet may be reworked.

Populations of the dinoflagellate *Cordosphaeridium microtriainum*, an Eocene to Oligocene species, are consistently present at 7,160 feet and below. There is a single occurrence of *Areosphaeridium diktyoplokus*, a predominantly Eocene species that ranges into the early Oligocene, at 7,550 feet. A solitary specimen of the Paleocene to middle Eocene palynomorph *Pistillipollenites mcgregori* at 7,640 feet is probably reworked.

Additional benthic foraminifera present include *Alabamina* sp. cf. *A. kernensis*, *Ammodiscus* sp., *Bathysiphon* sp., *Cassidulina* sp. cf. *C. galvinensis*, *Cyclammina* spp., *Eggerella* sp., *Ellipsonodosaria* sp. cf. *E. cocoaensis*, *Eponides* sp. cf. *E. frizzelli*, *E. gaviotaensis*, *Guttulina* sp. cf. *G. hantkeni*, *Gyroidina orbicularis*, *Karreriella* sp., *Lagena* sp., *Lagena* sp. cf. *L. costata*, *Lenticulina* sp. cf. *L. inornata*, *Lenticulina* sp. cf. *L. weaveri*, *Martinottiella*? sp. (fragment), *Orthomorphina*? sp., *Plectofrondicularia*? sp., *Rhabdammina* sp. cf. *R. eocenica*, *Uvigerina* sp. cf. *U. yazooensis*, and *Valvulineria* sp. cf. *V. tumeyensis*. Also present are *Cyclammina pacifica*, *Haplophragmoides* spp., and *Melonis pompilioides*. Planktonic foraminifera present include *Globigerina* sp. aff. *G. bulloides*.

Paleodepths were middle to lower bathyal from 7,250 to 7,340 feet. From 7,340 to 8,270 feet, paleodepths were upper to middle bathyal (fig. 64).

Eocene

The section from 8,270 to 17,810 feet (TD) is Eocene in age, and includes strata assignable to the Poul Creek and Kulthieth Formations, the Oily Lake siltstone, and, possibly, the Hubbs Creek basalt. The section is late Eocene from 8,270 to 11,750 feet, middle Eocene from 11,750 to 16,430 feet, and early to middle Eocene from 16,430 to 17,810 feet (TD).

Late Eocene

The section from 8,270 to 11,750 feet is late Eocene (Refugian, fig. 55) in age based on dinoflagellates and benthic and planktonic foraminifera.

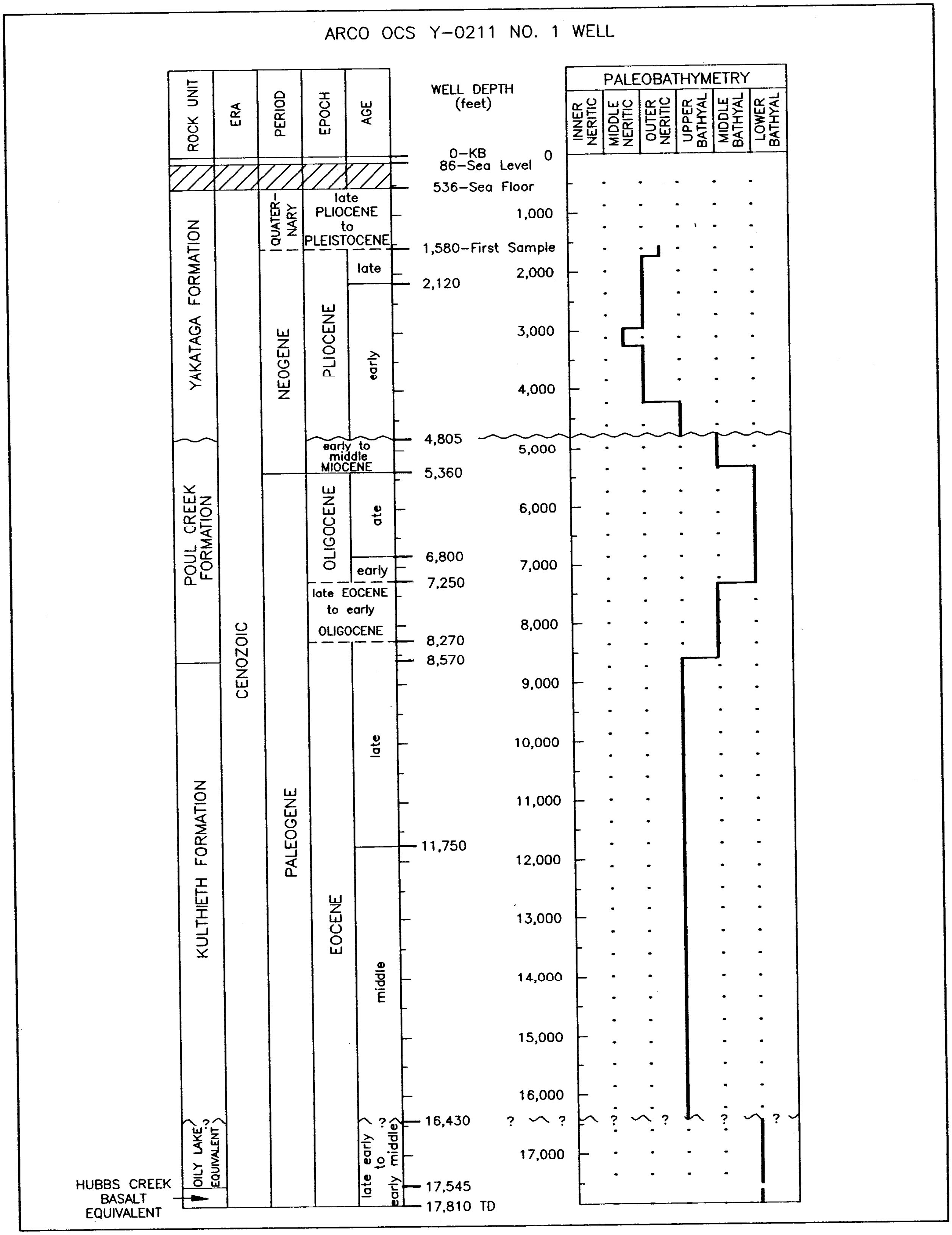


Figure 64. Biostratigraphy and paleodepth curve for the ARCO OCS Y-0211 No. 1 well. All depths are measured from the kelly bushing (KB), 86 feet above mean sea level. The well location is shown in figure 66.

Late Eocene–Poul Creek Formation

The upper part of the late Eocene section from 8,270 to 8,570 feet consists of Poul Creek Formation sediments. The top of the interval is marked by the highest occurrence of several late Eocene dinoflagellate species, including *Adnatosphaeridium patulum* at 8,270 feet and *Cordosphaeridium funiculatum* and *Impletosphaeridium implicatum* at 8,360 feet. A late Eocene age is also supported by the presence of several specimens of the planktonic foraminifera *Globorotalia insolita* (late Eocene; Jenkins, 1971) at 8,420 feet, and by the benthic foraminifera *Uvigerina* sp. cf. *U. vicksburgensis* at 8,510 feet. Other planktonic foraminifera present in the Poul Creek Formation section from 8,270 to 8,570 feet include *Globigerina* sp. cf. *G. eocaena* (late early Eocene to early Oligocene).

Additional benthic foraminifera present include *Biloculina* sp., *Lenticulina weaveri*, *Melonis* sp. aff. *M. umbonatus*, *Pseudoglandulina* sp., and *Valvulineria* sp.

Paleodepths in the late Eocene part of the Poul Creek Formation section were upper to middle bathyal (fig. 64).

Late Eocene - Kulthieth Formation

The late Eocene section continues from 8,570 to 11,750 feet. At 8,570 feet, well log data (SP, gamma ray, and sonic logs) indicate a change to sandier lithologies defining the top of the Kulthieth Formation (see chapter 5 and plate 6). Below 8,600 feet, the sand fraction increases in cuttings samples and coal fragments are frequent.

The foraminifera assemblage consists almost entirely of benthic species. It is similar to that of the overlying interval, but becomes sparse below 8,690 feet. Several of the species support a Refugian age, including *Uvigerina vicksburgensis* (8,690 feet), *Uvigerina* sp. cf. *U. gardneri* (8,960 feet), *Bulimina corrugata* (9,770 feet), *Epistomina* sp. cf. *E. eocenica* and *Osangularia tenuicarinata* (10,940 feet), and *Epistomina* sp. cf. *E. ramonensis* (10,850 feet). Other species include *Ammodiscus incertus*, *Ammodiscus* sp. cf. *A. macilentus*, *Bathysiphon* sp., *Bulimina* sp. cf. *B. ovata*, *Bulimina* sp. cf. *B. pupoides*, *Cibicides elmaensis*, *C. perlucidus*, *Cyclammina* sp. cf. *C. cancellata*, *C. pacifica*, *Discammina*? sp., *Eponides* sp., *Globobulimina pacifica*, *Gyroidina* sp., *Karreriella*? sp., *Lenticulina* spp., *L. alato-limbata*, *L. convergens*, *L. inornata*, *Plectofrondicularia* sp., *Quinqueloculina imperialis*, *Saracenaria* sp., *Spiroloculina texana*, *Spiroplectammina*? sp., *Textularia* sp., *Trochamminoides* sp., *Uvigerina atwilli*, *U. cocoaensis*, *Vaginulina* sp., and *Vaginulinopsis* sp. cf. *V. saundersi*. Planktonic foraminifera present include *Globigerina* sp. (crushed).

Rau and others (1983) refer to a similar Refugian foraminifera assemblage from the Gulf of Alaska onshore section as indicating "cold, deep-water conditions." However, they also maintain that the presence of species such as *Quinqueloculina imperialis* may indicate shallower depth. Furthermore, Robinson (1970) suggested that the bathymetric range of the *Cyclammina* may have extended into shallower depths in the Eocene. These observations, taken together with the sandy, more terrigenous sediments in which the foraminifera assemblage occurs, suggest outer neritic to upper bathyal paleodepths in the late Eocene part of the Kulthieth Formation (fig. 64).

Middle Eocene

The section from 11,750 to 16,430 feet also consists of Kulthieth Formation lithologies (see chapter 5). It is middle Eocene in age (Narizian, fig. 55) on the basis of the highest occurrences of the benthic foraminifera *Lenticulina chirana* at 11,750 feet and *Lenticulina* sp. cf. *L. welchi* at 11,930 feet. This age is also supported by the planktonic species *Globigerina tripartita* at 13,640 feet, and "*Turborotalia*" sp. cf. *T. wilsoni* (Toumarkine and Luterbacher, 1985, fig. 27.1, middle Eocene occurrence) and *Globigerina eocaena* at 14,270 feet. A Narizian age is also indicated by other elements of the benthic foraminifera assemblage, including *Budashaevella* sp. cf. *B. multicostata*, *Eponides mexicanus*, *Plectofrondicularia* sp. cf. *P. jenkensi*, and *Uvigerina* sp. cf. *U. garzaensis* at 12,110 feet; *Boldia hodgei* at 12,200 feet; *Bulimina* sp. cf. *B. microcostata* at 12,830 feet; *Chilostomella* sp. cf. *C. cylindroides* at 12,920 feet; *Uvigerinella* sp. cf. *U. obesa impolita* at 13,010 feet; *Lenticulina insueta* at 13,550 feet; *Pleurostomella* sp. cf. *P. paleocenica* at 14,000 feet; *Dorothia* sp. cf. *D. bulletta* at 14,360 feet; *Bolivina* sp. cf. *B. scabrata* at 14,540 feet; *Reticulophragmium* (*Alveolophragmium*) sp. cf. *R. amplectens* at 15,890 feet; *Bulimina* sp. cf. *B. instabilis*, *Cibicides* sp. cf. *C. fortunatus*, and *Tritaxilina* sp. aff. *T. zealandica* at 16,250 feet; and *Bulimina* sp. cf. *B. ampla*, *Bulimina* sp. cf. *B. corrugata*, *Bulimina* sp. cf. *B. lirata*, *Bulimina* sp. cf. *B. pyrula*, and *Polymorphina* sp. cf. *P. ovata* at 16,340 feet.

Other benthic species present include *Allomorphina* sp. cf. *A. macrostoma, Bulimina ovata, Cassidulina* sp. aff. *C. globosa, Ceratobulimina* sp. cf. *C. washburni, Chilostomella ovoides, Cibicides* sp. aff. *C. spiropunctatus, Cribrostomoides* sp., *Cyclammina* sp. cf. *C. clarki, Cyclammina* sp. cf. *C. simiensis, Globobulimina pacifica, G. pacifica oregonensis, Glomospira*? sp., *Haplophragmoides* sp., *Lenticulina* sp. cf. *L. inornata, Lenticulina* sp. aff. *L. vortex, Martinottiella*? sp., *Reophax* sp., *Sigmoilina* sp., *Spiroplectammina* sp., *Textularia* sp., *Trochammina* sp., *Uvigerina* sp., *Uvigerina* sp. cf. *U. churchi, Uvigerina* sp. cf. *U. yazooensis, Valvulineria* sp., *Valvulineria* sp. cf. *V. tumeyensis*, and *Virgulina* sp.

The spore *Pesavis tagluensis* occurs at 12,050 feet, supporting a middle Eocene age. Dinoflagellates present at 12,330 feet include *Wilsonidinium intermedium*, which ranges from early to middle Eocene, and abundant specimens of *Areosphaeridium diktyoplokus*.

Paleodepths throughout the middle Eocene interval were outer neritic to upper bathyal (fig. 64).

Late Early to Early Middle Eocene

The section from 16,430 to 17,810 feet (TD) is late early Eocene to early middle Eocene (Ulatizian, fig. 55) based on benthic and planktonic foraminifera. A change in lithology accompanied by a relatively large change in paleobathymetry from outer neritic/upper bathyal to middle to lower bathyal at the top of this interval suggests an unconformity (fig. 64). The section from the possible unconformity at 16,430 feet to 17,545 feet consists of dark-gray siltstone. Plafker (1987) described a dark-gray "Siltstone of Oily Lake" sequence (referred to as the Oily Lake siltstone in this study) of probable Ulatizian age that outcrops onshore in the Samovar Hills area, where it is separated from the overlying Kulthieth Formation by an apparent unconformity. Well log characteristics (SP, density, and sonic logs), lithology, stratigraphic position, age, and the possible unconformity at the top of the siltstone interval in the well suggest that it is probably equivalent to the Oily Lake siltstone sequence onshore (see chapter 5).

This interval is no younger than late early Eocene to early middle Eocene on the basis of the highest appearance of the benthic foraminifera *Vaginulinopsis mexicana vacavillensis* at 16,430 feet, *V. mexicana kerni* at 16,520 feet, and *V. verruculosa* at 16,610 feet. This age is supported by the presence of the planktonic foraminifera *Acarinina primitiva* (late Paleocene to middle Eocene) at 16,520 feet, and by the occurrence of *Acarinina bulbrooki* and *Turborotalia griffinae* (no younger than early middle Eocene) at 16,610 feet. Also at 16,610 feet are the middle Eocene species *Acarinina broedermani, Globigerina* sp. cf. *G. inaequispira, Planorotalites pseudoscitula*, and *Turborotalia cerroazulensis. Morozovella* sp. cf. *M. aragonensis* at 16,700 feet suggests an early to early middle Eocene age. Also present at 16,700 feet are *Globigerina* sp. cf. *G. boweri, Globigerina* sp. cf. *G. cryptomphala, Truncorotaloides topilensis*, and *Turborotalia cerroazulensis frontosa. Acarinina* sp. cf. *A. spinuloinflata* occurs at 16,790 feet, while *Acarinina* sp. cf. *A. pentacamerata* (no younger than early middle Eocene) and *Globigerina hagni* appear at 17,330 feet.

Other benthic foraminifera in the interval include *Alveolophragmium* sp., *Amphimorphina* sp. aff. *A. californica, Anomalina* sp. aff. *A. packardi, Anomalina* sp. aff. *A. tennesseensis, Anomalina*? sp. cf. *A. umbonata, Bulimina* sp. cf. *B. guayabilensis, Bulimina* sp. cf. *B. macilenta, Cibicides* sp. cf. *C. howelli, Cibicides pseudoungerianus lisbonensis, Cibicides* (*Cibicidoides*) sp. cf. *C. subspiratus, Cibicides* (*Cibicidoides*) sp. cf. *C. tuxpamensis, Cibicides* sp. cf. *C. venezuelensis, Clavulinoides californicus, Cyclammina clarki, C. incisa, Cyclammina* sp. cf. *C. pacifica, Cyclammina samanica, Dentalina* sp. cf. *D. catenula, Dentalina delicatula, Dentalina* sp. cf. *D. jacksonensis, Dentalina* sp. cf. *D. oolinata, Dorothia* sp. cf. *D. oxycona, Dorothia* sp. cf. *D. trochoides, Eggerella* sp., *Ellipsoglandulina* sp. cf. *E. subobesa, Eponides* sp. aff. *E. dorfi, Eponides* sp. cf. *E. ellisorae, Gaudryina* sp. cf. *G. laevigata, Gaudryina* sp. cf. *G. pyramidata, Gavelinella*? sp., *Gonatosphaera*? sp., *Gonatosphaera eocenica, Gyroidina* sp. aff. *G. florealis, Gyroidina orbicularis, Karreriella* sp., *Lagena* sp. cf. *L. vulgaris, Lenticulina* sp. cf. *L. coaledensis, Lenticulina alato-limbata, Lenticulina arcuato-striata, Lenticulina* sp. cf. *L. insueta, Lenticulina* sp. cf. *L. limbosa, Lenticulina* sp. cf. *L. pseudocultrata, Lenticulina* sp. cf. *L. pseudovortex, Lenticulina* sp. cf. *L. theta, Nodosarella constricta, Nodosaria deliciae, Nodosaria* sp. aff. *N. latejugata, Nonion*? sp. cf. *N. micrum, Oridorsalis umbonatus, Osangularia* sp. cf. *O. culter, Osangularia* sp. cf. *O. tenuicarinata, Ramulifera* sp. cf. *R. globulifera, Rotorbinella collicula, Tritaxilina* sp., *Uvigerina* sp. cf. *U. rippensis, Vaginulinopsis* sp. cf. *V. asperuliformis, Vaginulinopsis mexicana nudicostata, Valvulineria* sp. aff. *V. cooperensis, Valvulineria* sp. cf. *V. peruviana*, and *Vulvulina* sp.

Ostracodes are present at 17,330 feet.

Paleodepths from 16,430 to 17,545 feet were probably middle to lower bathyal (fig. 64).

Foraminifera are quite rare from 17,545 feet to 17,810 feet (TD), where basaltic rock fragments dominate the sample lithologies in a section that may be equivalent to the Hubbs Creek basalt (see chapter 5 and plate 6). Rare planktonic foraminifera recovered from the sample at 17,600 feet include *Acarinina* sp. cf. *A. pentacamerata* and *Pseudohastigerina wilcoxensis*. If these specimens are in place, an age of no younger than early middle Eocene is indicated.

No age-diagnostic microfossils were recovered below 17,600 feet. The section is dominantly basaltic down to the interval from 17,799.5 to 17,805 feet, where conventional core 6 (appendix F-6) recovered dark-gray shales with minor amounts of brown siltstone and fine-grained quartz sandstone. No age was determined for these lowermost samples, but presumably they are early middle Eocene or older. The few benthic foraminifera found from 17,600 to 17,810 feet (TD) appear to be part of the same assemblage found in the overlying interval, indicating similar deep-water conditions (fig. 64).

Although planktonic foraminifera were useful in the biostratigraphic zonation of the Paleogene section of the Tenneco Middleton Island State No. 1 well also, there was little basis for comparison with the Paleogene planktonic foraminifera fauna in the OCS Y-0211 No. 1 well (see the discussion of the Tenneco Middleton Island State No. 1 well, this chapter).

Correlation and summary

Correlation

Seven of the 13 wells drilled in the offshore Gulf of Alaska Planning Area (fig. 68), including the Middleton Island State No. 1 well and the OCS Y-0080 No. 1, OCS Y-0011 No. 1, OCS Y-0014 No. 1 and 2, OCS Y-0007 No. 1, OCS Y-0032 No. 1, and OCS Y-0211 No. 1 wells (fig. 66, table 3, and plate 5), bottomed in Miocene or older sediments. The other six wells did not penetrate deeper than the Plio-Pleistocene section of the glaciomarine Yakataga Formation. The seven wells that penetrated at least into the Miocene section were selected for examination in this study. Figure 65 shows the locations and biostratigraphic correlation of these wells.

Although a biostratigraphic correlation can be made between the pre-Yakataga Formation section of the Middleton Island State No. 1 well and the section to the east (see the corresponding interval in the OCS Y-0211 No. 1 well), there is probably little lithologic correlation. In addition to the distance between the two locations (fig. 65 and plate 5), a terrane boundary—a structurally complex feature called the Kayak zone—parallels Kayak Island and continues to the southwest (fig. 25 and plate 5), separating the pre-Yakataga Formation section of the Prince William terrane on the west (including the Middleton shelf and Kodiak shelf areas) from the Yakutat terrane to the east (figs. 3 and 25, plate 5). The convergence of the two terranes took place approximately during the middle(?) Miocene (see chapter 2); therefore only middle(?) to late Miocene and younger deposits, which include the Yakataga Formation, appear likely to be very closely related across the terrane boundary. Nevertheless, the pre-Yakataga stratigraphic sections of the Middleton Island State No. 1 well and the OCS Y-0211 No. 1 well at the opposite ends of the cross-section shown in fig. 65 show a generally similar sequence of depositional events, with comparable Oligocene, late Eocene to early Oligocene, and late Eocene sequences. The planktonic foraminifera faunas in the pre-Miocene sequences of these two wells were not directly comparable because none of the intervals containing relatively abundant or diverse planktonic foraminifera were age-equivalent between the two wells.

The Yakataga Formation in the Middleton Island State No. 1 well is considerably thinner (2,065 feet) than it is to the east, due principally to tectonic uplift and disturbance of the Middleton shelf segment of the Prince William terrane during Neogene and Quaternary times. The distance from major glacial sediment sources onshore may also have been a factor, although the presence of striated cobbles in the Yakataga Formation section on Middleton Island (Eyles, 1988) suggests that glaciers may have extended a considerable distance offshore and/or that grounded ice shelves fed by the glaciers have considerably influenced sea bottom morphology and sedimentation in the area (Eyles and Lagoe, 1990).

East of Kayak Island (figs. 65 and 66, plates 5 and 6), the Yakataga Formation is considerably thicker, exceeding 8,400 feet at the OCS Y-0080 No. 1 well and reaching 13,500 feet in thickness at the OCS Y-0032 No. 1 well (fig. 65). It thins to 4,805 feet at the OCS Y-0211 No. 1 well, where Neogene basin development seems to have been less and where Quaternary shelf

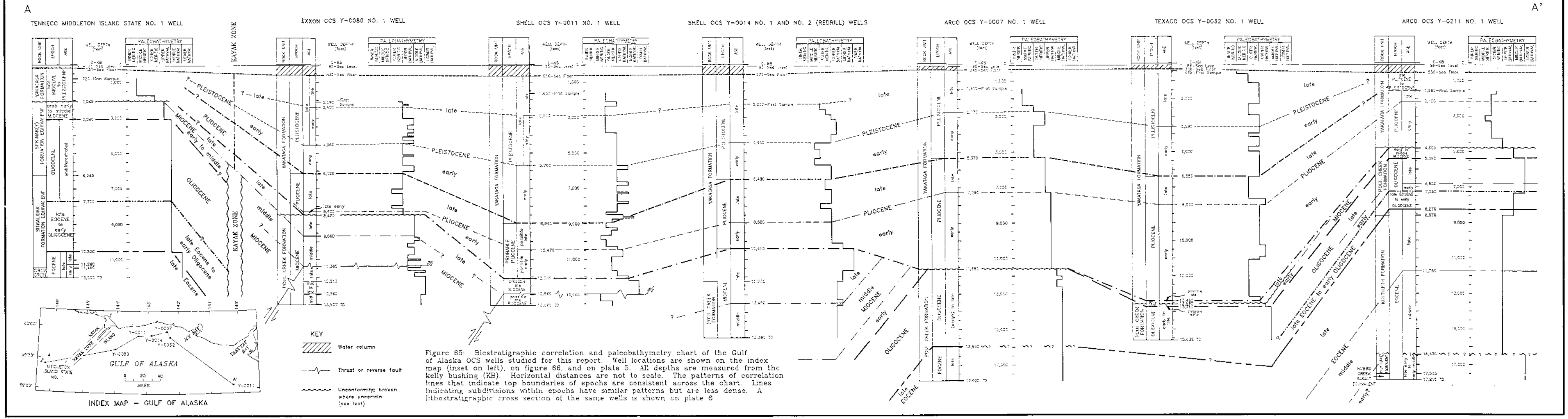


Figure 65: Biostratigraphic correlation and paleobathymetry chart of the Gulf of Alaska OCS wells studied for this report. Well locations are shown on the index map (inset on left), on figure 66, and on plate 5. All depths are measured from the kelly bushing (KB). Horizontal distances are not to scale. The patterns of correlation lines that indicate top boundaries of epochs are consistent across the chart. Lines indicating subdivisions within epochs have similar patterns but are less dense. A lithostratigraphic cross section of the same wells is shown on plate 6.

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edge uplift resulted in the truncation of an appreciable portion of the Pleistocene section.

Within the Yakataga Formation, biostratigraphic correlation shows that the Pleistocene section is thin or missing in the east at the OCS Y-0211 No. 1 well (fig. 65). It thickens west of this in the OCS Y-0032 No. 1 well, and thins slightly in a shoreward direction at the OCS Y-0007 No. 1 well. It is thickest in the west central portion of the area in the OCS Y-0014 No. 1 and 2 well, and especially in the OCS Y-0011 No. 1 well. The Pleistocene section thins somewhat in the OCS Y-0080 No. 1 well at the west end of the Yakutat terrane (figs. 3 and 65, plates 5 and 6). It is thin to absent in the Middleton Island State No. 1 well on the Prince William terrane.

The late Pliocene section is relatively uniform in thickness from the OCS Y-0080 No. 1 well to the OCS Y-0032 No. 1 well, and may be of similar thickness at the OCS Y-0211 No. 1 well. In contrast to the Pleistocene section, the early Pliocene section shows considerable thinning from east to west (fig. 65), especially between the OCS Y-0007 No. 1 and OCS Y-0014 No. 1 and 2 wells and between the OCS Y-0011 No. 1 and OCS Y-0080 No. 1 wells. The westward thinning of the early Pliocene section followed by at least local westward thickening of the Pleistocene section may have resulted from an eastward shifting of tectonic compression and uplift activity between Kayak Island and Icy Bay from early Pliocene to early Pleistocene times, accompanied by a westward shifting of Yakataga Formation depocenter development.

The Miocene section is quite thin in the eastern part of the area. An unconformity marks the removal and/or nondeposition of the middle Miocene section in the OCS Y-0032 No. 1 well. The Miocene section appears to have been removed altogether in the OCS Y-0007 No. 1 well. Unconformities also indicate the erosion of the late Miocene section in the OCS Y-0211 No. 1 well, and possibly in the Middleton Island State No. 1 well in the west (fig. 65). There is also an unconformity present at the top of the Miocene section in the OCS Y-0080 No. 1 well that appears to have removed more of the early Pliocene than the late Miocene. In contrast, no Miocene unconformity was discerned in the OCS Y-0011 No. 1 or OCS Y-0014 No. 1 and 2 wells, where an uninterrupted Miocene section may be present. From zero thickness in the OCS Y-0007 No. 1 well, the Miocene section thickens considerably to the south and west in the OCS Y-0014 No. 1 and 2 well. The thickness of the Miocene section is uncertain in the OCS Y-0080 No. 1 and the OCS Y-0011 No. 1 wells because it is faulted and possibly steeply dipping, but it was probably several hundred feet thick and may have been a few thousand feet thick. The western half of this area may have been a Miocene depocenter that subsequently shifted eastward in the early Pliocene and westward again in the Pleistocene.

The middle Miocene intervals of the OCS Y-0080 No. 1 and OCS Y-0014 No. 1 and 2 well (fig. 65) are the first definite middle Miocene sections described in the area. The presence of apparently uninterrupted middle and late Miocene and early Pliocene sections in some of the Gulf of Alaska offshore wells suggests that the widespread middle Miocene erosional episode (unconformity) indicated by Plafker and others (1975) and Plafker (1987), and/or the early to middle Miocene hiatus described in the Yakataga Reef section (Lagoe, 1983), are not uniformly present throughout the Gulf of Alaska OCS area.

Oligocene strata were encountered in the OCS Y-0007 No. 1, OCS Y-0032 No. 1, OCS Y-0211 No. 1, and Middleton Island State No. 1 wells, where erosion and/or nondeposition produced a thin or missing Miocene section and resulted in a shallower Paleogene section that could be reached by drilling. None of the other OCS wells was drilled deeply enough to penetrate Paleogene section.

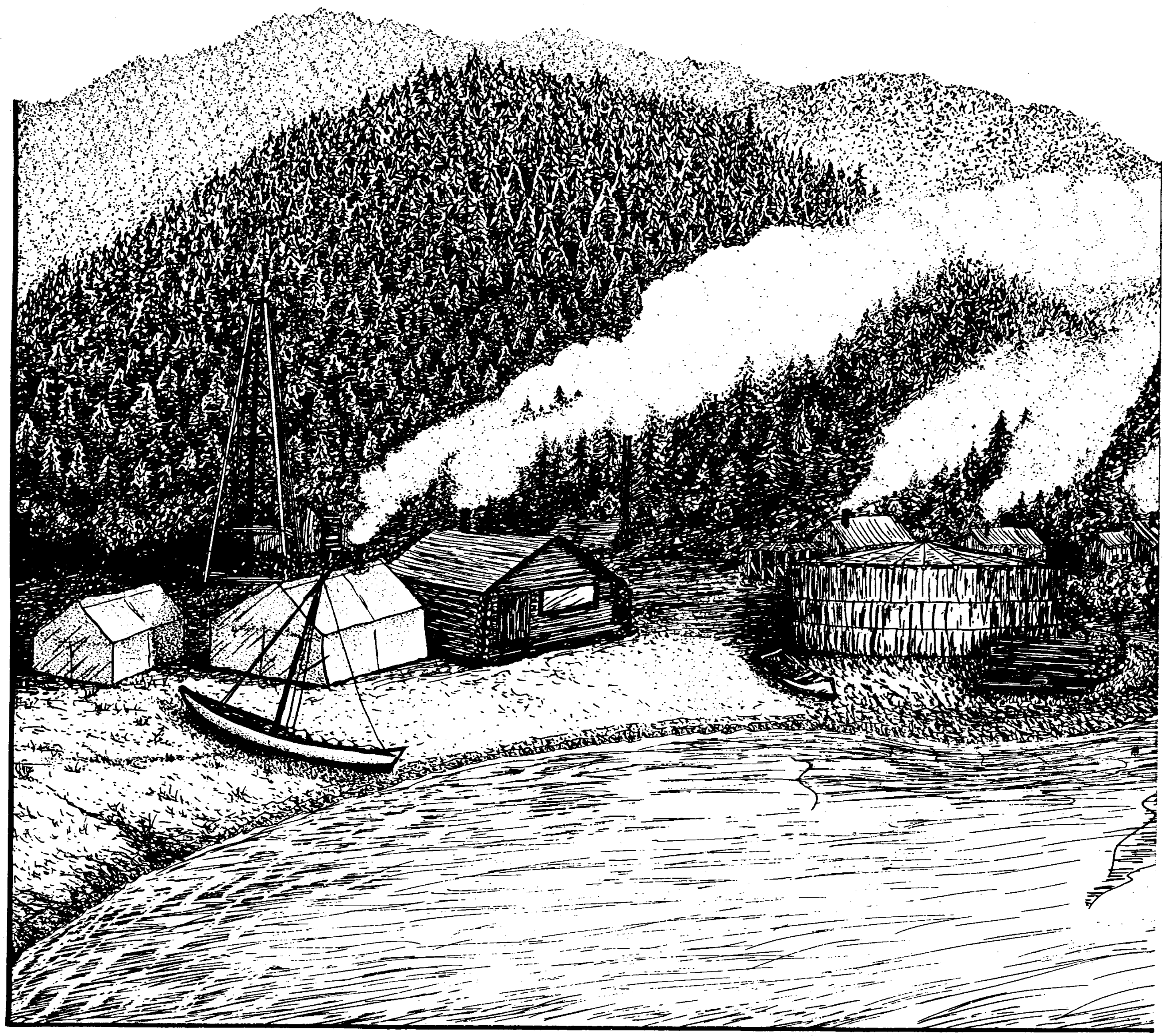
The OCS Y-0211 No. 1 well sampled the most complete Eocene section encountered in the Gulf of Alaska offshore (fig. 65). The section there comprises late, middle, and early to middle Eocene intervals. Eocene rocks are probably present not far below TD at the OCS Y-0032 No. 1 well. Late Eocene strata are present in the bottom of the OCS Y-0007 No. 1 well and also occur farther west in the bottom of the Middleton Island State No. 1 well.

Additonal Observations

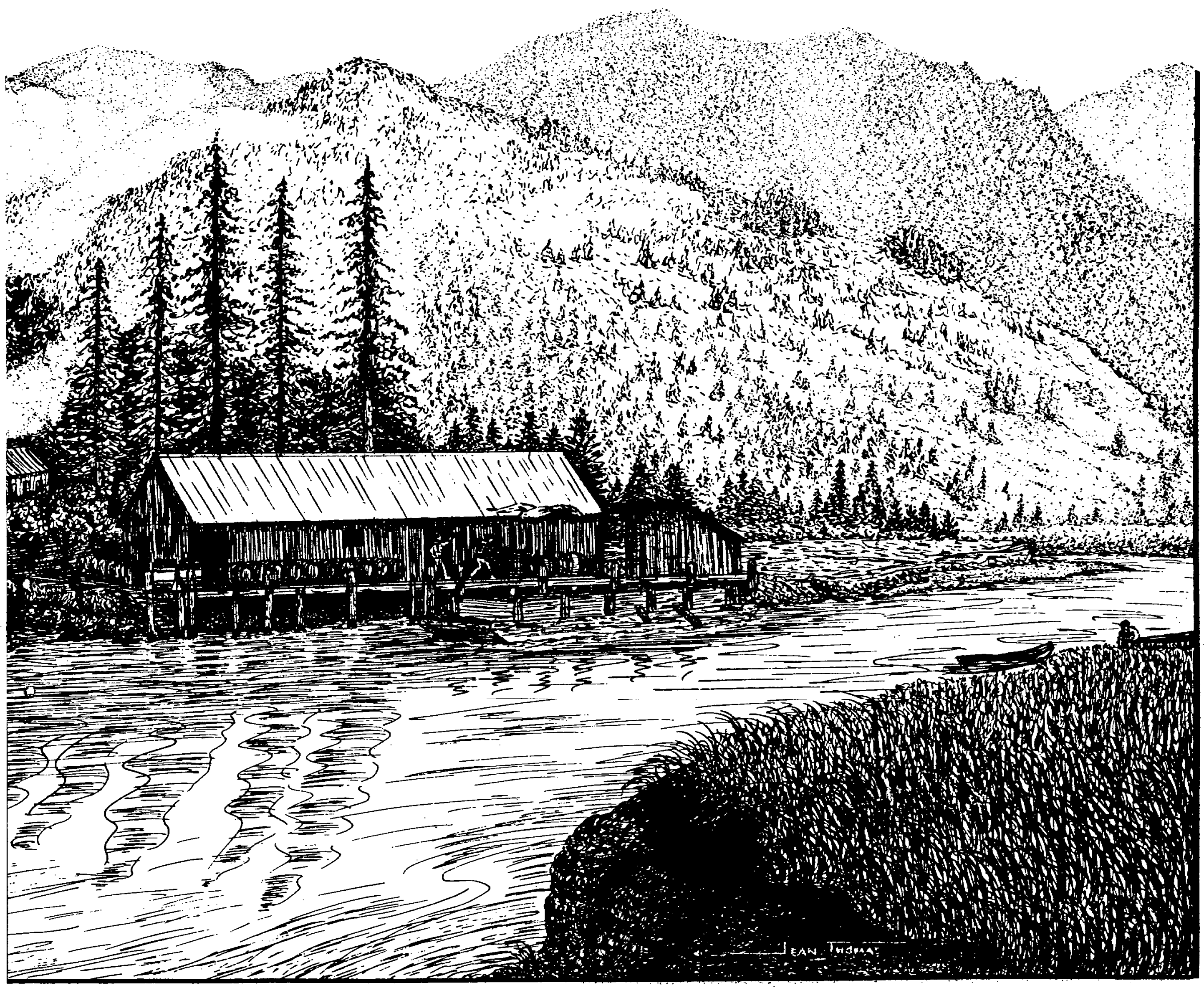
The indicated paleodepths of some of the intervals within the Yakataga Formation seem to be deeper or shallower during times when opposite trends are indicated on eustatic sea level curves. This trend was also noted onshore in the Pliocene section of the Yakataga Formation by Zellers (1989, 1990), who postulated a possible regional trend. However, these contra-eustatic trends do not appear to occur consistently within any given offshore well, nor do they appear to occur contemporaneously between wells. The well sections exhibiting contra-eustatic paleodepth curves may have been influenced by local tectonism and/or isostatic-crustal rebound resulting from local deglaciation (see the discussion of the early Pleistocene section of the OCS Y-0014 No. 1 and 2 well, this chapter).

A 60-foot section of dark-brown siltstone in the late Miocene section of the OCS Y-0080 No. 1 well contained an impoverished microfauna consisting mostly of arenaceous foraminifera, sponge spicules, fish bone fragments, and small shark teeth. It also had some of the most favorable source rock potential measured in the offshore wells (see discussion of the late Miocene section of the OCS Y-0080 No. 1 well). The characteristics of this interval suggest the possibility of a relatively organic-rich, silled Miocene basin similar to the one postulated by Armentrout (1983a).

Part II: Petroleum Geology



Katalla Oil Field at Katalla Slough, Gulf of Alaska. The log cabin, tents, derrick, and sailboat (left page) are from the earliest period of development; the oil storage tank and barge are from a later period. The Katalla field produced from 1901 to 1932 (see inside front cover for additional information).



7. Regional Petroleum Exploration History

Coastal Plain

Petroleum exploration in the Gulf of Alaska has taken place along the coast, mostly from Controller Bay to Dry Bay (fig. 66). Gold prospectors discovered oil and gas seeps near Katalla on the north side of Controller Bay about 1896 (Martin, 1921). Forty-four wells were drilled in this area between 1901 and 1932. None of these wells exceeded 2,350 feet in depth. Production in the Katalla district, which amounted to approximately 154,000 barrels of oil, ceased in 1933 because of a fire that partially destroyed the refinery.

Twenty-three other wells were drilled along the coastal plain of the Gulf of Alaska between Controller Bay and a point just east of Dry Bay. The General Petroleum Company Sullivan No. 1 well was completed to a depth of 2,005 feet in 1927 about 10 miles west of Icy Bay. The other 22 wells, some with redrills to greater depths, were drilled between 1954 and 1963. Total depths ranged from 3,230 feet in the Colorado Oil and Gas Company Core Hole No. 1 well, to 14,699 feet in the Richfield Oil Corporation Kaliakh River No. 1 well. No producible hydrocarbons were found in any of these wells. Table 1 (next page) lists pertinent data on the Gulf of Alaska onshore wells (fig. 66).

Kodiak Shelf

Six deep stratigraphic test (DST) wells (commonly referred to as COST wells) were drilled on the Kodiak shelf in 1976 and 1977. Their locations, operator, water depths, and completion dates are shown in table 2.

These wells, and the geology of the Kodiak Shelf, are discussed in considerable detail in OCS Report MMS 87-0109, *Geological and Operational Summary, Kodiak Shelf Stratigraphic Test Wells, Alaska* (Turner and others, 1987).

***Opposite.** Setting casing in the Chilcat Oil No. 20 well. The well was drilled using a cable tool rig. The Chilcat Oil Company was the last to commercially operate in the Katalla field, selling most of the oil produced locally as fuel for fishing boats.*

Deep Sea Drilling Project

In July of 1971, the Deep Sea Drilling Project (DSDP) of the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES) drilled 5 core holes in the slope and abyssal plain of the Gulf of Alaska from the drill ship *Glomar Challenger*. Penetration depths beneath the seafloor ranged from 358 to 2,607 feet. Sites 178 through 182, drilled in water depths from 4,705 to 16,152 feet, are discussed in volume XVIII of the *Initial Reports of the Deep Sea Drilling Project* (Kulm and others, 1973) and in OCS Report MMS 89-0097, *Geologic Report for the Shumagin Planning Area, Western Gulf of Alaska* (Horowitz and others, 1989).

Offshore Gulf of Alaska

Thirteen wells have been drilled offshore in the Gulf of Alaska to date (fig. 66). In 1969, the Middleton Island well was drilled by Tenneco Oil Company at lat 59°25' N, long 146°17' W, in State waters about 3 miles east of Middleton Island. No producible hydrocarbons were found.

In 1975, the ARCO Gulf of Alaska COST No. 1 well was drilled to a depth of 5,150 feet in the Lease Sale 39 area southeast of Kayak Island and southwest of Icy Bay (fig. 66). U.S. Geological Survey Open-File Report 76-635 (Bolm and others, 1976) discusses this COST well in some detail. Six exploratory wells were drilled in this area in 1977 and 4 more were drilled 1978. In 1983, one exploratory well was drilled south of Yakutat Bay in the Lease Sale 55 area (fig. 67). No producible hydrocarbons were discovered in any of these exploratory wells. Table 3 lists pertinent data concerning the 13 Gulf of Alaska offshore wells.

Geophysical Exploration

Geophysical exploration in the Gulf of Alaska has produced 116,015 miles of common-depth-point (CDP) data and 10,075 miles of high resolution (HRD) data. The Minerals Management Service Alaska OCS Region has collected 31,099 miles of CDP data and 3,911 miles

Table 1. Wells drilled in the Gulf of Alaska coastal plain.					
Ref. No.	**Well Name**	**Location Copper River Meridian**	**Operator**	**Well Depth (feet)**	**Completion Date**
1	Bering River No. 1	T18 S R7 E Sec 32	Richfield	6,175	Dec 2, 1962
2	Bering River No. 2	T19 S R7 E Sec 22	Richfield	6,019	Jan 20, 1962
3	Kaliakh River No. 1	T20 S R14 E Sec 34	Richfield	14,699	June 6, 1960
4	Kaliakh River No. 2	T20 S R14 E Sec 28	Richfield	9,575	Aug 30, 1960
5	Kaliakh River No. 2 RD	T20 S R14 E Sec 28	Richfield	12,135	Sept 17, 1961
6	Duktoth River No. 1	T20 S R15 E Sec 24	Richfield	10,390	Aug 18, 1961
7	White River No. 1	T21 S R18 E Sec 19	British Petroleum	7,928	Oct 31, 1961
8	White River No. 2	T21 S R19 E Sec 27	British Petroleum	12,417	Oct 31, 1962
9	White River No. 3	T21 S R19 E Sec 20	British Petroleum	6,984	July 10, 1963
10	Sullivan No. 1	T22 S R21 E Sec 7	General Petroleum	2,005	Oct 20, 1927
11	Sullivan No. 1	T22 S R21 E Sec 10	Phillips	10,013	Oct 28, 1955
12	Sullivan No. 2	T22 S R21 E Sec 10	Phillips	12,054	March 21, 1957
13	Sullivan Strat No. 1	T22 S R22 E Sec 19	Phillips	4,837	May 19, 1954
14	Riou Bay No. 1	T23 S R23 E Sec 26	Standard California	14,107	Sept 2, 1962
15	Chaix Hills No. 1	T22 S R25 E Sec 4	Standard California	10,015	Nov 10, 1961
16	Chaix Hills No. 1A	T22 S R25 E Sec 9	Standard California	10,121	March 3, 1962
17	Malaspina Nos. 1 & 1A RD	T24 S R32 E Sec 31	Colorado Oil & Gas	13,823	Oct 21, 1962
18	Yakutat No. 1	T27 S R34 E Sec 33	Colorado Oil & Gas	9,314	May 19, 1957
19	Yakutat No. 2	T28 S R34 E Sec 1	Colorado Oil & Gas	11,765	March 1, 1958
20	Yakutat No. 3	T28 S R34 E Sec 3	Colorado Oil & Gas	10,494	April 23, 1959
21	Core Hole No. 1	T27 S R35 E Sec 17	Colorado Oil & Gas	3,230	June 2, 1961
22	Core Hole No. 2	T29 S R36 E Sec 34	Colorado Oil & Gas	5,690	July 21, 1961
23	Dangerous River No. 1	T29 S R37 E Sec 16	Colorado Oil & Gas	8,634	Nov 19, 1960
24	Core Hole No. 3	T31 S R39 E Sec 6	Colorado Oil & Gas	5,484	Sept 11, 1961
25	Core Hole No. 4	T32 S R41 E Sec 36	Colorado Oil & Gas	5,326	Nov 5, 1961

of HRD data. The petroleum industry has also collected 13,349 flight-line miles of gravity and magnetic data.

Sale History

Three Federal offshore lease sales have been held in the Gulf of Alaska. Sale 39 was held April 13, 1976, and resulted in the leasing of 76 tracts. Sale 55, for the eastern Gulf of Alaska, was held October 21, 1980, and leased 35 tracts. Figure 67 shows the location of OCS lease sale areas 39 and 55. A reoffering sale (RS-1) was held on June 30, 1981, and resulted in the leasing of one tract in the eastern Gulf of Alaska. Figure 68 shows the location of the planned OCS Gulf of Alaska Yakutat Lease Sale 158 area. This sale is scheduled for August 1995.

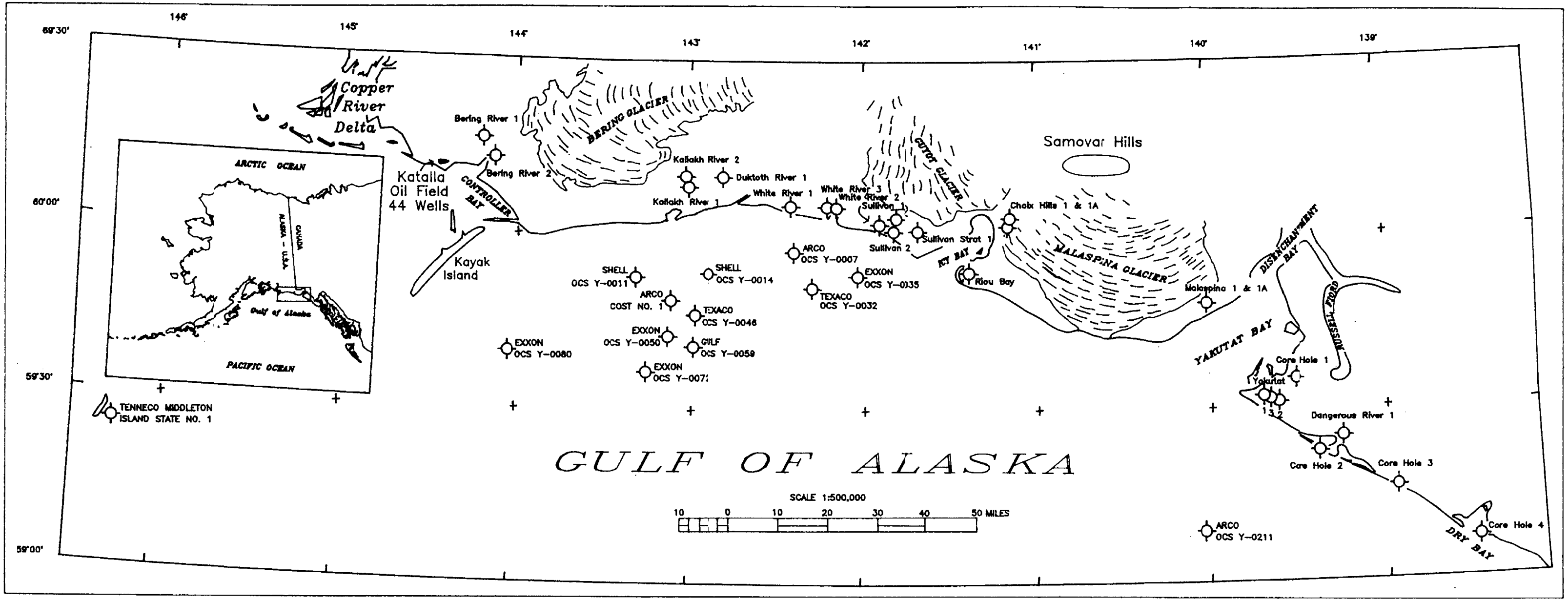


Figure 66. Locations of wells in the Gulf of Alaska and adjacent coastal plain. Tables 1 and 3 give well locations, operator, water depths, total well depths, and completion dates of the wells.

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The State of Alaska Department of Natural Resources, Division of Oil and Gas, is proposing to schedule a lease sale in this area on State land during May 1994. It has been designated as the Cape Yakataga Sale 79 and will offer about 350,000 acres of onshore and offshore land within the 3-mile limit between Katalla and Icy Bay. Figure 69 shows the location of this proposed lease sale.

Table 2. COST wells drilled in the Kodiak Shelf.

Well Name	Location		Operator	Water Depth (feet)	Well Depth (feet)	Completion Date
	N lat	W long				
KSST No. 1	56°24′	152°58′	Exploration Services, Inc.	162	4,225	Aug 1, 1976
KSST No. 2	57°00′	151°45′	Exploration Services, Inc.	237	4,307	Aug 23, 1976
KSST No. 4A	58°12′	150°20′	Exploration Services, Inc.	307	1,391	Sep 19, 1976
KSSD No. 1	57°60′	150°29′	Sun Oil Company	526	8,517	July 17, 1977
KSSD No. 2	58°32′	148°49′	Sun Oil Company	375	10,460	Sep 8, 1977
KSSD No. 3	56°57′	151°56′	Sun Oil Company	265	9,357	Oct 25, 1977

Table 3. Wells drilled in the Gulf of Alaska.

Well Name	Location		Operator	Water Depth (feet)	Well Depth (feet)	Completion Date
	N lat	W long				
Middleton Island	59°25′	146°17′	Tenneco	60	12,002	Aug 11, 1969
COST No. 1	58°48′	143°06′	ARCO	570	5,150	Oct 10, 1975
OCS Y-0007 No. 1	59°57′	142°23′	ARCO	250	17,920	Jun 3, 1977
OCS Y-0011 No. 1	59°52′	143°18′	Shell	541	13,565	Jan 28, 1977
OCS Y-0014 No. 1	59°53′	143°53′	Shell	485	13,598	Jun 19, 1977
OCS Y-0014 No. 2	59°53′	142°53′	Shell	485	15,390	Sep 12, 1977
OCS Y-0032 No. 1	59°51′	142°17′	Texaco	240	15,638	Feb 20, 1978
OCS Y-0035 No. 1	59°52′	142°01′	Exxon	184	11,731	Jul 1, 1978
OCS Y-0046 No. 1	59°46′	142°58′	Texaco	599	15,013	Jul 15, 1977
OCS Y-0050 No. 1	59°42′	143°07′	Exxon	585	12,995	Jul 8, 1977
OCS Y-0059 No. 1	59°40′	142°59′	Gulf	623	12,170	Aug 16, 1977
OCS Y-0072 No. 1	59°36′	143°15′	Exxon	873	9,835	Mar 17, 1978
OCS Y-0080 No. 1	59°40′	144°02′	Exxon	448	13,507	Jan 4, 1978
OCS Y-0211 No. 1	59°04′	140°20′	ARCO	450	17,810	Oct 22, 1983

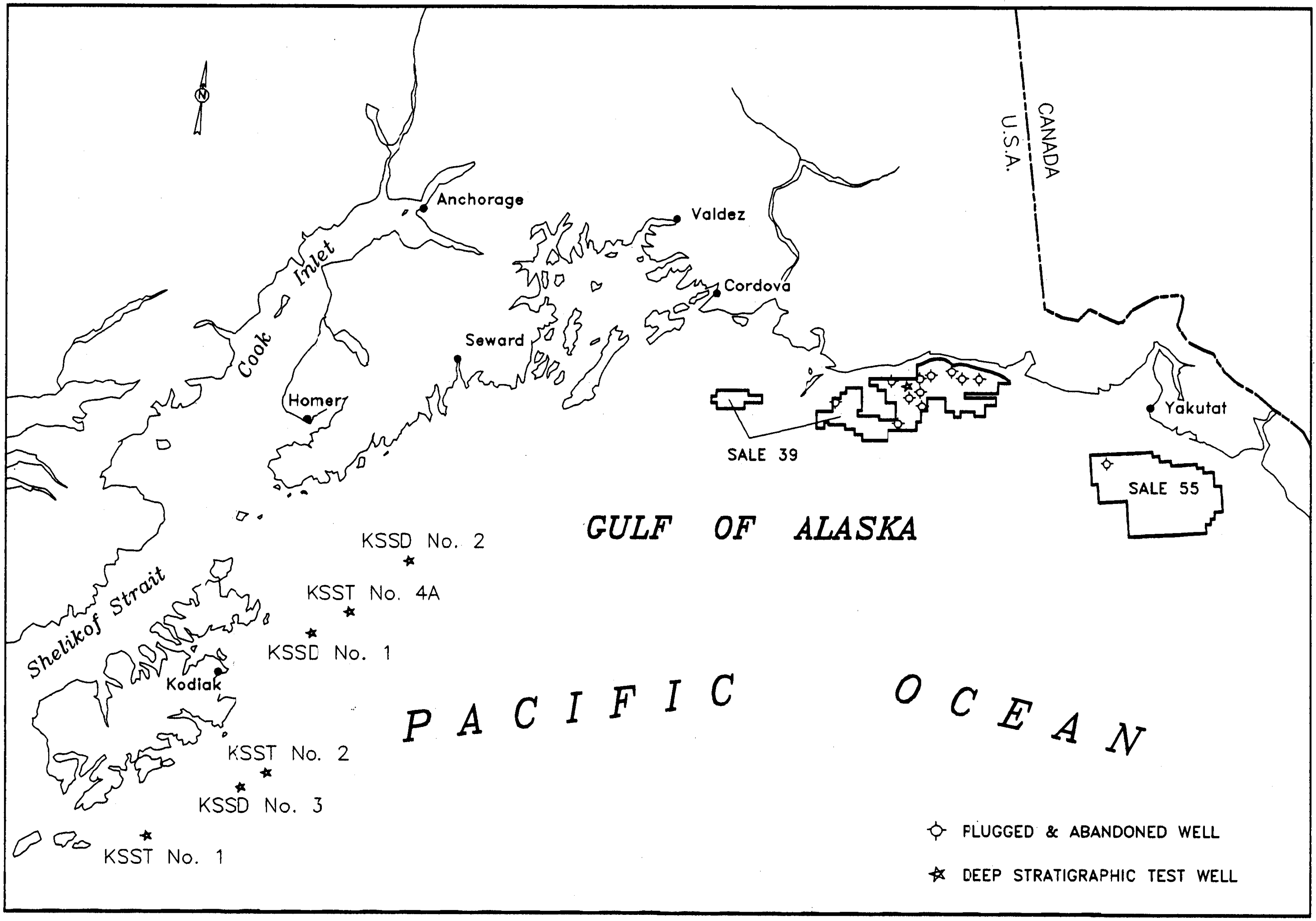


Figure 67. Location of OCS Lease Sale Areas 39, 55, and Kodiak COST wells.

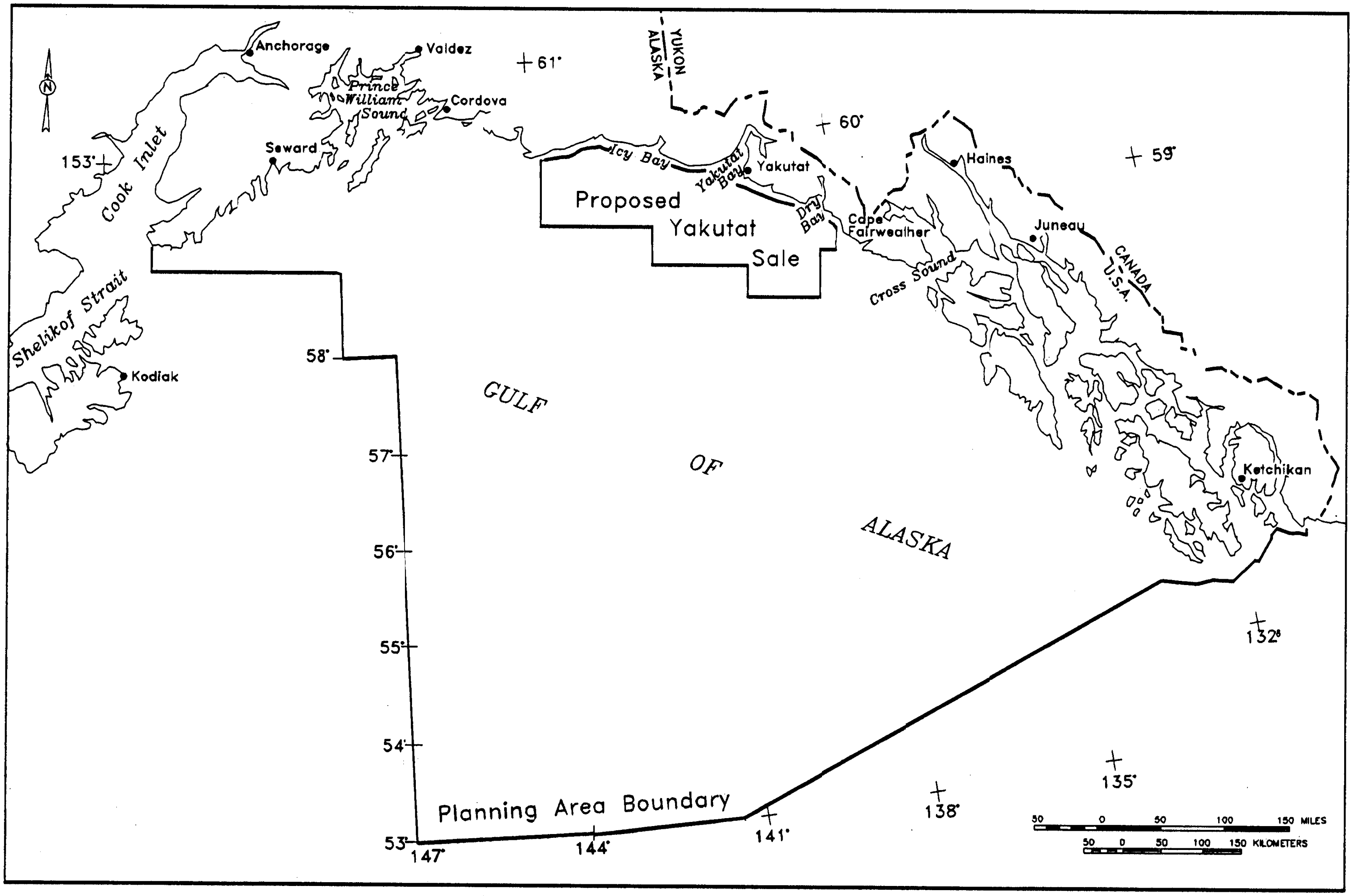


Figure 68. Gulf of Alaska Planning Area and location of proposed Lease Sale 158.

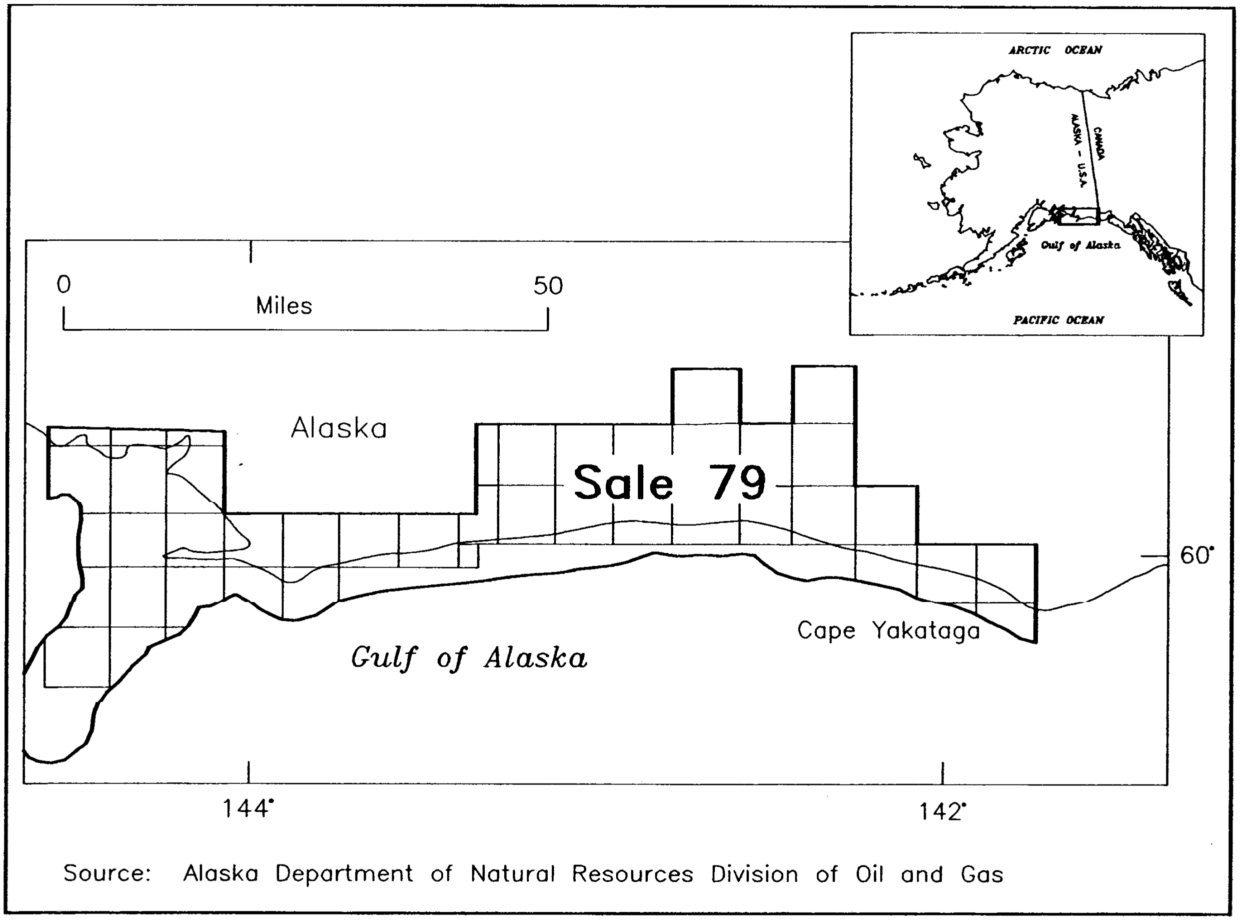
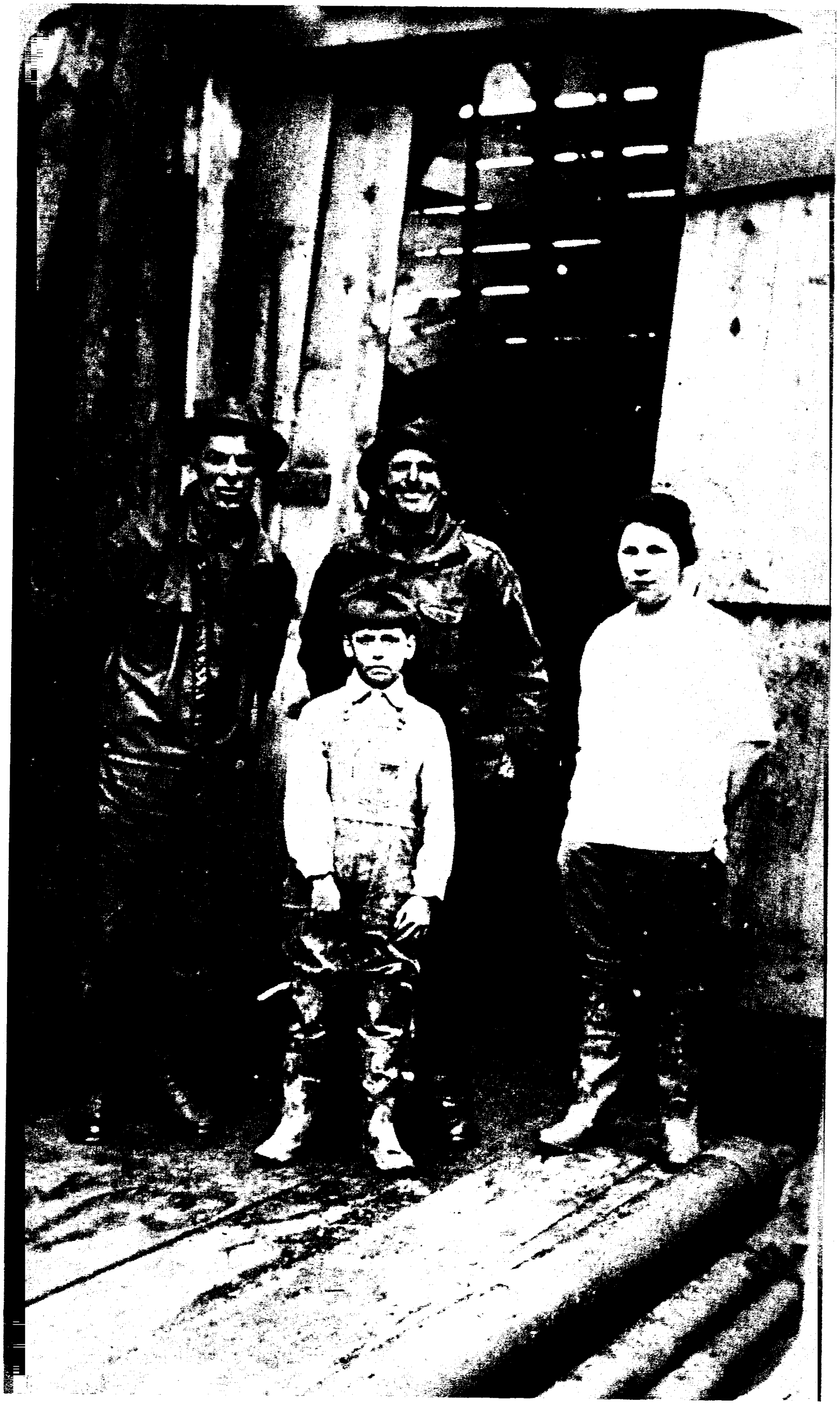


Figure 69. Location of proposed State of Alaska Cape Yakataga Sale 79.

Opposite. *Thomas George White (center), the "Sourdough Driller," was noted for narrow escapes and deeds of derring-do (see p. 154, "The Katalla Herald" newspaper of August 17, 1907). A fisherman, hunter, trapper, sawyer, miner, mariner, musher, and builder, he discovered oil in 1894 and drilled the first oil well in Alaska (1902), at Katalla Slough. When not actively exploring for oil, he found time to supervise the building of the Cape St. Elias lighthouse, serve as foreman at the Clear Creek water plant, and briefly act as a bodyguard for Gifford Pinchot, President Theodore Roosevelt's controversial chief forester. In the late 1940's, he worked as a camp cook for Don Miller, the U.S. Geological Survey geologist responsible for much of the modern mapping of the Gulf of Alaska Tertiary Province. Mt. Tom White, a peak in the Chugach Mountains north of Bering Glacier, is named in his honor. Mr. White's white house on White Slough, a local landmark that boasted the first bathtub in Katalla, was heated by natural gas piped in from nearby seeps. During the boom of 1907 in which the population of Katalla grew from a few hundred to more than 10,000, Mr. White was involved in a number of diverse entrepreneurial enterprises, including hotels, bars, pool rooms, sawmills, commercial docks, and building construction. In addition to his pioneering drilling activities, he was an elected school board official and also served for a time as the town "doctor," once successfully sewing his son's severed fingers back on after a sawmill accident. The woman pictured is his second wife, Susie Duval, a Yakutat/Tlingit Indian. The newspaper clipping of January 23, 1909 (see p. 62), recounts this wedding (his first wife, an Athabascan Indian from Eyak, died September 19, 1908). As this picture from the Barrett Willoughby Collection clearly shows (see front cover for credits), she soon shed her satin wedding gown for far less glamorous garb. The boy pictured is one of White's two sons who drowned in a tidal whirlpool on Christmas Eve, 1929, when their boat overturned returning from a drilling rig. Some of Mr. White's descendants still live along the Gulf of Alaska coast according to John F. C. Johnson of the Chugach Alaska Corporation, who generously provided much of the historical data about this remarkable pioneer.*



WORK IN CANYON

Large Number of Men Are Employed

STEAMER CHITTYNA A SUCCESS

Thos. G. White Has a Battle For His Life in the Rushing Water of Copper River.---Four Camps Have Been Established.

Thos. G. White, the well known Katalla pioneer, had a narrow escape from death in the water of the Copper river one day last week.

Going up the river the boat was turned and was swamped and Mr. White was forced to swim for his life in the swift and treacherous current. He struck out boldly for a point 300 feet distant which jutted out into the stream and fortunately reached it little the worse for his experience.

The new steamer Chittyna, of the Copper River and Northwestern railroad line is successfully navigating the Copper river above Abercrombie canyon for a distance of about 170 miles. The steamer is a double decker, 110 feet long, and draws 22 inches of water when loaded with freight, and with 30 inches of water she can get up the river in great shape. The Chittyna was built in Valdez by Capt. Hall last winter and taken over in sections to the mouth of the Tasnuna.

The Katalla company has four camps along the right of way below the canyon. All but one are on the east side of the river, the main camp being at the point where the river will be bridged, two miles this side of the rapids. The two upper camps are at the rapids, where there are 75 men, and Mr. White left Tuesday with an additional force of 18 men. Grading and rock work has been started and is being pushed in a vigorous manner.

KATALLA HAS A BRIGHT FUTURE

"I met many business men in Seattle all of whom predict a bright future for Katalla, and on the streets and about the hotels you hear talk of Katalla on every side," said T. H. French, of French & Lieber, the other day. Mr. French returned on the Saratoga from a business visit in Seattle.

Mr. French states that General Agent McMicken of the Northwestern Steamship Company told him that the company, next winter, will begin a systematic and thorough advertising campaign of Katalla and the Copper river country. Mr. McMicken knows how to advertise to secure the best results. This advertising campaign would have been begun sooner but for the fact that the company has now all the traffic that it can take care of.

The steamship company also proposes to install its own lighterage system in the immediate future at Katalla.

While waiting for the Saratoga to sail from its dock for Katalla Mr. French's stateroom was entered by a sneak thief and his suit case containing a few articles of clothing and some valuable papers was stolen.

OVERTURNED IN THE BAY.

Edward Lawrence Casey and Peter Olsen took an involuntary bath in the bay Wednesday afternoon, from which, however, they were quickly rescued. Casey and Olsen were working on the barge Savannah, and getting into a small boat they started shoreward to anchor the barge. In attempting to throw the anchor their boat capsized and [illegible] went into the water. Casey [illegible] lustily for help, and Olsen threw him an oar, and then both men managed to get on top of the boat, while another boat from the shore [illegible] them safely. Casey says the [illegible] that he suffered was from [illegible], he having sunk thirteen [illegible] during which he imbibed thirteen [illegible] of salt water.

[illegible] VISIT KATALLA.

A. B. Murphy, a leading operator of [illegible], and J. D. Mennoch, the [illegible] of Valdez were passengers [illegible] Santa Clara, which arrived from Seattle Sunday morning. Both gentlemen came ashore and expressed surprise at the growth of this city, and predicted a great future for it.

[illegible] Dipling[illegible], wife of the defaulting former City Comptroller of Seattle, says that her husband will return and that he will make it uncomfortable for several prominent Seattle men.

A STRIKE OF GOLD QUARTZ

REPORTED ACROSS FROM BERING

Charles Doughton Makes a Sudden Journey to Seattle Taking With Him a Sack Filled With Rock---Gold Placers Said to Be Found.

What is believed to have been a rich gold quartz strike was made about six weeks ago across the divide from the Bering coal fields. The strike is said to have been made by Charles Doughton, who has been prospecting for coal and other minerals in that section for a number of years.

About six weeks ago Doughton returned from a trip which took in the other side of the mountain range. He had a sack filled with rock which he refused to show anyone claiming that the men who were backing him, former Gov. McGraw and D. A. McKenzie, of Seattle should be first apprised of his discovery. So Doughton left for Seattle taking his precious sack with him. He told a friend before leaving Katalla, however, that he had found a mighty good thing and would "put him next" upon his return from the south.

Little is known concerning the Alaskan range to the eastward of Katalla, few prospectors ever have explored even a small part of it. According to William Hukhill, a mining man of Sheridan, Wyo., who is now in town, Jim Baker, an old prospector, is authority for the statement that not only gold quartz but placer ground as well, are found in the Bering river country so it is not all impossible that beyond the divide, gold and other minerals will be found when the country shall have been thoroughly, or even partially prospected.

ANOTHER MOUNTAIN RECEIVES A NAME

Mr. R. S. Ryan and party, including Mr. T. P. McDonald and Miss Grace McDonald, while visiting the coal fields of Carbon mountain, last week, were participants in the ceremony of christening one of the unnamed mountains of that district. Standing at the extreme end of the Carbon mountain range, overlooking Martin river glacier, to the north, the great Bering glacier to the east, and a vast stretch of country containing inestimable values in anthracite coal, which in the very near future will add to the continued prosperity and wealth of the territory, rears in majestic grandeur Mt. Grace, so christened in honor of Miss Grace McDonald, who made the ascent, and who is without question the first white woman who had that honor, and the occasion was made notable by perpetuating the event. Mr. R. S. Ryan in a few appropriate words congratulated the young "sponsoress," when handing her the proverbial bottle, which she broke, saying: "I christen thee Mt. Grace. May we all live to see you the sentinel and vanguard of the new Pittsburg of Alaska."

Miss McDonald, who is a student at Wellesley College, Mt. Holyoke, Mass., has been spending the summer with her father, who is largely interested in coal mines with Mr. Ryan in the immediate vicinity. She will return early in September and will take back with her many pleasant memories of Katalla district, but beyond them all the knowledge that she has a monument to herself in the new empire of the west which will outlive centuries.

KATALLA COAL [illegible].

Alfred White, Superintendent of motive power and machinery for the Katalla Company, has made several tests of Bering coal now being mined by T. P. McDonald, and it gives excellent satisfaction, containing a low percentage of water than Puget Sound coal. Mr. White comes from Dickinson, N. D., where for twenty years he was superintendent of machinery for the Northern Pacific.

A SAW MILL ON MARTIN RIVER

The Katalla Company, (the constructing company of the Copper River and Northwestern Company's lines) will have their saw mill in operation on Martin river, near camp 7 in about a week. A logging camp is being established by Geo. Smith, who has a contract for supplying the mill with logs.

J. Thompson, a [illegible], at camp 7, who was in town this week, says that fine timber is found near the mill. There are trees from two to four feet in diameter and 40 to 80 feet long. Work he says is progressing finely in all directions.

PROGRESS OF MINING

Development Work at Bering Lake

VENTILATION FOR THE TUNNEL

T. P. McDonald & Company Will Increase Force of Men---A Saw Mill Has Been Put In and the Coal Output Will Be Increased.

A back entry for the ventilation of the Bering lake coal mines, now being developed by T. P. McDonald & Co. has been completed and additional miners will be put at work taking out coal.

"We have experienced all the delays usually incident to the opening up and development of coal mines," said Mr. McDonald, who was in town this week. "As soon as our back entry ventilation is completed, which will be this week, we can open up more chambers. On account of the coal being quite gaseous we have been unable to do this, hence our output has been limited, until that work has been completed.

"We are employing a dozen or so men at the mine, and quite a crew at the saw mill which we are putting in, and which will be in operation within a week. More coal miners will also be employed, and we expect to increase our force of men and our output as well. A tunnel has been run in a distance of 175 feet, coal having been found at 54 feet."

Mr. McDonald is the first man to undertake coal development in this district, "and," says Mr. McDonald, [illegible] ing first in the field others who [illegible] after us can profit by our errors and experiences. The quantity and [illegible] of coal are here and we have [illegible] et. Some people think that [illegible] of coal is too high, and judging [illegible] tain conditions elsewhere it is; but judging by the conditions obtaining here, some allowance must be made. We are taking the chances, and, therefore must charge more than a normal price.

"We are operating in a part of a field that has been turned down by every mining expert that has examined it, and I recognize the fact that we may be called chumps, but as I said, we are taking chances. The coal is there, but whether the broken condition of that section in which it occurs will permit it to be mined at a profit remains for us to demonstrate. And this we are trying to do."

FOUND MANY COAL VEINS

A. W. Watson is in town from Stillwater, where he has been prospecting coal lands belonging to James Wardell, whose claims parallel Canyon creek [illegible] the west. Mr. Watson says the [illegible] coal showings are excellent, not [illegible] the Wardell property but on the [illegible] by Clarence Cunningham and others [illegible] the same locality.

Mr. Watson uncovered several veins of fine coal averaging in width from one to fifteen feet. The ground where the veins were found is high and it can be [illegible] mined.

Secretary of Agriculture Wilson, of [illegible] said that the West is [illegible] ably for Roosevelt for a third [illegible] that he can't help winning [illegible] and that he must run [illegible] presidency.

FIRST TO FIND OIL

AND THE FIERY CONSEQUENCES

Tom White's Thrilling Experiences With Fire and Crevasses---Thirteen Years Continuously a Resident of Katalla--Believed in Future.

The man who first found oil in this section, according to authenticated statements, was Thos. G. White, a well known pioneer of Katalla, where he has resided continuously for the past 13 years. This was in 1896. He had wounded a bear and followed its trail for some distance. He smelt oil and he had been told by the Indians that it was to be found in the vicinity. Presently he came to a [illegible] part of the field and he lit a match [illegible] the pond. There [illegible] which [illegible] a [illegible] the [illegible] trees, and a [illegible] the [illegible] smoke enveloped the mountain tops. Then he knew that he had not only "touched off" an oil deposit but a gas accumulation as well.

This property is now owned by the Alaska Development Co. [illegible] to the Pacific Coal and [illegible] locally the English [illegible]. The first two rigs erected were burned [illegible] gas becoming ignited.

Mr. White is an interesting [illegible] He has not been out of Alaska [illegible] years, and he knows the coast [illegible] pretty thoroughly. In 1890 he accompanied Prof. Israel C. Russell on a trip through the [illegible] St. Elias range.

Mr. [illegible] a charmed life. Only the other day he narrowly escaped drowning in the Copper river. Twice while with Prof. Russell he fell into ice crevasses, and twice he escaped almost miraculously. Into the first crevasse he [illegible] feet, landing on an ice ledge [illegible] which he was extricated by aid [illegible] lowered to him. The second [illegible] 60 feet, and this time he [illegible] wedged in between two opposing [illegible]. This time he was carrying [illegible] filled with rocks belonging to Prof. Russell. "Send up the rocks" yelled the professor when Tom asked what he should do with them. The rocks were saved first.

Besides these adventures he has been wrecked in the surf a number of times, so it is that he believes that he was not born to die an unnatural death.

"After finding oil I concluded to stay [illegible] country," he [illegible] by. [illegible] here." [illegible] has been [illegible] commercial [illegible]

COMPLET[illegible] THE SURVEYS

D. B. Skinner, the pioneer surveyor of the Bering coal fields, where he has been employed for the past [illegible] years, was in town this week. Mr. Skinner has nine men in his employ, assisting in surveying work, making camps, etc., principals being M. A. Green, Harry White and associates. Much work has been accomplished in the way of completing and preparing maps of the surveys made.

M. A. Green & Co. are putting in a telephone line to the coal fields. It will be twenty-two miles in length, or as far as Stillwater, which place it will reach in three weeks. McDonald's coal camp and the Pacific Coal & Oil Company's oil plant are now connected with [illegible] by a telephone line.

[illegible] service, cleanliness, courteous [illegible]---Northern Cafe.

8. RESERVOIR ROCKS

Tertiary sandstones are the principal rocks in the Gulf of Alaska stratigraphic section that appear suitable as potential reservoirs for commercial hydrocarbon accumulations. Sandstone or conglomerate occurs in all or most of the Tertiary units onshore, but offshore, only the Yakataga and Kulthieth Formations appear likely to contain coarse-grained strata of sufficient thickness and areal distribution to represent prospective reservoir targets. Other types of potential reservoir rock include fractured rock along faults and folds and weathered metamorphic or igneous basement rock along unconformities. The oil from the Katalla field, for example, was produced primarily from fracture porosity in shales and siltstones along a fault zone that cuts steeply dipping Poul Creek strata (Miller, 1975). However, the probability of such occurrences of nonsandstone reservoirs containing hydrocarbons in commercial quantities is thought to be low relative to that of the Tertiary sandstones.

Yakataga Formation

Depositional Environments and Sandstone Composition

Sandstones and conglomerates in the Yakataga Formation are predominantly glaciomarine in origin and were deposited in inner shelf to upper slope settings. Studies of Yakataga sedimentation suggest that many of these sandstones and conglomerates were deposited by various sediment-gravity-flow processes in large submarine mega-channel systems that were located downslope from tidewater glaciers (Plafker and Addicott, 1976; Armentrout, 1983b; Eyles, 1987). Channel-fill sandstones and conglomerates that originate from turbid glacial meltwater plumes are not generally subject to much winnowing and, consequently, tend to be poorly sorted and mineralogically immature. In addition, sandstone-to-shale ratios often vary widely within short lateral distances in Yakataga Formation outcrops because of the lenticular character of these submarine channel-fill sand deposits (Winkler and others, 1976, p. 19).

Nonglacial marine deposits such as linear shoreface or marine-bar sands are also reported in outcrops of the Yakataga Formation (Lyle and Palmer, 1976; Armentrout, 1983b). Many of these Yakataga shoreface and marine-bar sands may represent glaciomarine deposits that were reworked by normal marine processes during interglacials. These shoreface and marine-bar sands should represent the most prospective reservoir targets within the Yakataga Formation because they have greater lateral continuity and because winnowing has improved sorting and, possibly, removed some of the mineralogically unstable lithic detritus. For example, porosity and permeability measurements of fourteen outcrop samples of Yakataga sandstones from a Yakataga shoreface sandstone averaged 23.7 percent porosity and 139 millidarcies (md), whereas nineteen samples from a submarine channel-fill complex averaged only 6.9 percent porosity and 0.47 md (Lyle and Palmer, 1976, p. 19). Paleocurrent and paleoenvironmental data suggest that the geometry of these nonglacial sandstone bodies will be tabular to linear and elongated in northwest to west directions (Lyle and Palmer, 1976).

Petrographic studies indicate that Yakataga sandstones, as would be expected from their glacial origin, are texturally and mineralogically diverse and tend to contain more unstable grains and primary matrix than sandstones of older Tertiary units (Winkler and others, 1976; Lyle and Palmer, 1976). Yakataga sandstones generally fall within the lithic arkose category (fig. 70). The mean composition of the main framework components is 35 percent quartz, 40 percent feldspar (primarily plagioclase), and 25 percent lithic fragments (Lyle and Palmer, 1976). The lithic clasts are predominantly igneous and metamorphic in origin. Accessory heavy minerals such as epidote, hornblende, biotite mica, and others form an average of about 5 percent of the sandstone and occasionally are as abundant as 12.5 percent (Winkler and others, 1976; Lyle and Palmer, 1976). Conglomerate clasts range widely in composition and reflect the igneous, metamorphic, and sedimentary rocks of the bordering St. Elias and Chugach Mountains. Conglomeratic clasts from the lower Yakataga Formation commonly include meta-diorite, meta-andesite, and meta-andesite tuff, with lesser quantities of slate, graywacke, epidote, amphibolite, and foliated and nonfoliated granodiorite (Lyle and Palmer, 1976).

Log Analysis Methods

Log responses to Yakataga Formation sediments are complicated by the textural and mineralogical complexity of the grain or clast framework of the sandstone and conglomerate, and the silt- to clay-sized glacial rock flour that makes up the bulk of the mudstone, shale, and diamictite. Standard multiple porosity cross-plots and log analysis methods for shaly sandstones frequently fail to yield reliable porosity estimates in mineralogically complex sandstones (Patchett and Coalson, 1982). In such complex sandstones, the density log generally yields the most reliable porosity relative to that of conventional cores, provided the grain density is predictable and favorable borehole conditions exist (Patchett and Coalson, 1982; Turner and others, 1988).

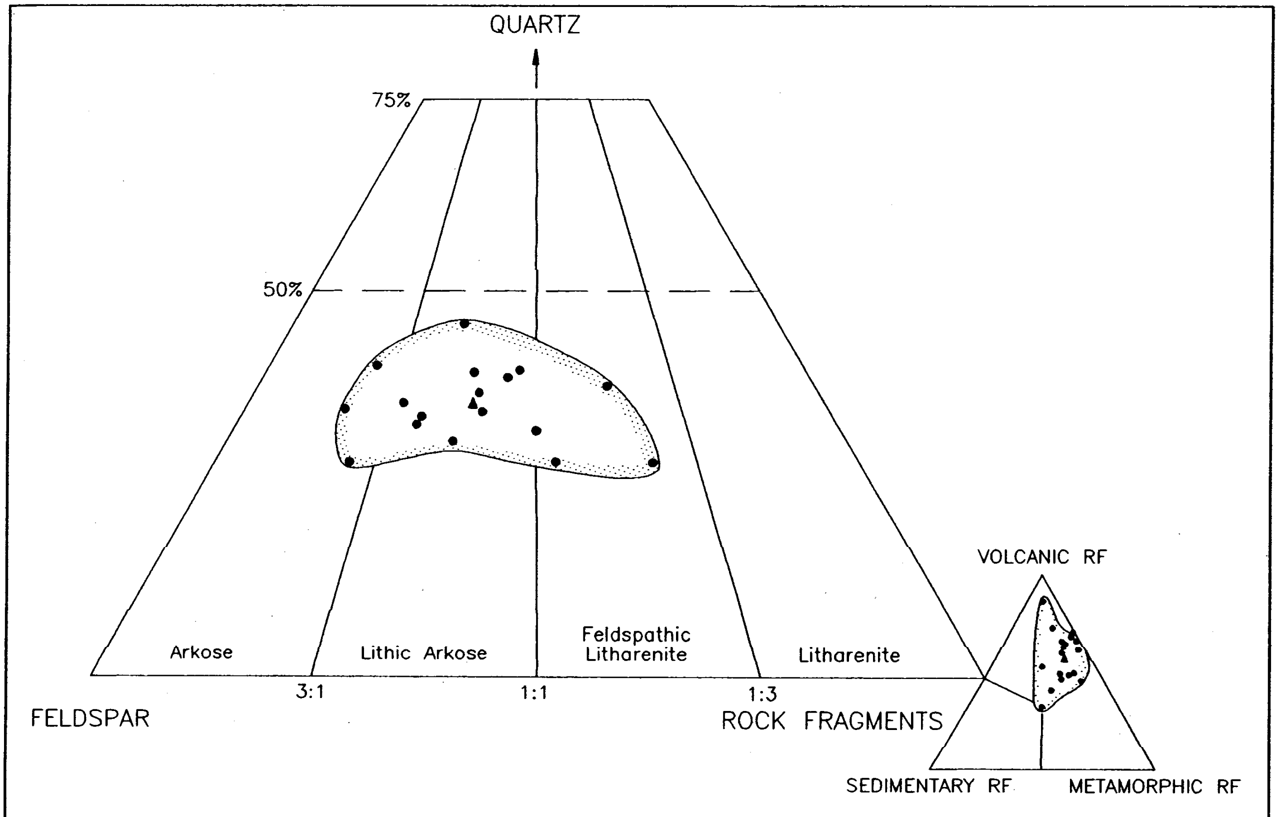
The standard equation (Schlumberger, 1972) used to derive porosity (ϕ_D) from the density log is

$$\phi_D = (\rho ma - \rho b)/(\rho ma - \rho f)$$

where: ρma = matrix (grain) density
ρb = bulk density from density log
ρf = fluid density.

It is standard practice in using this equation to assume a ρma (matrix or grain density) of 2.65 grams per cubic centimeter (gm/cm^3), the density of quartz. However, in

Figure 70. Quartz, feldspar, and lithics (QFL) and rock fragment ternary diagrams showing mineralogy of Yakataga Formation sandstones from onshore exposures (after Lyle and Palmer, 1976).



Yakataga		Q	F	L	V	S	M
n=17	Mean ▲	35	40	25	59	12	29
	Range	28–46	23–57	11–49	33–88	1–33	6–42

	C/Q	P/F	V/L
Mean ▲	.13	.89	.59
Range	.06–.20	.82–.95	.33–.88

Q=Total quartzose grains
C=Polycrystalline quartzose grains
F=Total feldspar
P=Plagioclase
L=Total rock fragments (RF)
V=Volcanic RF
S=Sedimentary RF
M=Metamorphic RF

complex sandstones the ρma is likely to be higher owing to the presence of lithic clasts and mafic mineral grains which are usually denser than quartz. Thus, for complex sandstones, an alternate value of ρma must be estimated. The reliability of the density porosity obtained is dependent on how representative the estimate is and how variable the actual grain density of the sandstone is from the estimate.

The most accurate method of determining matrix or grain density of sandstones is from physical measurements of cores. The distribution of grain density in Yakataga sandstones determined from analysis of sidewall and conventional core data from four OCS exploratory wells is shown in the histogram of figure 71. The histogram indicates grain density ranging between 2.65 and 3.63 gm/cm^3, with a mean of 2.72 gm/cm^3.

The wide range in grain density displayed in figure 71 is a reflection of the diversity of the mineral and lithic clasts and resulting diagenetic cements composing Yakataga sandstones and conglomerates. The histogram of grain density does not represent either a normal or lognormal distribution (Koch and Link, 1970, p. 218), as the data do not pass the Kolmogorov-Smirnov goodness-of-fit test for normality (Ostle, 1972, p.471). Because the distribution about the mean is not normal, the standard deviation, the traditional measure of fluctuation based on the normal distribution, does not apply. However, examination of the histogram reveals that 73 percent of the data falls within ± 0.03 gm/cm^3 of the mean value of 2.72 gm/cm^3, and 95 percent falls within ± 0.07 gm/cm^3. These percentages are roughly equivalent to the percentages (68% and 95%) of normal populations that are generally found within one and two standard deviations, respectively.

The grain density distribution of figure 71 suggests that density porosity calculated from the mean value over the range of typical Yakataga Formation sandstone bulk densities (2.20 to 2.60 gm/cm^3) should be accurate to within ± 1.5 percentage points 73 percent of the time and to within ± 3.5 percentage points 95 percent of the time. The histogram indicates that the source of the greatest potential error in porosity calculation is from the five percent of the sandstones with grain densities higher than 2.79 gm/cm^3. Most of these are probably an indication of either abundant, dense igneous and metamorphic lithic clasts or abundant, dense cements such as siderite. Lithic clasts become predominant in conglomerates and sandstones composed largely of coarse-grained through granule-sized clasts. Coarser lithologies and highly cemented sandstones probably pose the greatest potential for error in porosity evaluation.

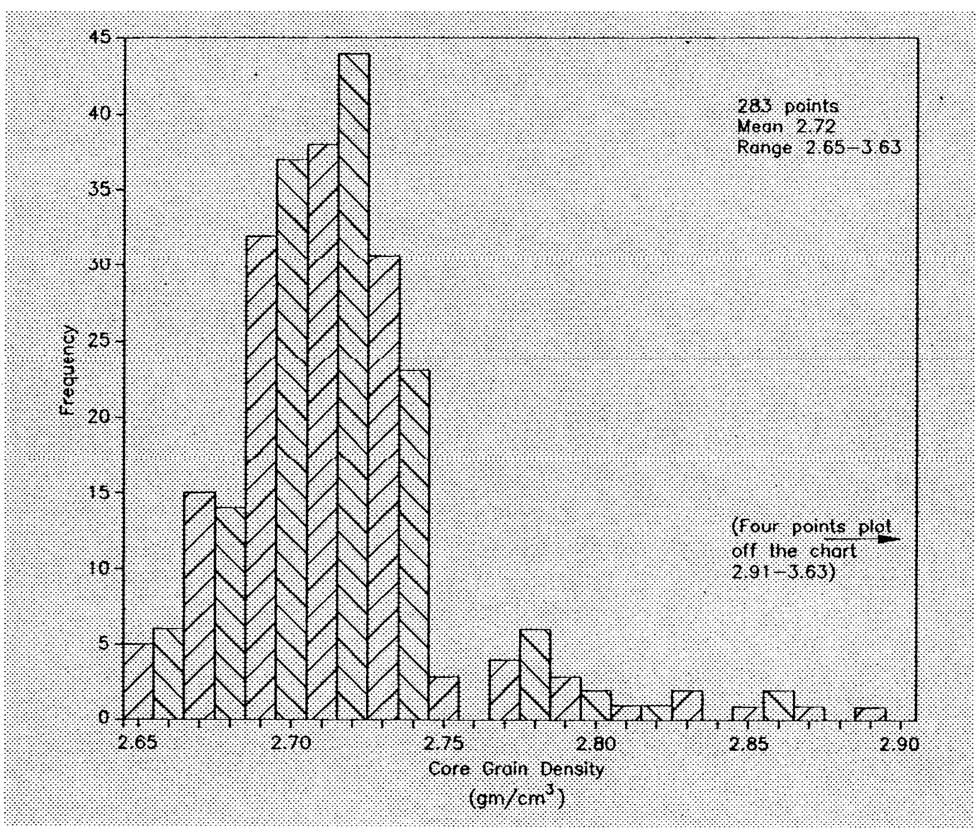


Figure 71. Histogram of grain density distribution of Yakataga Formation conglomerate, sandstone, and siltstone. Core analyses from the OCS exploratory wells Y-0007 No. 1 and No. 2, Y-0032 No. 1, and Y-0080 No. 1.

The complex textural and mineralogic composition of Yakataga sediments not only creates difficulties in evaluating porosity, but also in determining lithology. The two logs primarily used in determining lithology are the natural gamma ray and the spontaneous potential (SP) logs. The typically distinctive gamma ray log contrast between sandstones and shales, which is due primarily to the difference in natural radioactivity between quartz and clay, is frequently muted in the Yakataga Formation because the various glaciomarine lithofacies frequently differ more in texture and grain size than in mineralogy. Consequently, sandstone or conglomerate beds were usually identified from the SP log from intervals that displayed deflections of at least 10 millivolts.

Generally, the SP log reliably distinguishes sandstone or conglomerate from shale or mudstone in the Yakataga Formation, provided the drilling muds used are not too saline. Unfortunately, from the standpoint of log analysis, seawater-based drilling muds were commonly used in drilling the upper four to five thousand feet of hole in some of the OCS exploratory wells. In one well (OCS Y-0059), the entire well was drilled using a saline mud. In this well, the SP log trace was flat and of little use in determining lithology because the drilling fluid resistivity closely matched that of the saline formation water. In wells or well intervals with poor SP logs and muted gamma ray logs, the identification of sandstone and conglomerate beds was rather tenuous. In these instances, the resulting error in interpretation is probably an underestimation of total sandstone content owing to the inability to identify porous lithologies.

Sandstone Distribution and Thickness

Sandstone and conglomerate beds in the Yakataga Formation on the mainland identified from exploratory well logs and measured sections compose from 30 to more than 80 percent of the formation. In offshore exploratory wells, sandstone and conglomerate identified from SP and gamma ray logs apparently diminishes to between about 10 and 30 percent of the formation (fig. 72). This trend suggests that the Yakataga Formation along the southern margin of the Yakutat terrane is generally composed of less than 10 percent sandstone. Some of the apparent decrease in sandstone abundance offshore may be due to the difficulty mentioned above in identifying porous lithologies, but, overall, the trend is thought to be real. Yakataga Formation sediment source areas were in the northern mountainous uplifts and sediment depocenters lay just offshore of the modern coast line. Under these conditions, coarse-grained lithofacies would normally diminish in a southerly offshore direction. In terms of total aggregate sandstone thickness, the sandstone percentage trends represent a range from about 250 feet in the OCS Y-0211 well, where the Yakataga Formation is relatively thin and far from sediment source areas, to over 3,800 feet in the OCS Y-0035 well located near Icy Bay (plate 8) along glaciomarine depocenters.

Sandstone and conglomerate encountered in the offshore exploratory wells range from beds less than 5 feet thick to a bed or bedding sequence 630 feet thick. The distribution of sandstone by bed thickness for the Pleistocene and for Pliocene and Miocene sections of the Yakataga Formation in offshore exploratory wells is illustrated in figures 73 and 74. The greatest number of sandstone beds occur in the 10- to 25-foot thickness category. However, average bed thickness (arithmetic mean) is between 40 and 45 feet, and approximately two-thirds of all sandstone beds fall between about 5 and 100 feet in thickness. Although fewer beds greater than 100 feet thick occur in the Yakataga Formation, they form a significant percentage of the total quantity of sandstone owing to their greater individual thicknesses. About 45 percent of the total sandstone is contained in beds greater than 100 feet thick in the upper Yakataga Formation, and about 34 percent in the lower Yakataga Formation. Consequently, these thick sandstone beds are important potential reservoir targets.

Sandstone Reservoir Quality

The abundance of labile lithic and feldspar grains in Yakataga sandstones makes them susceptible to diagenetic alteration and rapid loss of effective porosity with burial depth. Figure 75 illustrates the relationship between density porosity (ϕ_D) and burial depth from several of the OCS exploratory wells which encountered complete or nearly complete sections of the Yakataga Formation. Also included are porosity values obtained from conventional cores (solid points). There is considerable scatter in the data owing to the diverse character of Yakataga sandstone and conglomerate, but a definite trend of porosity decline with depth is evident. The extremely wide scatter in porosity (5% to 38%) at shallow depths probably reflects the large variance in primary porosity resulting from the diverse depositional energies and sorting capabilities of the varied glaciomarine and nonglacial marine environments. At increasing burial depths, the range of porosity scatter is narrowed somewhat as diagenesis and compaction become the predominant factors in porosity reduction.

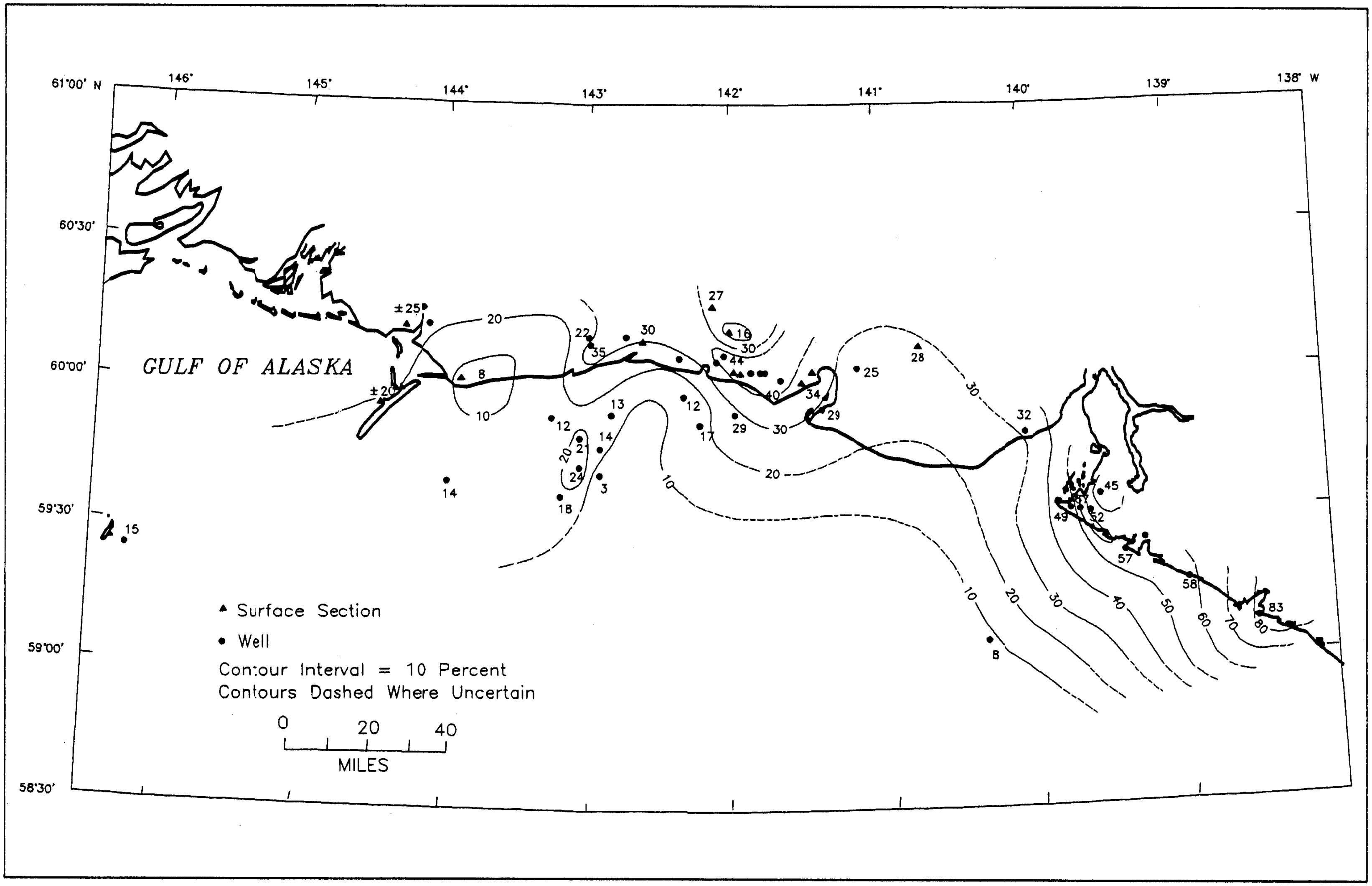


Figure 72. Sandstone percent map of the Yakataga Formation.

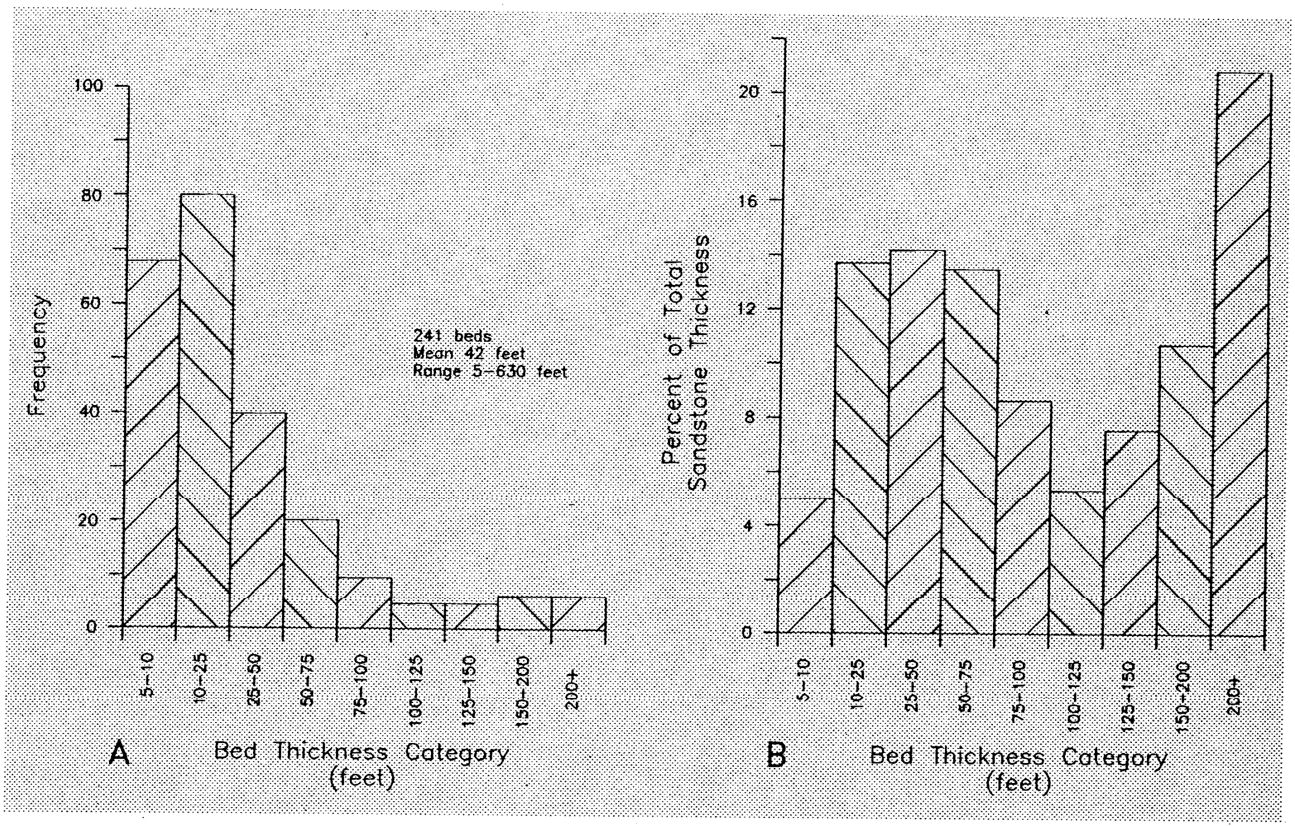
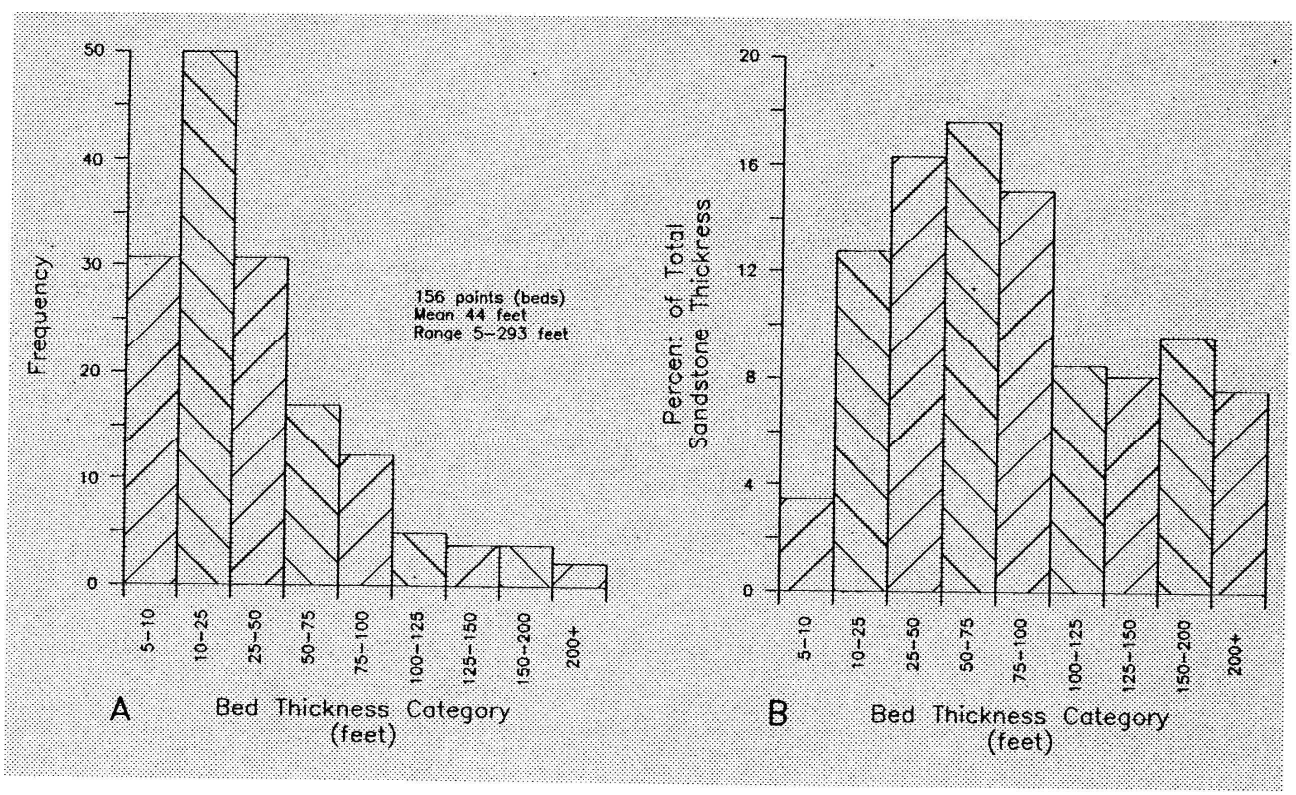


Figure 73 (above), Upper Yakataga Formation and **figure 74** (below), Lower Yakataga Formation sandstone bed thickness distribution. Histograms A illustrate bed thickness frequency of occurrence and histograms B illustrate percent of total sandstone in each bed thickness category. Sandstones were identified from spontaneous potential logs of Gulf of Alaska OCS exploratory wells. Sandstone beds less than 5 feet thick were not counted.



The line to the left in figure 75 that passes through the middle of the cloud of points is a linear regression of all the data points and represents the average porosity-depth relationship. This line suggests that at a burial depth greater than about 11,700 feet, typical Yakataga sandstones will generally fall below 10 percent porosity. The porosity-versus-permeability relationship obtained from conventional cores of Yakataga sandstone (fig. 76) suggests that at these depths permeability will be less than about 1.5 md and the sandstone would be poor to non-reservoir rock. The line to the right in figure 75 is a visual fit of the highest porosity values and represents the porosity-depth relationship of the most prospective reservoir-quality sandstones. The trend of this line suggests that these sandstones may retain porosity in excess of 10 percent to depths as great as 14,000 feet.

Three of the sandstones that lie along the trend of the higher porosity line of figure 75 were cored by the OCS Y-0007, OCS Y-0014, and OCS Y-0032 wells. The most extensively cored of these sandstones was in the OCS Y-0007 well. Forty-three feet of the upper part of a 150-foot-thick sandstone (8,760-8,910 feet) was cored (OCS Y-0007, core 3, appendix B-5). The wireline logs, core porosity measurements, and lithologic interpretation for this sandstone are illustrated in figure 77. Wireline logs of the interval suggest good reservoir potential. The caliper (CALI) log deflection indicates mudcake development and permeability, and the SP log deflection and separation of the resistivity curves also indicate permeability. Porosity (ϕ_D) of the density log (DPHI) for this sandstone averages 17.0 percent. The core was analyzed every foot, and the analyses indicate good reservoir potential. Core porosity ranges from 12.2 to 26.6 percent with a mean of 19.5 percent, and core permeability ranges from 48 to 479 md with a mean of 261 md (Core Laboratories, Inc., 1977a).

The density porosity in the sandstone of figure 77 is systematically about 2 to 3 percentage points lower than the core porosity over equivalent depth intervals, even though the average grain density from the core (2.71 gm/cm^3) closely matches that used to calculate the density porosity (2.72 gm/cm^3). The cause of the discrepancy is uncertain, but small increases in core porosity and permeability generally occur as a result of changes in temperature, pressure, and fluids during removal of the core to the surface and the subsequent laboratory analysis (Schlumberger, 1972, p. 91; Helander, 1983, p. 15). This may account for a significant part of the discrepancy.

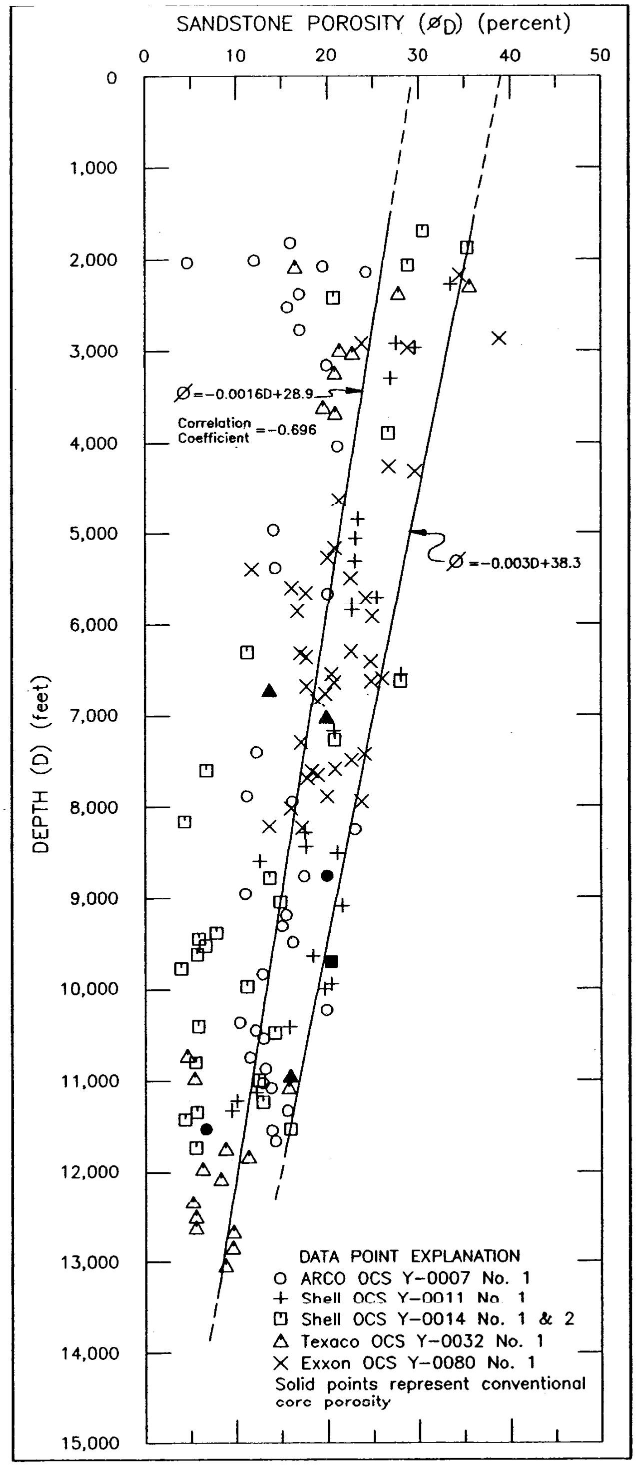


Figure 75. Yakataga Formation sandstone porosity versus depth plot. Data points represent average porosity calculated from density logs in sandstone intervals identified from spontaneous potential and gamma ray logs. The left line is from a linear regression of all points and represents the average porosity-depth relationship. The right line is a visual fit of the higher porosity points and represents the approximate maximum porosity versus depth plot.

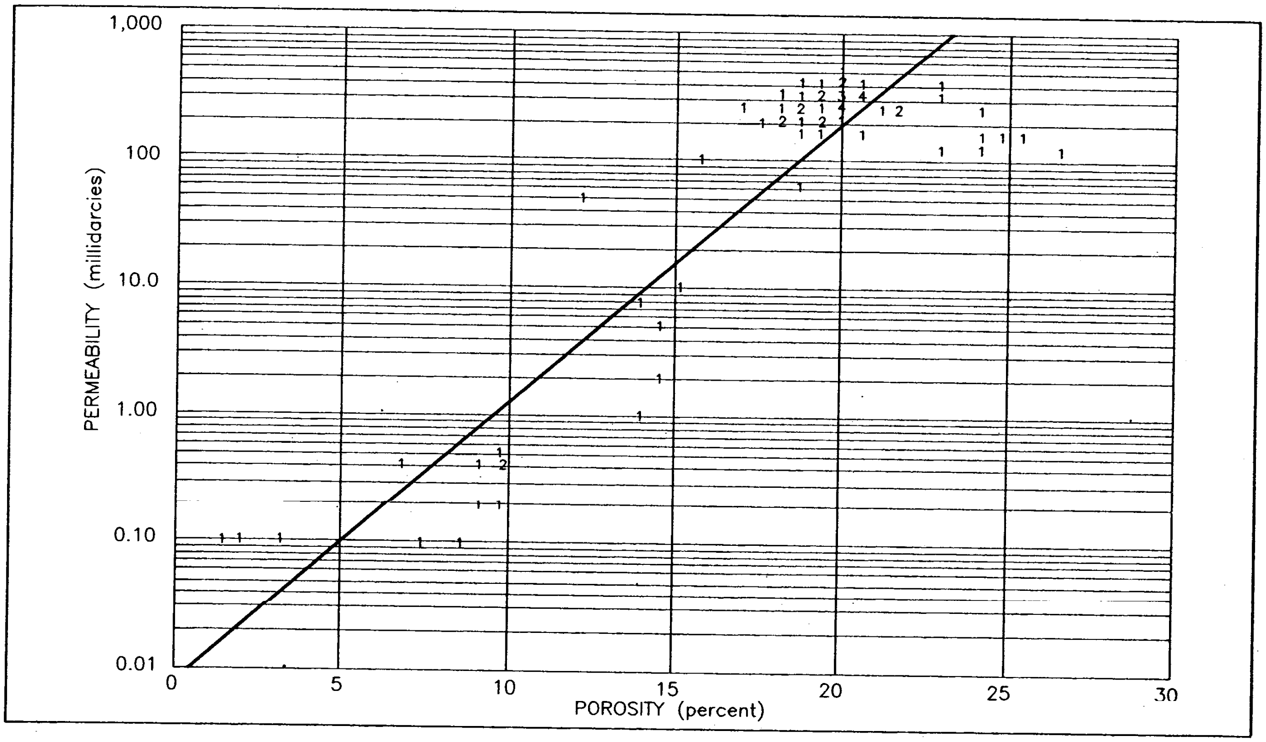


Figure 76. Cross-plot of porosity versus permeability from conventional cores of Yakataga Formation sandstones and conglomerates from OCS exploratory wells Y-0007 No. 1, Y-0014 No. 1, and Y-0032 No. 1. The number at the plotted data point indicates the frequency of data plotting at that point.

Grain size from the cored interval of figure 77 ranges from very fine grained in the lower part to medium grained in the upper part (Core Laboratories, 1977a). A slight coarsening-upward profile is also displayed by the SP log and, to a small degree, by the gamma ray log. Such a profile is characteristic of sand bars, and this sandstone could be a submarine bar deposit, although the deep-water environment of deposition (upper bathyal) of the enclosing finer grained strata suggest this sandstone may be a submarine fan deposit.

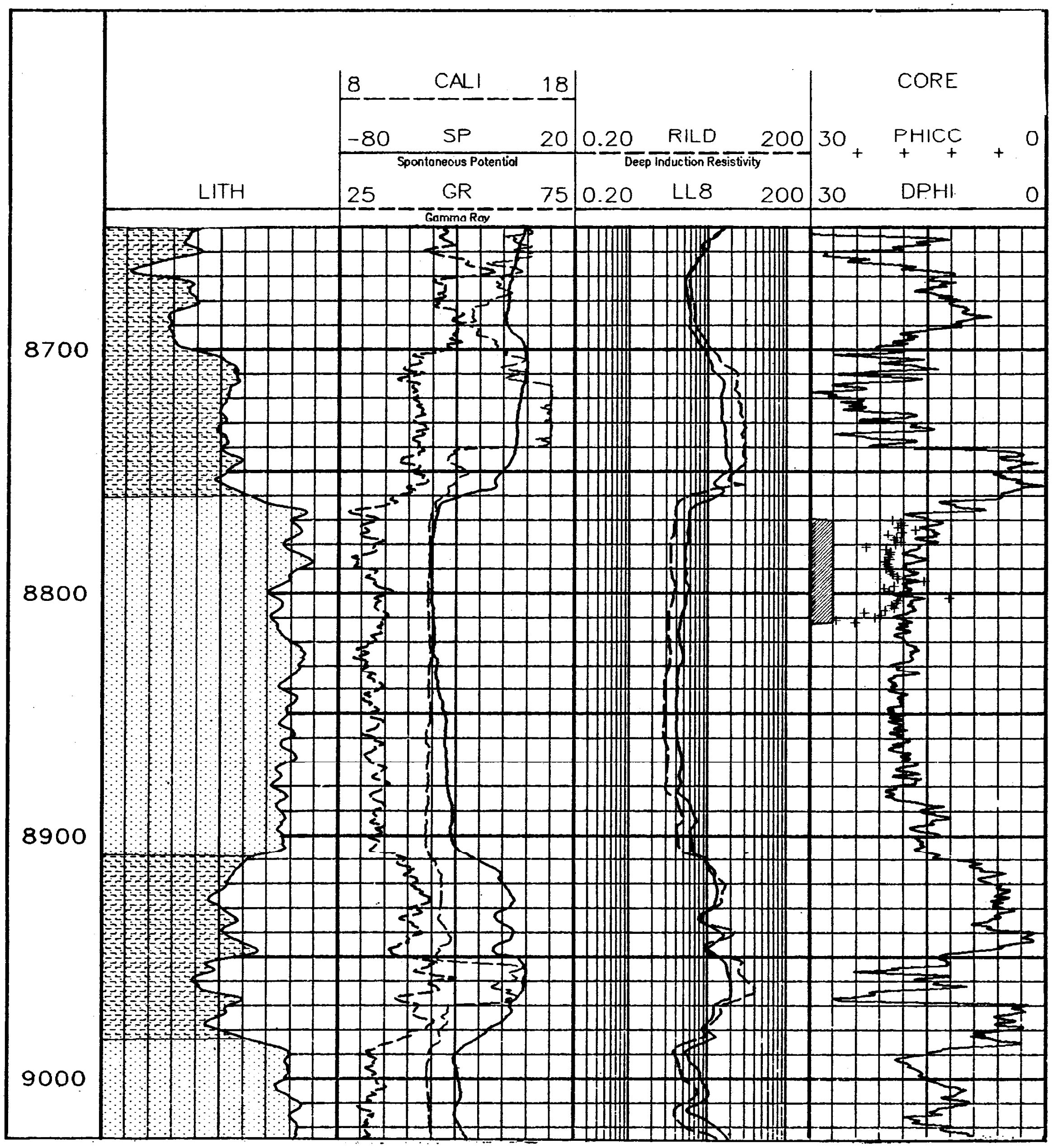
The other two sandstones from the trend line of higher porosity sandstones (fig. 75) were from the OCS Y-0032 No. 1 and OCS Y-0014 No. 1 wells. Unfortunately, these sandstones were not cored as extensively as the sandstone in the OCS Y-0007 No. 1 well. Core 5 of the OCS Y-0032 well sampled 7.5 feet of the upper part of a 165-foot-thick coarsening-upward sequence of sandstone and conglomerate at 11,005 feet. The core consisted of silty, very fine- to fine-grained, locally calcareous sandstone, friable medium-grained sandstone, and conglomerate in a silty to coarse sand matrix (Larson and Wills, 1977). Core recovery from the conglomerate section was poor and the conglomerate was largely disaggregated. The fine-grained, silty sandstone lithofacies from the top of the core appears to be a gradational unit at the top of the sandstone sequence. Two analyses from the silty sandstone lithofacies indicated poor reservoir potential with only 2.7 percent and 13.6 percent porosity and permeability less than 1 md. Three samples from the medium-grained sandstone at the bottom of the core averaged 20.4 percent porosity and 241 md permeability. The logs suggest that the majority of the sandstone sequence probably has reservoir potential similar to the medium-grained sandstone core. Bulk density throughout most of the sandstone sequence is similar to that in the medium-grained lithofacies of the core, suggesting comparable porosity and permeability. In addition, the SP log profile and average density porosity (15.6%) in this sandstone are similar to those of the OCS Y-0007 sandstone, suggesting analogous depositional environments and reservoir potential.

Core 3 in the OCS Y-0014 No. 1 well sampled 18 feet of the upper part of a 120-foot-thick coarsening-upward sequence at a depth of 9,720 feet. The core was recovered as unconsolidated sand and broken fragments of sandstone and conglomerate and was described as very poorly sorted, very fine to coarse-grained, pebbly sandstone and conglomeratic tillite (Daugherty and Bingham, 1977). Seven analyses from this core indicated an average porosity of 19.1 percent and permeability of 104 md (Core Laboratories, Inc., 1977b). This suggests good reservoir potential. However, density porosity (ϕ_D) over the cored interval averages only about 7.5 percent, and when considered in light of the lithologic description and fragmented condition of the core, the high porosity and permeability from the core analyses are suspect.

Summary

Yakataga sandstones and conglomerates were deposited by marine and glaciomarine processes from glacial detritus shed from the coastal mountainous uplifts bordering the Gulf of Alaska. Wireline log data indicate that substantial aggregate thicknesses (250 to 3,800 feet) of Yakataga sandstone occur offshore, although near the southern margins of the Gulf of Alaska shelf sandstone

Figure 77. Log, core, and lithologic data of a prospective reservoir sandstone in the Yakataga Formation of the ARCO OCS Y-0007 No. 1 well. (Lith=lithology, CALI=caliper in inches, LL8=shallow resistivity in ohm-meters, PHICC=core porosity in percent, DPHI=density porosity in percent, sandstone=stippled pattern, mudstone=dashed and stippled pattern.)



may be sparse, as the percentage of sandstone in the Yakataga Formation rapidly diminishes southward. Sandstone beds of the lower Yakataga Formation represent the most prospective reservoir targets. They are stratigraphically closer to potential thermally mature source rocks, and the lower Yakataga Formation contains a higher proportion of nonglacial lithofacies. Yakataga sandstones that were deposited or reworked by marine processes exhibit much higher primary porosity and permeability than those deposited by glaciomarine processes. Sandstone beds in the 50- to 75-foot range make up the highest percentage of the total sandstone in the lower Yakataga Formation, but a substantial percentage (34%) is made up by beds from 100 to over 200 feet in thickness.

Yakataga sandstones and conglomerates are texturally and mineralogically diverse, and might be expected to exhibit a rapid loss of primary porosity and permeability with increasing depth of burial. However, sandstones with good to moderate reservoir potential occur in the Yakataga Formation at burial depths in excess of 14,000 feet. Conventional core data from the OCS Y-0007 and OCS Y-0032 wells indicate that Yakataga sandstones retain porosity and permeability of over 19 percent and 200 md as deep as 11,000 feet. Comparable porosities and burial depths in sandstones of similar mineralogy are predicted by compaction models developed from laboratory compaction experiments of lithic sands (Pittman and Larese, 1991, fig. 19). High sedimentation rates during deposition of the Yakataga Formation have contributed to a low geothermal gradient and overpressuring in the Gulf of Alaska Neogene section. A low geothermal gradient tends to retard diagenesis and cementation and overpressuring tends to retard mechanical compaction (Galloway, 1974; Dixon and Kirkland, 1985; Scherer, 1987; Schmoker and Gautier, 1988; Pittman and Larese, 1991). These two factors probably cause higher porosity in Yakataga sandstones than would be anticipated for their burial depth.

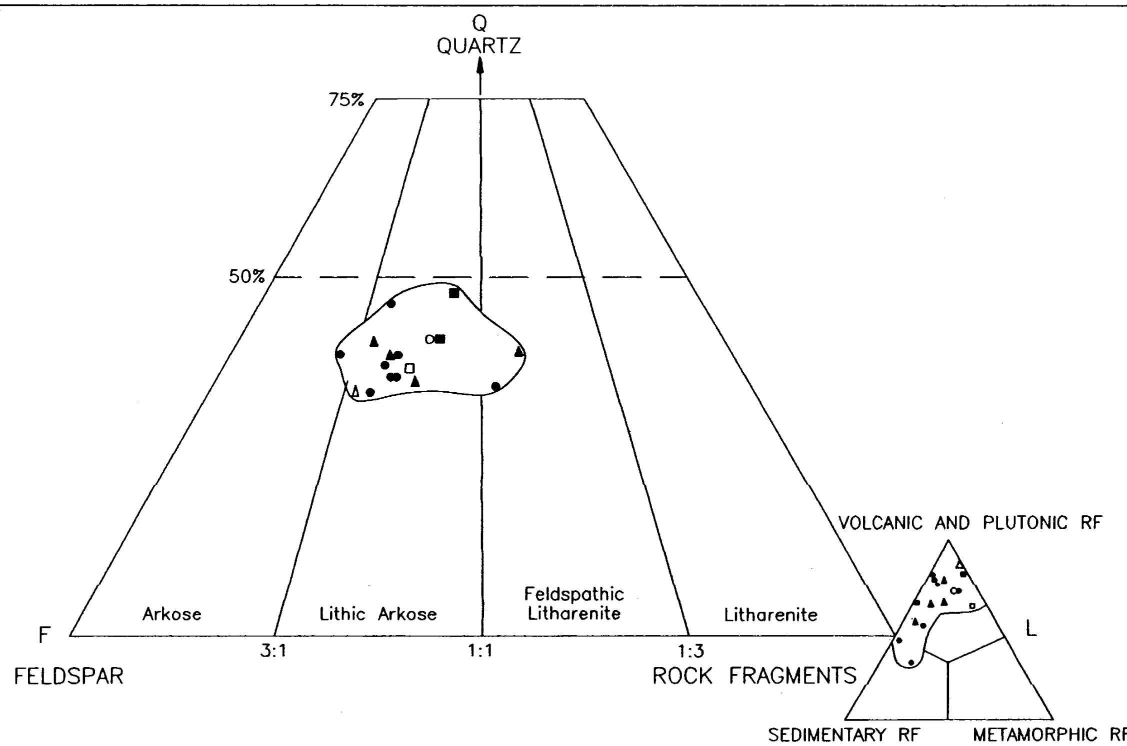
Kulthieth Formation

Depositional Environments and Sandstone Composition

Surface and subsurface geologic data indicate that the sandstones of the Kulthieth and Tokun Formations were deposited in nonmarine to relatively deep-marine environments in an oceanic basin along a continental margin. Kulthieth sandstones onshore appear to be predominantly fluvio-deltaic in origin and were deposited in regressive sequences that prograded southwesterly into fairly deep-marine environments. In the offshore, data on Kulthieth sandstones are largely limited to the OCS Y-0211 No. 1 well, which was the only offshore well to penetrate the formation. Kulthieth sandstones in the OCS Y-0211 well appear to be largely submarine fan and/or outer shelf/slope break deposits that apparently prograded longitudinally along the basin axis as a result of prevailing northwestern marine current systems (see Kulthieth Formation, chapter 5).

Kulthieth sandstones in onshore studies are generally described as arkosic or feldspathic. Petrographic studies by Winkler and others (1976) and Plafker and others (1980) of onshore outcrops and offshore dredge samples of Cretaceous and Paleogene sandstones indicate that those of the Kulthieth and Tokun or equivalent strata are chiefly lithic arkoses (Folk, 1974) with a mean framework composition of 40 percent quartz, 38 percent feldspar (primarily plagioclase), and 22 percent lithic clasts that are predominantly volcanic (fig. 78). Accessory minerals make up 1 to 4 percent of these sandstone samples and consist predominantly of mica (mainly biotite) and epidote. Petrographic and x-ray diffraction studies (Dandavati and Schlottmann, 1984) of numerous samples of Kulthieth sandstones from conventional and sidewall cores of the OCS Y-0211 well (fig. 79) indicate a range from lithic arkoses to litharenites, but most are feldspathic litharenites (Folk, 1974). Petrographic modal analysis from this study indicates that the average composition of the major framework constituents in Kulthieth sandstones of the OCS Y-0211 well is 48 percent quartz, 18 percent feldspar (mostly plagioclase), and 34 percent lithic fragments that are largely metamorphic (mainly biotite mica) and volcanic in origin.

Arkosic or feldspathic sandstones characteristically contain large detrital mica grains (Pettijohn and others, 1987, p. 150). Mica in Kulthieth sandstones is abundant. Detrital mica (chiefly biotite) generally makes up more than 5 percent, and locally exceeds 20 percent, of the sandstone in the OCS Y-0211 No. 1 well. Core lithologic descriptions of Kulthieth sandstone from onshore (British Petroleum White River No. 2 well) and offshore wells (OCS Y-0211 No. 1 well) indicate that the mica occurs both as scattered grains in the sandstone and as dark laminations of silt- to sand-sized biotite grains (British Petroleum, 1962; Barnes and others, 1983). The bulk of the mica appears as laminations which are interpreted to result largely from suspension deposition. Detrital mica generally occurs as flakes that



	UNIT	Q	F	L	V	S	M
OFFSHORE	Oligocene ■ n=2	45	32	23	73	25	2
OFFSHORE	Eocene ● n=8	38	42	20	65	25	10
OFFSHORE	Pre–Tertiary ▲ n=4	38	38	24	68	23	9
ONSHORE	Poul Creek Fm n=10 □ MEAN	37	41	22	67	6	27
ONSHORE	Tokun/Kulthieth Fm n=8 o MEAN	41	34	25	74	11	15
ONSHORE	Yakutat Group n=35 Δ MEAN	34	50	16	89	9	2

Q=Total quartzose grains
F=Total feldspar
L=Total rock fragments (RF)
V=Volcanic and plutonic RF
S=Sedimentary RF
M=Metamorphic RF

Figure 78. Quartz, feldspar, and lithics (QFL) and rock fragment ternary diagrams comparing sandstone compositions of dredged Paleogene samples (solid symbols) and the mean compositions of probably coeval onshore rocks (open symbols) (from Winkler and others, 1976, and Plafker and others, 1980).

have low settling velocities and tend to be concentrated during waning current cycles with quartz and feldspar grains of finer sand or silt size (Doyle and others, 1983). In submarine fan and turbidite sandstones, like those of the OCS Y-0211 well, there tends to be a greater abundance of micas in the finer grained, distal parts of the deposits (Pettijohn and others, 1987).

Log Analysis Methods

Log analysis of Kulthieth sandstone was focused mainly on the OCS Y-0211 well. The onshore exploratory wells that penetrated the Kulthieth Formation were drilled in the late 1950's and early 1960's and have a smaller suite of well logs available for interpretation. Generally, the only porosity log run in these wells was a sonic log, which, as previously mentioned in the Yakataga analysis

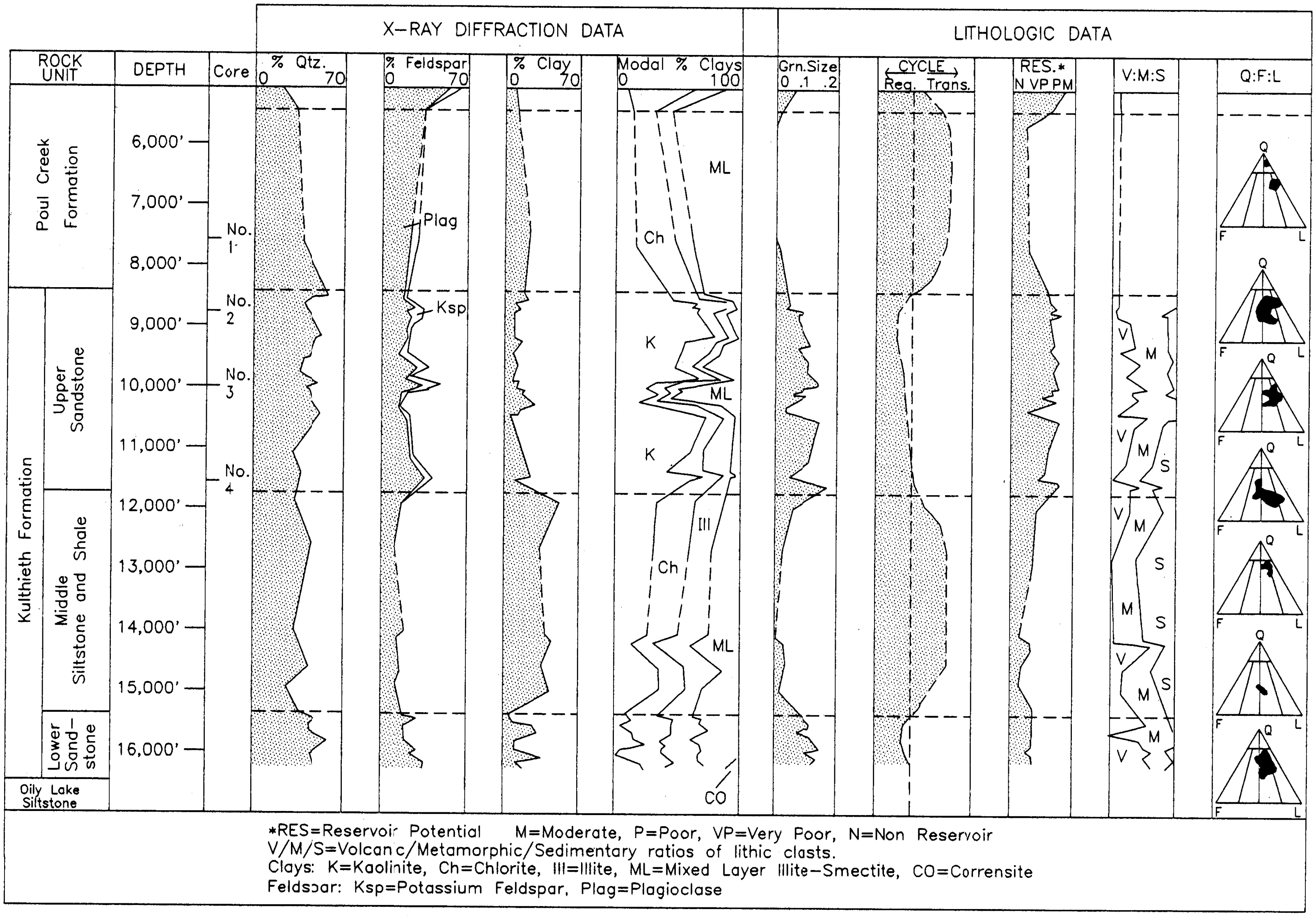


Figure 79. Summary chart showing lithologic and mineralogic data for the ARCO OCS Y-0211 No. 1 well (modified from Dandavati and Schlottmann, 1984).

discussion, yields less reliable porosities in sandstones that are shaly or of complex mineralogy. Consequently, log interpretation of Kulthieth sandstone in the onshore wells consisted mainly of the identification of sandstone and the determination of thickness from SP logs. Porosity analysis was focused on the offshore OCS Y-0211 well, which was drilled in 1983 and logged with a greater number of modern petrophysical tools.

Log analysis of Kulthieth sandstone, as in Yakataga sandstone, is hindered by the mineralogical complexity of the sandstone. In particular, the abundance of biotite mica in Kulthieth sandstones creates log interpretation difficulties because it is heavy and radioactive. Biotite mica is relatively dense (typically 3.1 gm/cm^3) compared to quartz (2.65 $gm/cm,^3$), and if sandstone matrix or grain density is not adjusted for the mica content, apparent porosity calculated from the density log (ϕ_D) will be consistently too low. For example, in a sandstone with a 10 percent mica content and an actual porosity of 15 percent, if the grain density was assumed to be that of quartz, then the calculated porosity would be 12.7 percent.

Because mica is radioactive it will be detected by the gamma ray log as clay or shale and micaceous sandstones will appear shalier than they actually are. Overestimation of shale or clay volume in micaceous sandstone leads to two additional errors in interpretation. First, when apparent porosity (ϕ_D) is corrected for nonexistent shale, the effective porosity (ϕ_E) will calculate too low. This compounds the existing error in apparent porosity (ϕ_D), which is already too low because of the component of dense mica. Then, because porosity is underestimated, water saturation calculated from resistivity logs will be overestimated. The net result is that micaceous sandstones will be interpreted pessimistically with regard to porosity, shaliness, and hydrocarbon saturation (Hodson and others, 1976; Roberts and Campbell, 1976; Suau and Spurlin, 1982).

Fortunately, the SP log is largely unaffected by mica in sandstone, and when used as a clay indicator, it does not overestimate shaliness in micaceous sandstones (Roberts and Campbell, 1976). Mica has a resistivity similar to that of quartz, whereas clay often significantly reduces resistivity and, therefore, SP log response. The SP log in the OCS Y-0211 well (plate 6), as well as in the onshore exploratory wells, appeared to provide a good response between sandstone and shale beds and was used as the primary lithology indicator.

Although the SP log can generally be relied on as a clay indicator in micaceous sands, the density effect of mica needs to be quantified in order to compute accurate porosity from the density log (ϕ_D). Two methods of correcting for mica in Kulthieth sandstones of the OCS Y-0211 well were used, and the resulting porosities from the density log were compared with core porosity. The first method used the average or mean grain density value from core data, as was done in the preceding evaluation of Yakataga sandstones (fig. 80). The second method used natural gamma ray spectrometry logs to estimate the volume of mica in sandstones and adjust the grain density for the estimated mica volume. The first method has the advantage of using direct physical measurements from cores, which account for the average density affects of mica as well as all other mineral components. The second method has the advantage of providing specific point estimates of mica and its grain density effect vertically in the borehole rather than relying on a constant average value as in the first method.

The capability of evaluating mica content and its density effect on a level-by-level basis in the borehole would clearly be more advantageous than using a constant average value as in the first method. As previously noted, mica has fairly unique sedimentological characteristics owing to its sheet-like grain geometry and high relative density. It is probable that mica abundance varies considerably with depositional environment. Evidence for this is the variability of mica in Kulthieth sandstone cores, which is significant both within and between sandstone beds (British Petroleum, 1962; Barnes and others, 1983; Dandavati and Schlottmann, 1984).

Generally, applicable log interpretation techniques for sandstones of complex mineralogy that do not require complex computer analysis are not well established. However, interpretation methods for evaluating micaceous sandstones using modern logs have been developed by Suau and Spurlin (1982) using cross-plots of various logs, particularly natural gamma ray spectrometry and litho-density logs. Peveraro and Russell (1984) evaluated these cross-plots against extensive petrographic and x-ray analytic data from cores and concluded that the thorium-potassium (Th-K) cross-plot from natural gamma ray spectrometry logs was quantitatively the most useful. They indicated that the Th-K cross-plot showed moderate accuracy in measuring mica and potassium feldspars (K-feldspar), although there was a tendency to overestimate

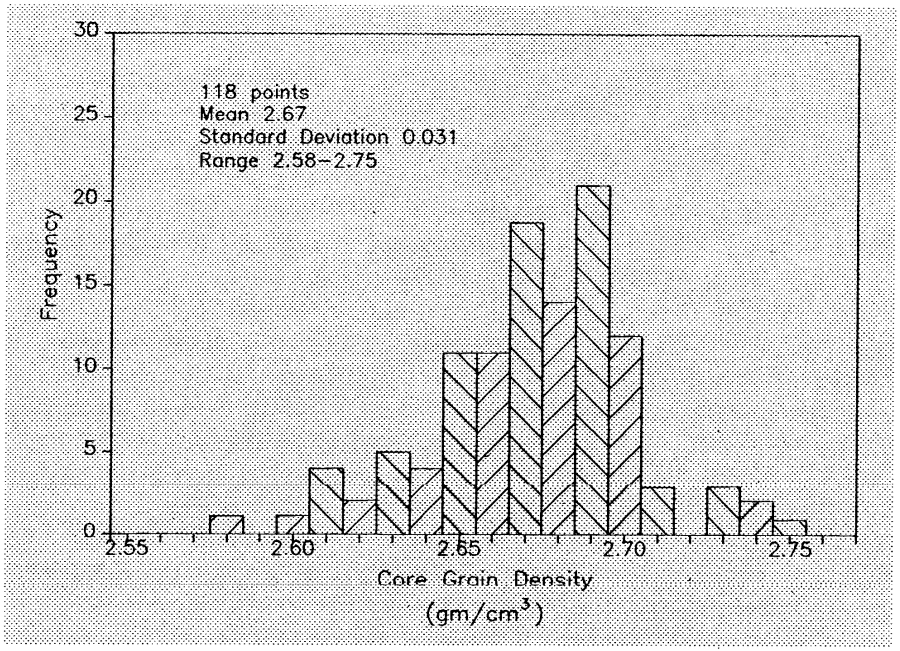


Figure 80. Histogram of grain density distribution in Kulthieth sandstone core samples from the ARCO OCS Y-0211 No. 1 well.

K-feldspar and underestimate mica. This cross-plot was used to estimate mica abundance in Kulthieth sandstones.

Figure 81 illustrates the general principles of the Th-K cross-plot. The cross-plot is used to detect the presence of radioactive minerals: in this instance mica, K-feldspar, and clays that primarily compose shale. Nonradioactive minerals such as quartz and plagioclase feldspar plot at or near the origin. Log responses to mixtures of these minerals are considered to vary linearly between the various end-member mineral points and the origin. The composition of any data point is determined by the relative distances to the vertices of the end-member triangle it falls within. Thus, mineral fractions composing the sandstone framework can be quantified from the cross-plot without resorting to complicated mathematics and complex computer analysis.

Assuming that accurate data is obtained from the logging tool, the validity of this cross-plot analysis is largely dependent upon two assumptions. The first assumption is that K-feldspar, mica, and clay minerals are the main radioactive components, and the second is that thorium and potassium contents of these minerals are reliably known.

For the Kulthieth Formation, the first assumption appears valid. Petrographic and x-ray studies of Kulthieth sandstones from the OCS Y-0211 well, outcrops, and offshore dredge samples suggest that these are the main radioactive minerals in the sandstones (Winkler and others, 1976; Plafker and others, 1980; Dandavati and Schlottmann, 1984).

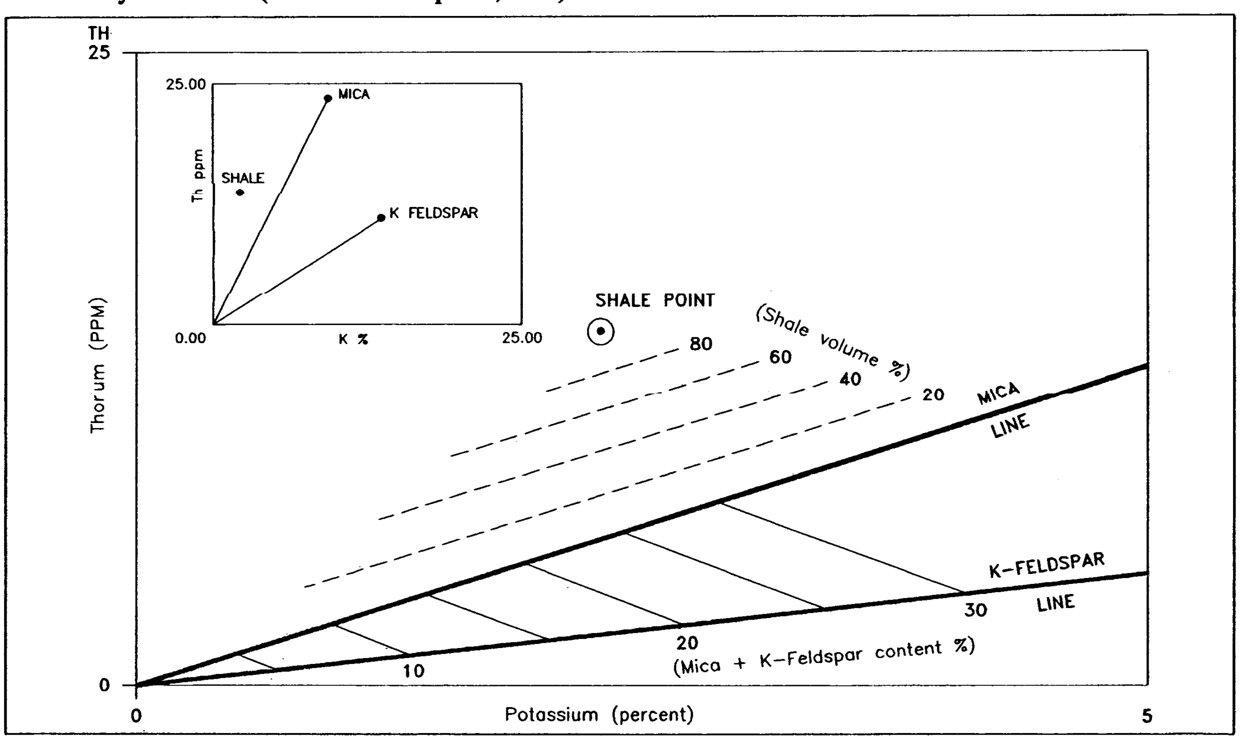
The second assumption is less certain, because of a lack of chemical analytic data on the potassium and thorium content of mica and K-feldspar from Kulthieth sandstones. However, specific analytic data are largely unnecessary in the case of potassium. Potassium contents of mica and K-feldspar are relatively constant, because potassium is an integral part of the crystal lattices of these minerals. Unfortunately, this is not the case for thorium, which is a trace element in these minerals (Edmundson and Raymer, 1979; Serra and others, 1980). Thus, the thorium content of these minerals could, in theory, be highly variable from one region to another.

The unknown thorium content of mineral end-member points is the principal uncertainty in the cross-plot analysis of Kulthieth sandstones in the OCS Y-0211 well. However, this did not present a serious problem in locating the shale point (assumed to be mainly clay minerals), because it was determined empirically from plots of known shales in the well. Unfortunately, this empirical method is not applicable for locating the mica and K-feldspar points, because no pure intervals of these minerals are likely to occur in the sedimentary section. Lacking specific analytic data on thorium contents of K-feldspar and mica in Kulthieth sandstones, it was necessary to use the published values from the literature (Suau and Spurlin, 1982). It is unknown how applicable these values are to the Kulthieth sandstones. However, studies suggest that fairly narrow and distinctive ranges of thorium-potassium ratios are typical for K-feldspar, mica, and other aluminosilicate minerals (Hassan and others, 1976; Schlumberger, 1988, p. 58–59). Since the potassium contents of K-feldspar and mica are relatively fixed, their distinctive thorium-potassium ratios suggest that variations in thorium should not be too large.

Examination of the range in Th-K ratios from log chartbooks (fig. 42) (Schlumberger, 1988, p. 59) indicates that the variation in thorium will primarily affect the slopes of the mica and K-feldspar lines. These are shown to vary by ± 18 percent and ± 9 percent, respectively. On the cross-plot analysis of figure 82, this amount of variation will have the largest effect on the estimate of the relative proportion of mica to K-feldspar, but only a minor effect on the estimate of the total amount of these two minerals. The tendency noted by Peveraro and Russell (1984, p. 504) for the Th-K cross-plot to consistently overestimate feldspar and underestimate mica, may possibly relate to the slope of the mica line being too high. These discrepancies and uncertainties do not appear severe enough to invalidate the cross-plot analysis, but do suggest that the results should be viewed cautiously as semiquantitative estimates unless calibrated to specific core and analytic data.

A Th-K cross-plot of the upper Kulthieth sandstone unit is illustrated in figure 82. The cross-plot suggests that the cleaner Kulthieth sandstones contain variable amounts of radioactive minerals (mica and K-feldspar) ranging from about 5 percent to 25 percent, with an average of about 15 percent. This compares moderately well with visual and petrographic estimates of these minerals in sandstone core samples, which indicate a similar range and an average content of 13 percent mica plus K-feldspar (Barnes and others, 1983; Dandavati and Schlottmann, 1984). According to the cross-plot, mica appears to form the bulk of these percentages, since the largest number of points fall closer to the mica line than the K-feldspar line. A frequency distribution of mica content in clean Kulthieth sandstone calculated from the cross-plot suggests a mean mica content of 11 percent (fig. 83).

Figure 81. Diagrammatic thorium-potassium cross-plot for evaluating micaceous and feldspathic sands from natural gamma ray spectrometry log data. The cross-plot is derived from the inset diagram (upper left), which is a cross-plot with a horizontal potassium scale large enough to encompass the pure mica and K-feldspar end-member points. Nonradioactive minerals such as quartz and plagioclase plot at the origin. Mineral admixtures are considered to vary linearly between end-member points. Points falling below the mica line represent micaceous to feldspathic sandstones that are largely shale-free. Points falling above the mica line represent shales, siltstones, and shaly sandstones (after Suau and Spurlin, 1982).

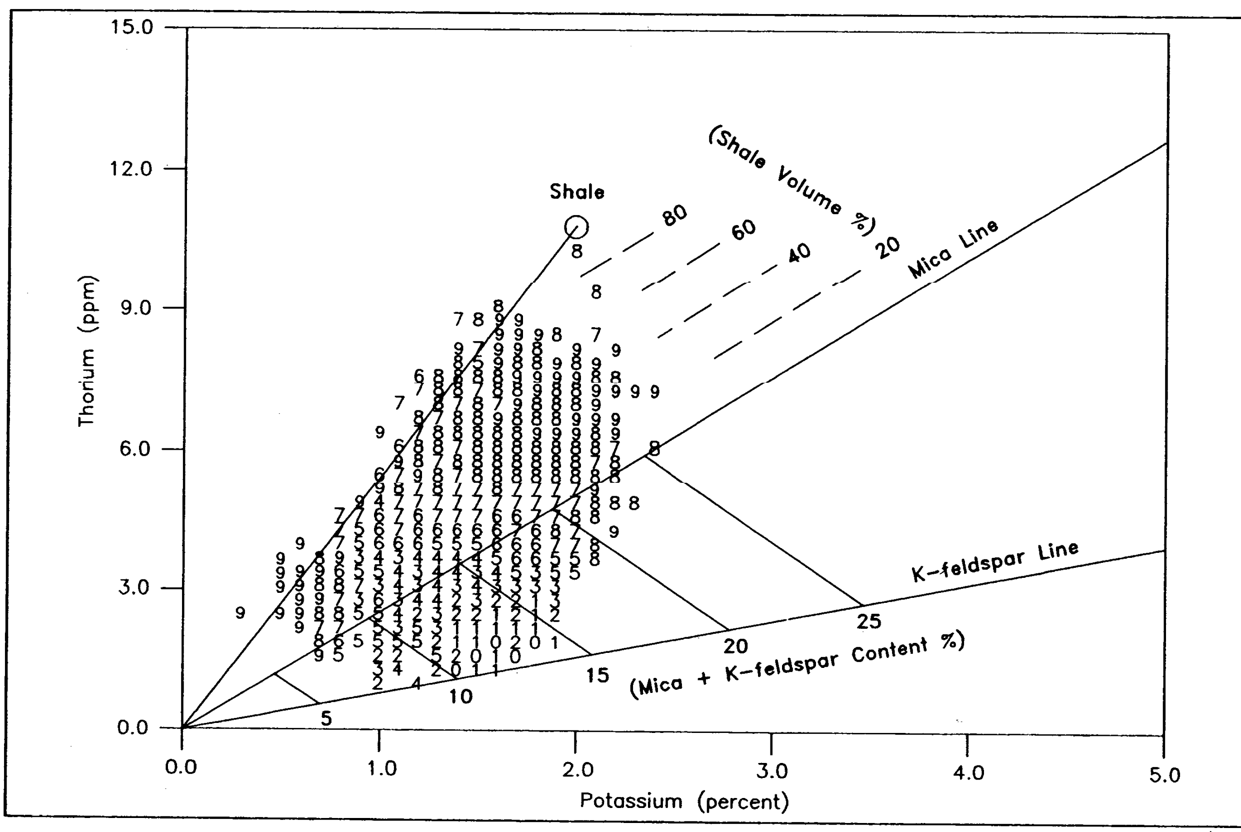


From the relative abundance of mica and K-feldspar that was estimated from Th-K cross-plot, a sandstone matrix or grain density was calculated for each log point from the percentage and known density of each of the different mineral components. The nonradioactive minerals were assumed to be quartz and plagioclase, in a ratio of about 4:3 based on the petrographic data. Plagioclase exhibits a fairly large range of density from 2.62 gm/cm^3 to 2.76 gm/cm^3 (Berry and Mason, 1959), and an intermediate value (2.69 gm/cm^3) was assumed in the analysis. Plagioclase feldspars in Kulthieth sandstone are interpreted to have originated mainly from igneous and meta-igneous rocks that were chiefly intermediate in composition (Winkler and others, 1976).

Grain density determined from the Th-K cross-plot analysis was then used to calculate porosity from density logs (ϕ_{Dx}). The mean grain density from core data (fig. 80) was also used to calculate porosity from density logs (ϕ_{Dc}). These two types of density porosity were compared with porosity from conventional cores (ϕ_C) to test which method of estimating grain density yields the most accurate porosity. Cross-plots of these porosity data are shown in figure 84.

Ideally, if a one-to-one linear relationship exists between core porosity and the calculated density porosity, the points will plot equally along either side of the central diagonal of the cross-plots in figure 84. The data in plot A involving the ϕ_{Dx} come closer to plotting this way, but exhibit greater scatter than the data in plot B involving ϕ_{Dc}. In addition, linear regression of the data indicates that the slope in plot A (0.88) diverges more from the diagonal (1.0) than that of plot B (1.02). Furthermore, the data of plot A have a lower correlation coefficient and a greater standard deviation of regression than that of plot B. This indicates that while the average ϕ_{Dx} more closely approximates ϕ_C, it has a weaker linear relationship and a wider range of error than ϕ_{Dc} in plot B. However, ϕ_{Dc} in plot B consistently underestimates porosity by an average of 1.5 percentage points relative to ϕ_C.

Figure 82. Thorium-potassium cross-plot used in evaluating the mineralogy of the upper Kulthieth sandstones in the OCS Y-0211 No. 1 well (8,570 to 11,650 feet). Numbers at plotted points represent relative SP log response (0=clean sand and 9=shale). The plot suggests that cleaner Kulthieth sandstones (points falling between the mica and K-feldspar lines) contain between 7 and 23 percent mica and K-feldspar. The shale point used in evaluating shaly sandstones is extrapolated somewhat beyond the shale trend line because log and core data indicate that the shales are quite silty.



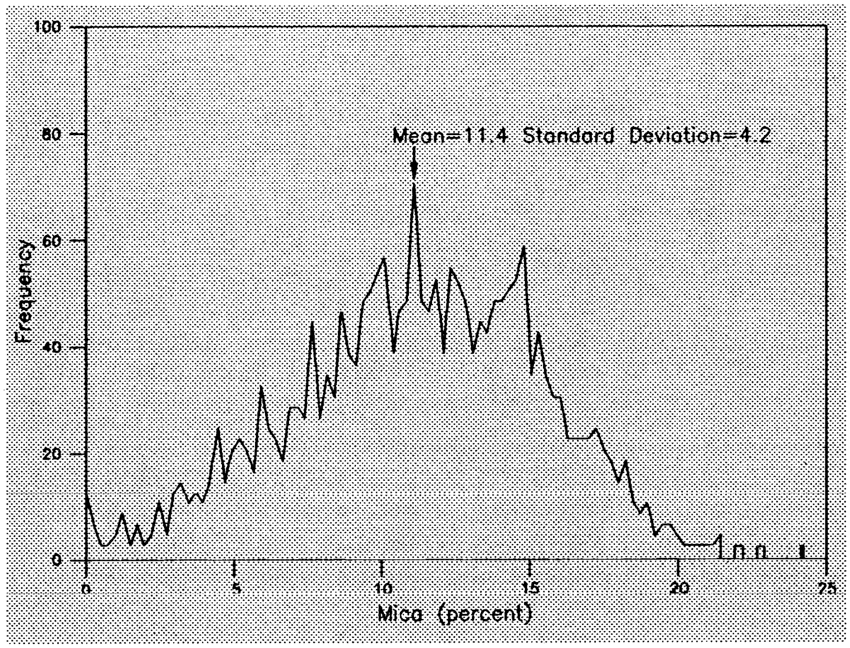


Figure 83. Frequency distribution of mica content (percent volume) in relatively shale-free Kulthieth sandstones in the OCS Y-0211 No. 1 well (depth interval 8,500 to 12,000 feet). The mica content was evaluated from thorium-potassium cross-plots from natural gamma ray spectrometry logs (fig. 82).

The reason for the porosity underestimation of ϕ_{Dc} is uncertain, but may be attributable in part to slight artificial porosity increases in cores relative to the in situ formation porosity. The problem with increased scatter in the ϕ_{Dx} evidently results from variation in the accuracy of grain density evaluated from the Th-K cross-plot analysis. The cause of this inaccuracy in grain density is uncertain, but a number of factors could be responsible. Statistical variations in the gamma ray logs, inaccuracies in the values of the end-member mineral points of the Th-K cross-plot, and the presence of minerals with large density contrasts that are not detected by the cross-plot, such as pyrite, siderite, or coaly detritus, could all introduce error in the grain density evaluated from the Th-K cross-plot analysis.

The ambiguous results of the statistical analysis of the porosity data in figure 84 can be interpreted in two different ways. If one assumes that porosity measurements from cores (ϕ_C) are inflated relative to the actual in situ formation porosity, then the ϕ_{Dc} clearly yields the most accurate porosity. If, however, one assumes that ϕ_C accurately represents in situ formation porosity, then ϕ_{DX} provides a better average approximation of formation porosity.

Given the uncertainties in the assumptions and parameters involved in the Th-K cross-plot analysis, it seems probable that ϕ_{Dc} is the more accurate porosity of the two. However, the difference in the range of error in these two methods of calculating porosity is not great. The standard deviation of the regressions suggests that about two-thirds of the time ϕ_{Dc} and ϕ_{Dx} will be accurate to within ± 2.5 and ± 3.0 percentage points, respectively. Thus, in wells where micaceous sandstones are known to occur, but where quantitative core data are lacking, the Th-K cross-plot analysis appears to provide a workable method of estimating mineralogy and sandstone grain density for calculating density porosity. Both types of density porosity were included in the evaluation of Kulthieth sandstones (table 4).

The density porosity from these two techniques measures the total or bulk-volume porosity of the sandstone. In clean sandstones containing little or no shale or clay, the total porosity is generally representative of the effective permeable porosity. However, in shaly sandstones, the total porosity also includes ineffective microporosity within the shale or clay, which is essentially impermeable. Therefore, in shaly sandstone intervals, it is necessary to correct the density porosity (ϕ_D) for the shale or clay porosity component in order to obtain effective porosity (ϕ_E). The shale porosity component ($\phi_{V_{sh}}$) was calculated using the following equation adapted from Asquith (1982):

$$\phi_{V_{sh}} = V_{sh}[(\rho_{ms}-\rho_{bs})/(\rho_{ms}-\rho_f)]$$

where: V_{sh} = volume of shale
ρ_{ms} = matrix density of shale
ρ_{bs} = bulk density of adjacent shale
ρ_f = fluid density.

The porosity due to shale ($\phi_{V_{sh}}$) was then subtracted from the density porosity (ϕ_D) to obtain effective porosity (ϕ_E).

Because there were indications of oil shows in upper Kulthieth sandstones in the cuttings and cores, water saturation (Sw) was also calculated from the logs to determine the presence and amount of hydrocarbons (oil or gas saturation = 1-Sw). Low values of Sw indicate prospective hydrocarbon-bearing zones. The following equation from Simandoux (1963) was used to determine water saturation:

$$Sw = (0.4R_w/\phi_E^2)[-(V_{sh}/R_{sh})+\{(V_{sh}/R_{sh})^2+(5\phi_E^2/R_tR_w)\}^{0.5}]$$

where: R_w = resistivity of formation water
R_{sh} = resistivity of adjacent shale
R_t = true formation resistivity
ϕ_E = effective porosity
V_{sh} = volume of shale.

An R_w value of 0.16 ohm-meter (170 °F) was used in the equation. This Rw value was derived from salinity analyses of formation water produced during drill stem tests of the OCS Y-0211 well. The Simandoux equation was used because it is appropriate for shaly sandstones where the shale is primarily interlaminated rather than dispersed within the pore space (Asquith, 1990). Descriptions of cores from the OCS Y-0211 well suggest that the bulk of the shale in Kulthieth sandstones is of this type (Barnes and others, 1983).

The actual calculations in the log interpretation of Kulthieth sandstones of the OCS Y-0211 well were made using a computer algorithm of the various methods discussed and are shown in table 4. Well log data were obtained from a digital magnetic library tape in Log Information Standard (LIS) format. Borehole and environmental corrections were applied to the log data and calculations were made every 0.5 feet over the interval of the upper Kulthieth sandstone unit. No calculations were made below about 12,000 feet in the well. Below this depth, the SP log did not deflect opposite Kulthieth sandstone beds, indicating little or no ionic permeability. This suggests that compaction and diagenesis has essentially eliminated all effective

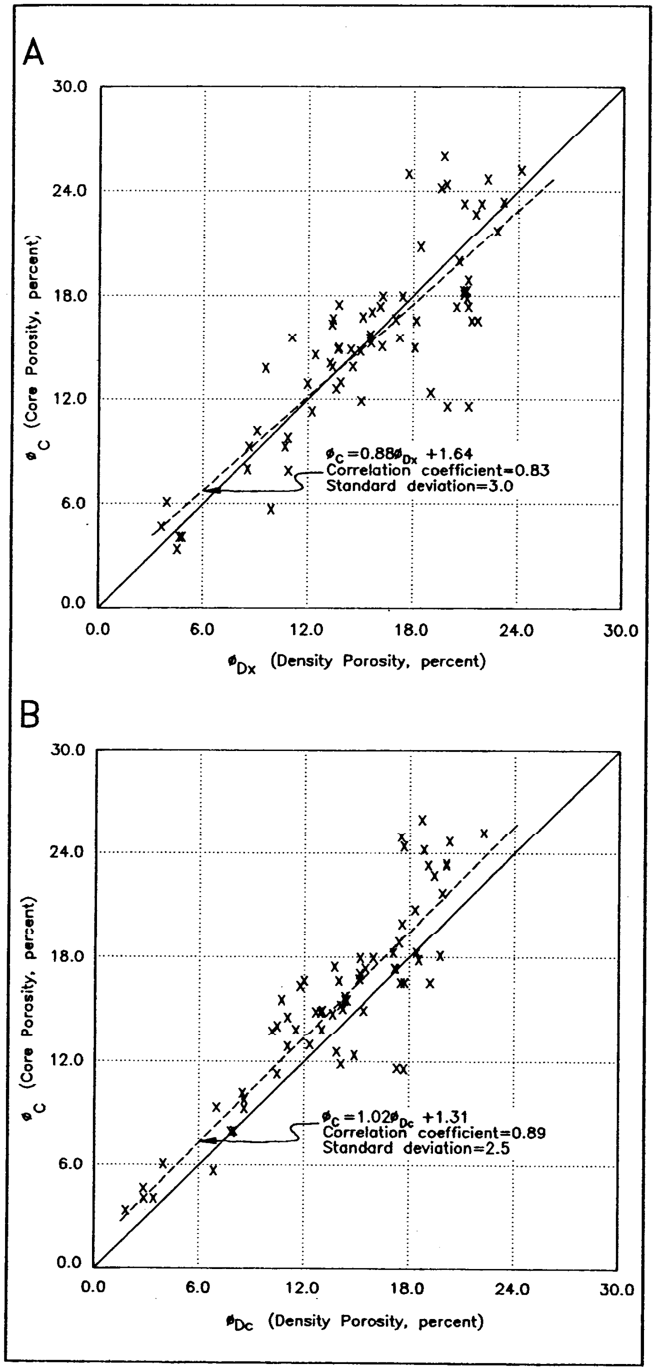


Figure 84. Cross-plots of conventional core porosity versus density porosity of Kulthieth sandstones, ARCO OCS Y-0211 No. 1 well. In plot A, density porosity was calculated using variable grain density. The grain density was determined from spectrometry logs (figs. 81 and 82). In plot B, density porosity was calculated using a constant grain density (2.67 gm/cm^3) obtained by average core grain density measurements (fig. 80). The solid diagonal lines of the plots represent an ideal one-to-one relationship between core and density log porosity. Linear regression (dashed lines) indicates that the equation of the porosity data in plot A ($\phi C=0.88\phi Dx+1.64$) falls closer than that of plot B ($\phi C=1.02\phi Dc+1.31$) to the diagonal, one-to-one line. However, the data of plot A have a lower correlation coefficient and a greater standard deviation of regression than in plot B, indicating that the density porosity derived from the Th-K log analysis introduces more scatter than density porosity derived from the average grain density.

porosity and permeability in Kulthieth sandstone below 12,000 feet in the OCS Y-0211 well.

Sandstone Reservoir Quality

The results of the log analysis of Kulthieth sands in the OCS Y-0211 well are shown in table 4. Compositionally, the log analysis suggests that the sandstone of most beds averages about 60 to 85 percent quartz and plagioclase, 1.5 to 7 percent K-feldspar, 4 to 14 percent mica, and 1 to 30 percent shale. Many of the thicker sandstones are apparently quite clean and have less than 5 percent shale. Ductile deformation of mica flakes or grains is probably a significant factor in the reduction of porosity and permeability in Kulthieth sandstone. Compared to Yakataga sandstones, Kulthieth sandstones are highly compacted and generally exhibit high packing density (Winkler and others, 1976). Because core descriptions indicate that a significant part of the mica is concentrated in the form of thin

Table 4. Kulthieth sandstone composition and reservoir character from log analysis of the ARCO OCS Y-0211 Yakutat No. 1 well.

Depth Interval (feet)	Net Thickness (feet)	Sandstone Composition (%)[1]				Porosity (%)				Water Saturation (%)
		Quartz and Plag[2]	K-spar	Mica	Clay[3]	Total[4] $Ø_D$		Effective $Ø_E$		
						$Ø_{Dc}$	$Ø_{Dx}$[B]	$Ø_{Ec}$	$Ø_{Ex}$	
8,574–8,602	28	60.8	2.4	7.4	29.4	16.6	18.1	12.8	14.6	98
8,662–8,721	56	58.8	2.3	10.6	28.3	18.7	20.3	15.0	16.8	92
8,945–9,085	140	85.3	5.0	8.3	1.4	22.6	24.4	22.5	24.2	92
9,095–9,158	64	72.6	2.4	9.0	16.0	18.0	19.9	15.9	18.0	95
9,170–9,177	7	79.0	2.3	12.2	6.5	17.4	20.1	16.2	19.3	82
9,196–9,205	11	83.6	2.4	9.6	4.4	17.4	19.6	16.8	19.1	85
9,223–9,264	36	67.6	2.5	9.0	20.9	15.0	16.9	12.3	14.3	90
9,315–9,338	23	61.5	2.6	9.5	26.4	16.9	18.7	13.3	15.5	89
9,370–9,525	153	83.2	3.6	10.6	2.6	19.2	21.5	18.8	21.1	82
9,545–9,556	12	75.9	2.7	12.4	9.0	18.0	20.6	16.8	19.5	79
9,586–9,641	54	80.4	4.4	9.8	5.4	17.3	19.5	16.5	18.8	80
9,665–9,701	34	77.2	2.7	10.7	9.4	15.2	17.5	13.9	16.4	86
9,718–9,732	13	83.9	2.6	11.9	1.6	17.7	20.3	17.5	20.1	80
9,778–9,800	23	83.5	4.4	8.0	4.1	18.7	20.5	18.1	20.0	86
9,807–9,820	13	84.4	6.8	7.8	1.0	20.0	21.6	19.9	21.5	88
9,828–9,925	96	83.9	5.0	9.8	1.3	19.5	21.6	19.3	21.4	85
9,936–9,990	54	83.6	5.0	10.3	1.1	19.7	21.9	19.6	21.8	85
10,013–10,026	13	80.0	3.3	12.6	4.1	20.0	22.7	19.5	22.2	90
10,037–10,053	16	73.8	3.1	9.2	13.9	16.1	18.1	14.3	16.4	92
10,210–10,216	6	79.0	3.5	14.0	3.5	14.3	17.4	14.0	17.2	71
10,229–10,265	37	79.0	2.6	9.9	13.2	13.0	15.2	11.8	14.2	82
10,280–10,330	50	81.9	2.8	9.2	6.1	11.6	13.8	11.1	13.4	82
10,445–10,484	39	81.6	3.5	9.7	5.2	14.9	17.1	14.3	16.8	69
10,510–10,548	38	81.0	2.4	9.7	7.4	14.2	16.5	13.1	15.9	69
10,601–10,674	73	72.6	3.4	10.5	13.5	12.3	14.6	11.0	13.6	80
10,930–11,020	90	78.8	3.0	11.5	6.7	7.5	10.4	6.9	9.9	92
11,140–11,180	40	82.9	3.0	6.9	7.2	11.4	13.2	10.8	12.6	83
11,406–11,413	7	85.3	1.6	4.4	18.7	17.4	18.4	14.9	17.1	56
11,456–11,530	67	74.3	2.2	7.2	16.3	11.2	12.9	9.5	11.7	73

Abbreviations: Plag = plagioclase feldspar, K-spar = potassium feldspar.
Symbols: $Ø_D$ = density porosity; $Ø_{Dc}$ =density porosity calculated using a matrix or grain density of 2.67 gm/cm^3, $Ø_{Dx}$ = density porosity calculated using a matrix or grain density adjusted for sandstone mineralogy. $Ø_E$ = density porosity corrected for clay; subscripts c and x as in $Ø_D$.

[1]Sandstone mineralogy evaluated from thorium-potassium cross-plots from natural gamma ray spectrometry logs.

[2]Includes other nonradioactive or weakly radioactive minerals.

[3]Excludes kaolinite and chlorite clays that are weakly radioactive to nonradioactive.

[4]See figure 84 for comparison of density porosities with core porosity.

laminations, vertical permeability may be significantly restricted within most Kulthieth sandstone beds.

Average sandstone porosity from the log analysis (table 4) ranges from as much as 24 percent in a thick bed near the top of the formation to about 10 percent in the lower part of the upper sandstone section near the depth where the SP log stops responding to sandstone beds. This indicates that when average porosities fall below about 10 percent, Kulthieth sandstones are largely impermeable. This suggests that a substantial amount of the total porosity (an average of about 10 percentage points) consists of ineffective microporosity. Consistently low permeability in Kulthieth sandstone, despite relatively high porosity also suggests abundant microporosity.

The relationship between porosity and permeability from measurements of conventional cores from three Kulthieth sandstones in the OCS Y-0211 well is depicted in figure 85, part A. Two populations of data points are evident that suggest two distinct types of sandstone reservoir quality. In the lower and larger population, when porosity falls below about 20 percent, permeability is generally less than 1 md. This relationship indicates that most of the porosity is in the form of ineffective microporosity. This type of sandstone would be very poor reservoir rock. The sandstone represented by the upper, smaller population of points would be somewhat better reservoir rock: permeability does not fall below 1 md until the porosity is less than about 9 percent, and at porosities of 18 percent or more, permeability may be over 10 md. This type of sandstone would have poor (1–10 md) to moderate (10–100 md) reservoir quality.

A comparison of these porosity-permeability relationships with those of other sandstones with various types of authigenic clays (fig. 85, part B) suggests that pore-bridging clays or cements are affecting the lower permeability Kulthieth sands, and pore-lining clays and cements are affecting the somewhat better quality Kulthieth sandstones. Although the log analysis derived from the Th-K cross-plot suggests that many of the Kulthieth sandstones are relatively clay free (less than 5%), it should be noted that the cross-plot is relatively insensitive to nonradioactive clays such as kaolinite and chlorite (Suau and Spurlin, 1982). These nonradioactive clays would go largely undetected by this log analysis technique.

Petrographic and x-ray diffraction data from the OCS Y-0211 well (fig. 86) indicate that aside from compacted mica and ductile lithic grains, authigenic kaolinite clay and calcite cement are probably among the most significant components occluding the intergranular porosity of upper Kulthieth sandstones. Kaolinite appears to be the most pervasive component, while calcite, although significant, is generally more localized. Alteration of the abundant plagioclase in Kulthieth sandstone is interpreted to be the main source of the authigenic kaolinite. The formation of kaolinite and the dissolution and alteration of plagioclase and volcanic rock fragments have apparently resulted in the development of abundant secondary microporosity that is evident from the log and core analysis.

The core data of figure 85 provide a rather bleak assessment of Kulthieth reservoir potential because the bulk of the formation recovered by the cores consists of low permeability sandstone with pore-bridging clays and cements. However, this assessment may be too pessimistic because none of the conventional cores sampled the rocks that log analysis indicates are the best sandstones. Cores 2 and 3 primarily sampled mud-rich, bioturbated intervals, and core 4 was cut in a zone characterized by thinly interbedded sand and shale or siltstone (fig. 48 and appendix F).

The better Kulthieth sandstones that were not cored may fall closer to the trend of the higher permeability population of figure 85. For example, the Kulthieth sandstone with the highest average porosity (24 percent, fig. 87) has an average permeability of 18 md based on calculations from drill stem test data. The porosity and permeability of this sandstone plot near the middle, pore-lining-clay trend-line of moderate reservoir quality sandstones in figure 85, part B. The drill stem test of this sandstone was conducted through perforations in the well casing between 8,950 and 9,070 feet, and the initial flow and pressure buildup data suggested a flow rate of about 850 barrels of formation water per day (ARCO, 1983). If the formation was not significantly damaged during the drilling and casing process, this in situ test may be the most accurate assessment of permeability in the better Kulthieth sandstones of the OCS Y-0211 No. 1 well.

Similar permeability data have been obtained elsewhere from some of the more prospective onshore Kulthieth sandstones. A comparable maximum flow rate from a drill stem test was obtained from a Kulthieth sandstone onshore (600 barrels of formation water per day, drill stem test No. 2, British Petroleum White River No. 2), and similar maximum permeabilities (10 to 20 md) have been measured from conventional core samples of

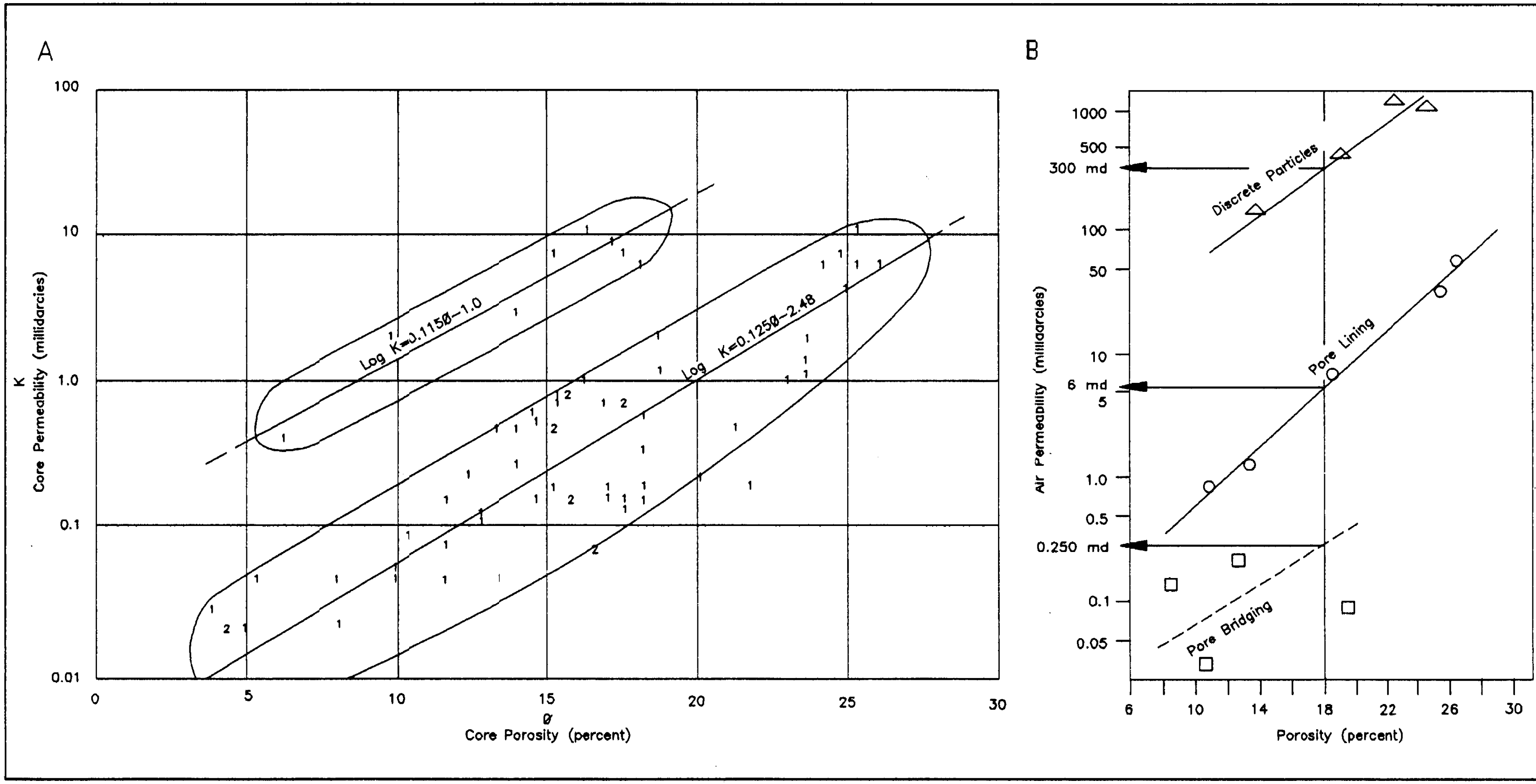


Figure 85. (A) Porosity-permeability relationships in Kulthieth sandstones from conventional cores of the OCS Y-0211 No. 1 well. (B) Effect of authigenic pore clays on permeability (after Neashan, 1977, cited in Asquith, 1990). For constant porosity, different types of clays have dramatically different effects on permeability. In the Kulthieth sandstones of plot A, the population of points in the upper left suggests pore-lining clays and at the lower right, pore-bridging clays.

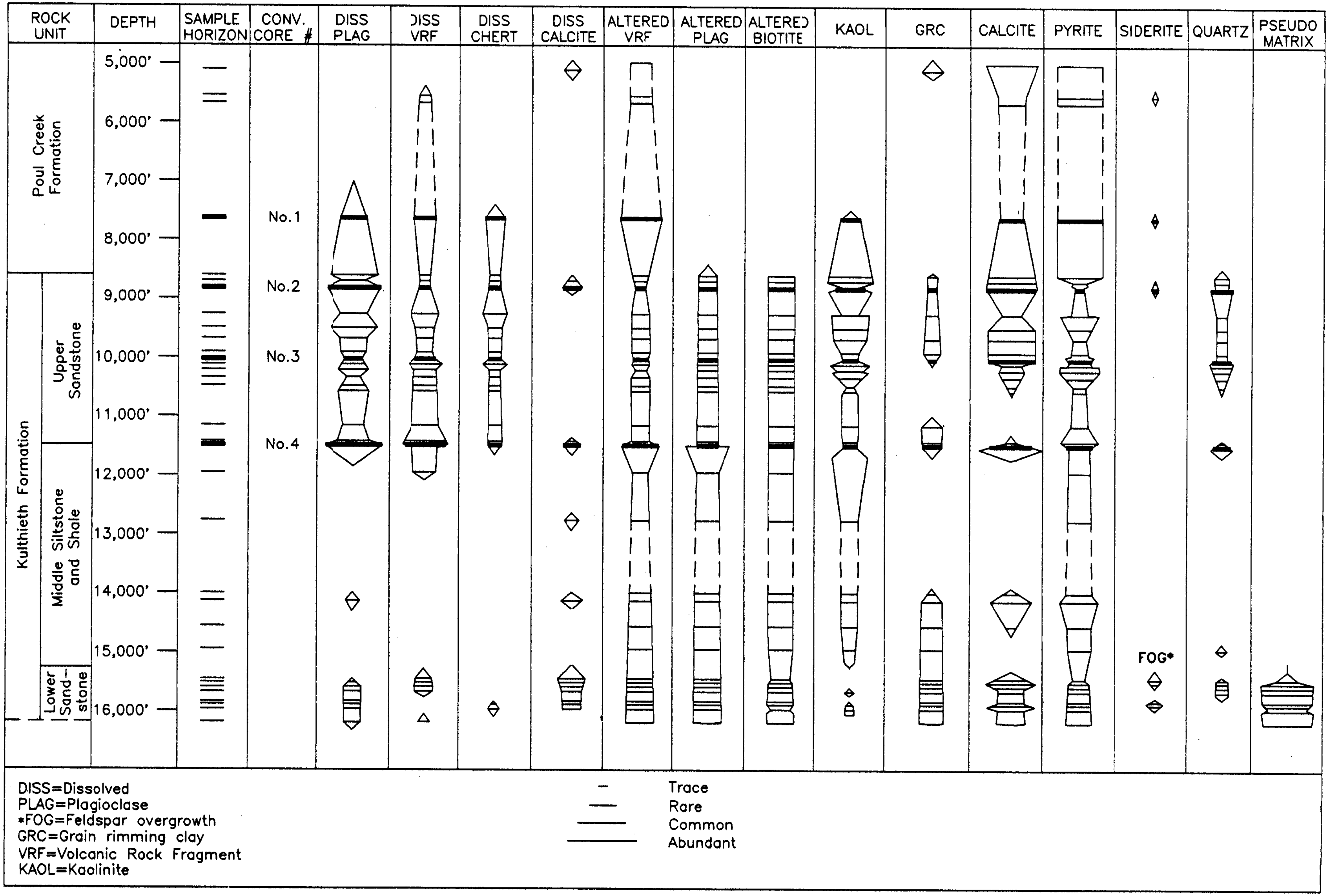


Figure 86. Summary chart showing diagenetic constituents in the OCS Y-0211 No. 1 well (modified from Dandavati and Schlottmann, 1984).

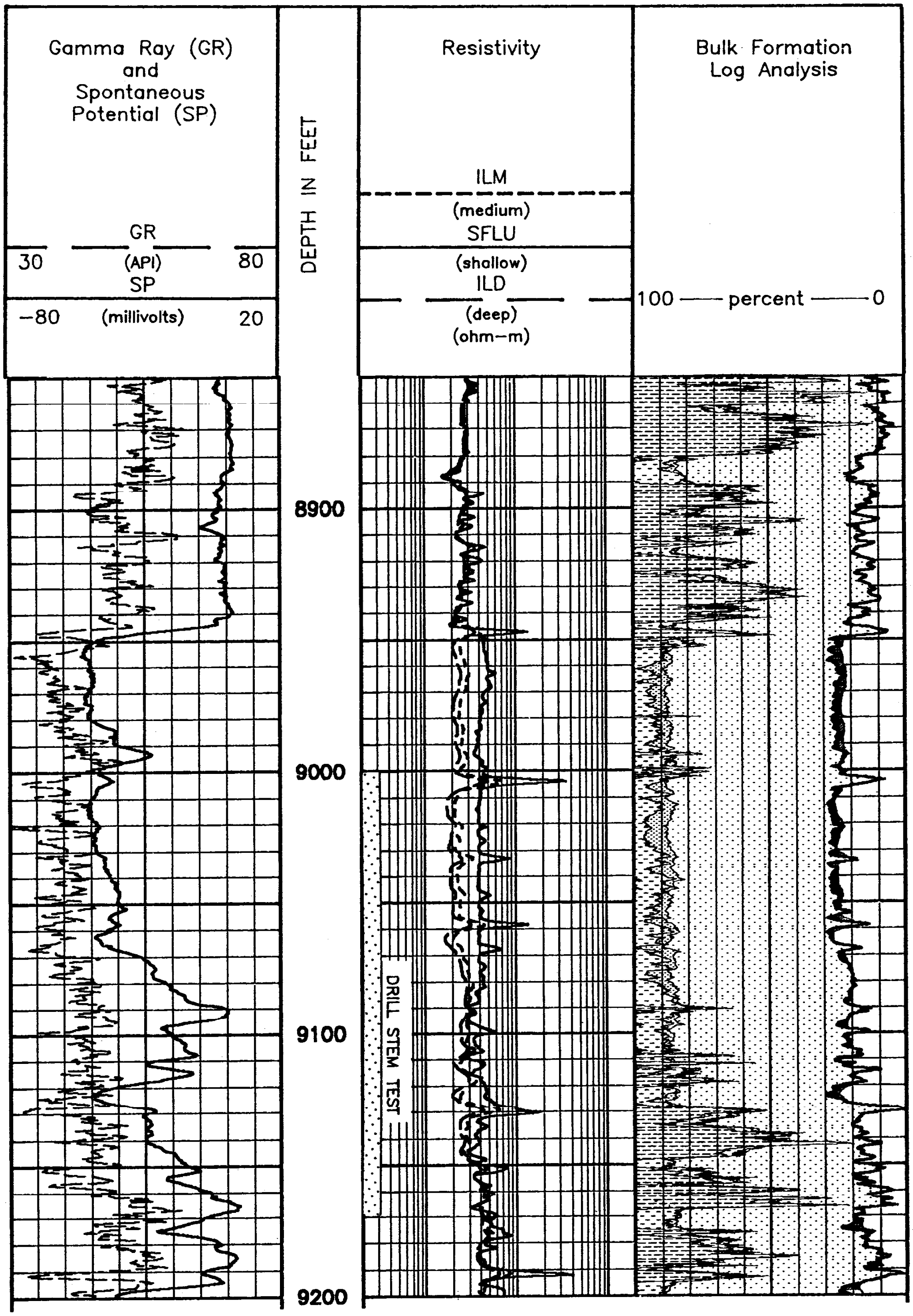


Figure 87. Wireline logs and interpretation of the Kulthieth sandstone with the highest reservoir potential in the OCS Y-0211 No. 1 well. This sandstone (8,945 to 9,085 feet) has an average porosity of about 24 percent and is relatively clay free (see table 4). Drill stem test data suggest an average permeability of 18 md. The interpretation in the right track depicts clay-shale (long dashed), mica (short dashed), K-feldspar (finely stippled), quartz and plagioclase (coarsely stippled), hydrocarbon saturation (diagonally ruled), and porosity (no pattern).

Kulthieth sandstones from the Phillips Sullivan No. 2 well.

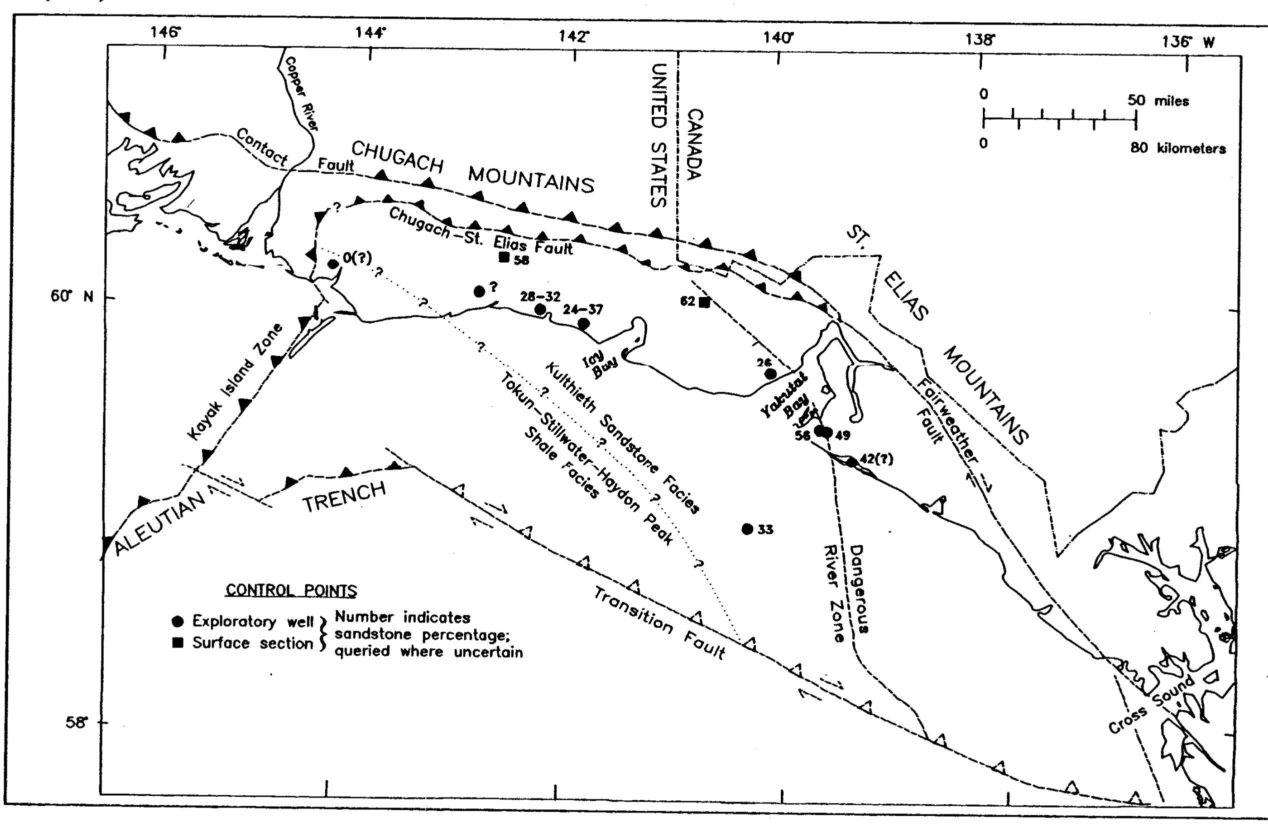
Oil shows were noted in cores and cuttings from the Kulthieth Formation in the OCS Y-0211 No. 1 well, but water saturations from the log analysis in table 1 are consistently high and do not suggest any hydrocarbon production capability. Several drill stem tests of Kulthieth sandstones in the OCS Y-0211 well failed to produce significant hydrocarbons (ARCO, 1983). Probably the most favorable oil shows from the Kulthieth Formation were encountered in the onshore Phillips Sullivan No. 1 well, which produced a maximum of 15 barrels of oil and 45 barrels of water per day during testing (Phillips, 1954).

Sandstone Thickness and Distribution

Data on the areal distribution of sandstone in the Kulthieth Formation in the Gulf of Alaska are sparse compared to that of the Yakataga Formation. Only the offshore OCS Y-0211 No. 1 and onshore Malaspina No. 1-A wells penetrated the entire Kulthieth Formation. The Kulthieth Formation was partially penetrated in eight (or possibly ten) other coastal onshore wells, but in these wells thrust faulting, folding, unconformities, or shallow penetration has complicated interpretation (Plafker, 1967; Rau and others, 1983; Larson and others, 1985a).

The paucity of well control precludes the construction of representative sandstone isopach or percentage maps. Nevertheless, some trends were delineated (fig. 88). In surface exposures from the northern part of the Yakataga district and in the Samovar Hills, the Kulthieth Formation is about 60 percent sandstone (Winkler and others, 1976). Southeast of Yakutat Bay in the Yakutat district, the Kulthieth Formation that was penetrated by several coastal onshore wells is about 50 percent sandstone. South and southwest of these areas in coastal onshore wells of the Yakataga and Malaspina districts and in the offshore OCS Y-0211 well, the Kulthieth Formation is generally about 30 percent sandstone. In the Katalla area, the Richfield Bering River No. 1 well penetrated about 6,100 feet of steeply dipping and faulted shaly Eocene lithofacies without encountering

Figure 88. Eocene sandstone trends in the Tokun-Kulthieth-Stillwater-Haydon Peak stratigraphic sequence. Stratigraphic trends and the limited well and outcrop control suggest that shaly lithofacies of the Tokun-Stillwater-Haydon Peak Formations may predominate in the southwestern part of the Yakutat terrane. For wells, sandstone content (percent) was interpreted from SP logs; for measured sections, it was taken from Winkler and others (1976).



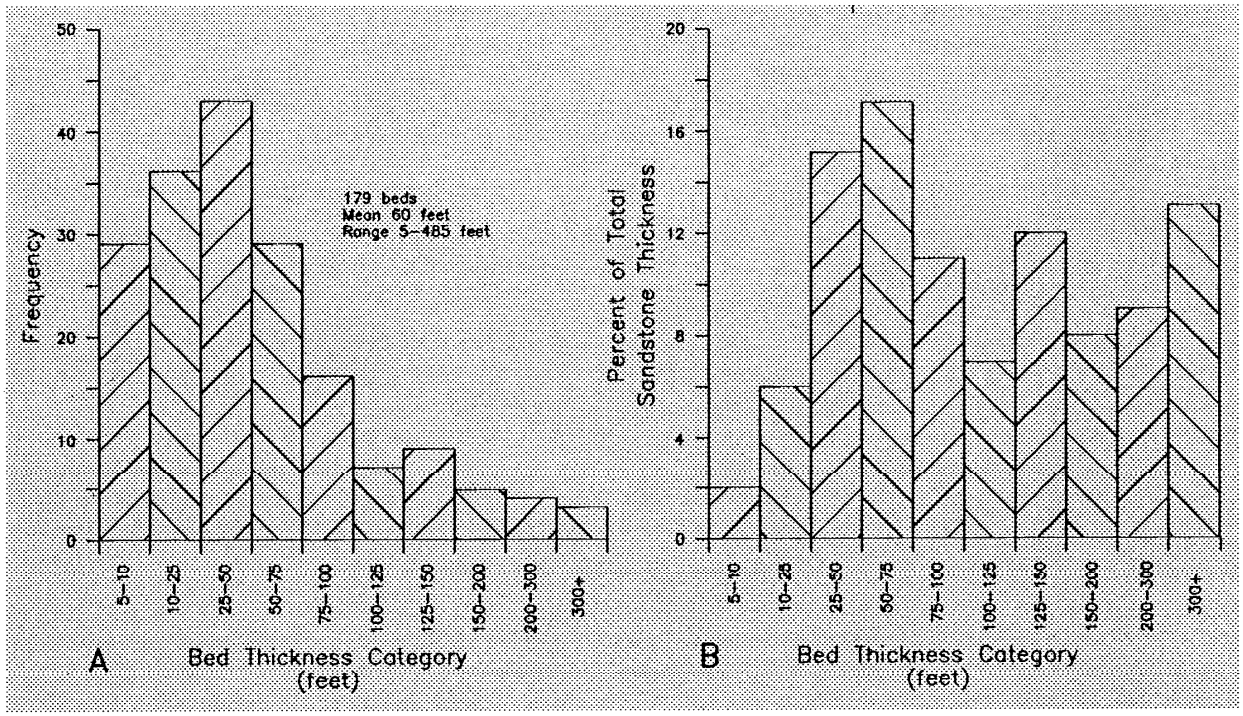


Figure 89. Kulthieth sandstone bed thickness distribution from seven onshore exploratory wells. Histogram A displays bed thickness frequency of occurrence and histogram B displays percent of total sandstone thickness of each bed thickness category. Sandstones were identified from SP logs. Sandstone beds less than 5 feet were not counted. (British Petroleum White River No. 2 and No. 3 wells, Phillips Petroleum Sullivan No. 1 and No. 2 wells, and Colorado Oil and Gas Malaspina No. 1-A and Yakutat No. 1 and No. 3 wells.)

any Kulthieth sandstone facies. However, the well did not drill through the entire Tokun-Kulthieth-Stillwater sequence. These data suggest a diminishing sandstone trend to the southwest away from northeastern to eastern sediment source areas. This sandstone trend is in general agreement with lithofacies distribution, paleodepocenters, and paleocurrent data, all of which suggest a northwesterly trending Eocene paleoshoreline with sediment source areas to the northeast (see chapter 5).

It is uncertain how far offshore in the Gulf of Alaska the sandstones of the Kulthieth Formation may extend. In the Katalla district the Kulthieth Formation apparently shales out to the southwest into the Tokun and Stillwater Formations. It seems likely that this may also occur offshore in the Gulf of Alaska as sediment source areas became more distal. However, the stratigraphic trends and the relative abundance of Kulthieth sandstone encountered in the OCS Y-0211 No. 1 well suggest that Kulthieth sandstone occurs offshore along the southwest flank of the Dangerous River zone in a southeasterly trending belt which extends to at least the Paleogene basin depocenter (plate 5).

Kulthieth sandstones identified from SP logs of seven onshore exploratory wells occur in beds up to 485 feet thick. The relative distribution of Kulthieth sandstone by bed thickness in these wells is shown in figure 89. The average bed thickness is about 60 feet and most beds are between 5 and 125 feet thick. All of the thicker beds in excess of 200 feet were encountered in wells drilled east of Yakutat Bay. For comparison, Kulthieth sandstones drilled in the offshore OCS Y-0211 No. 1 well are shown in figure 90. In the OCS Y-0211 well Kulthieth sandstone beds range from 5 to over 150 feet thick and have a mean thickness of 36 feet. A significant part of the sandstone in the OCS Y-0211 well occurs near the top of the formation in a 1,100-foot-thick sequence of stacked beds with a net sandstone thickness of over 760 feet.

The distribution of Kulthieth sandstone in the onshore wells and the offshore OCS Y-0211 is quite similar if the thicker beds from east of Yakutat Bay are ignored. In those wells that drilled several thousand feet or more of the Kulthieth Formation, the aggregate total thickness of sandstone encountered is generally between 1,000 and 2,500 feet.

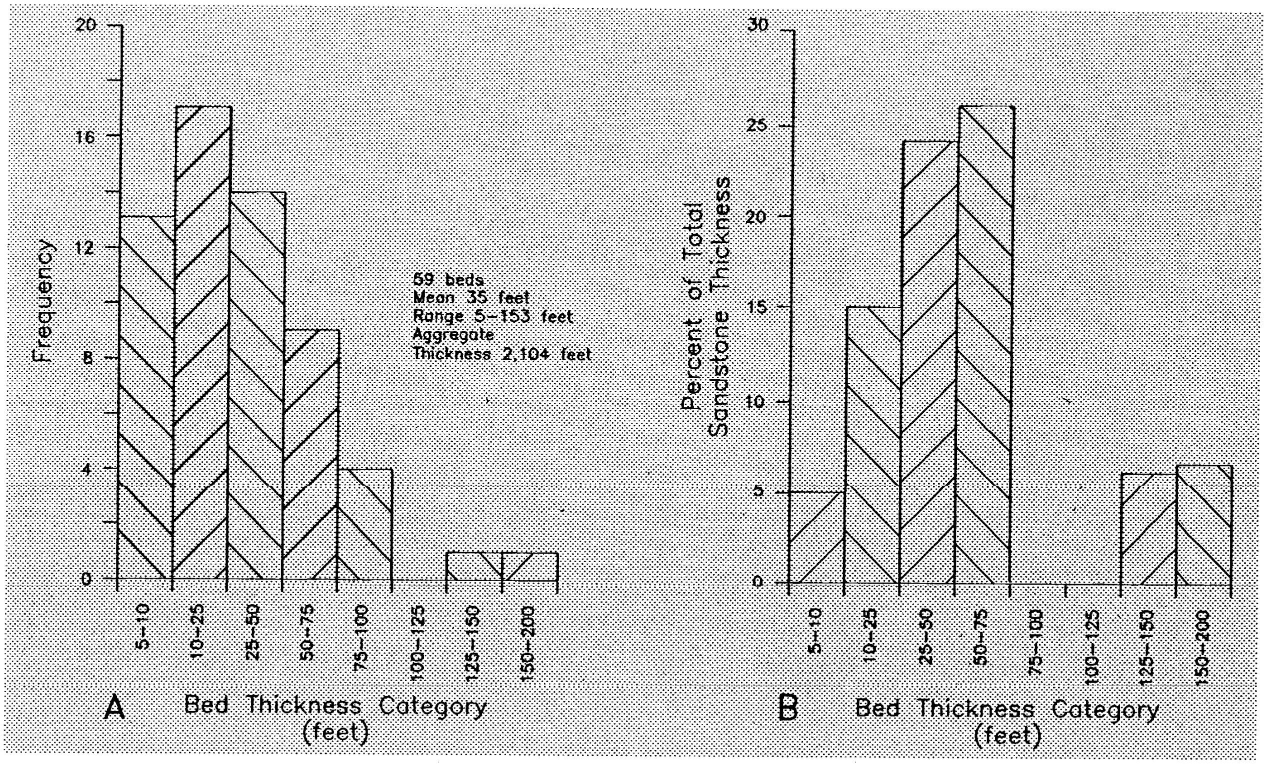


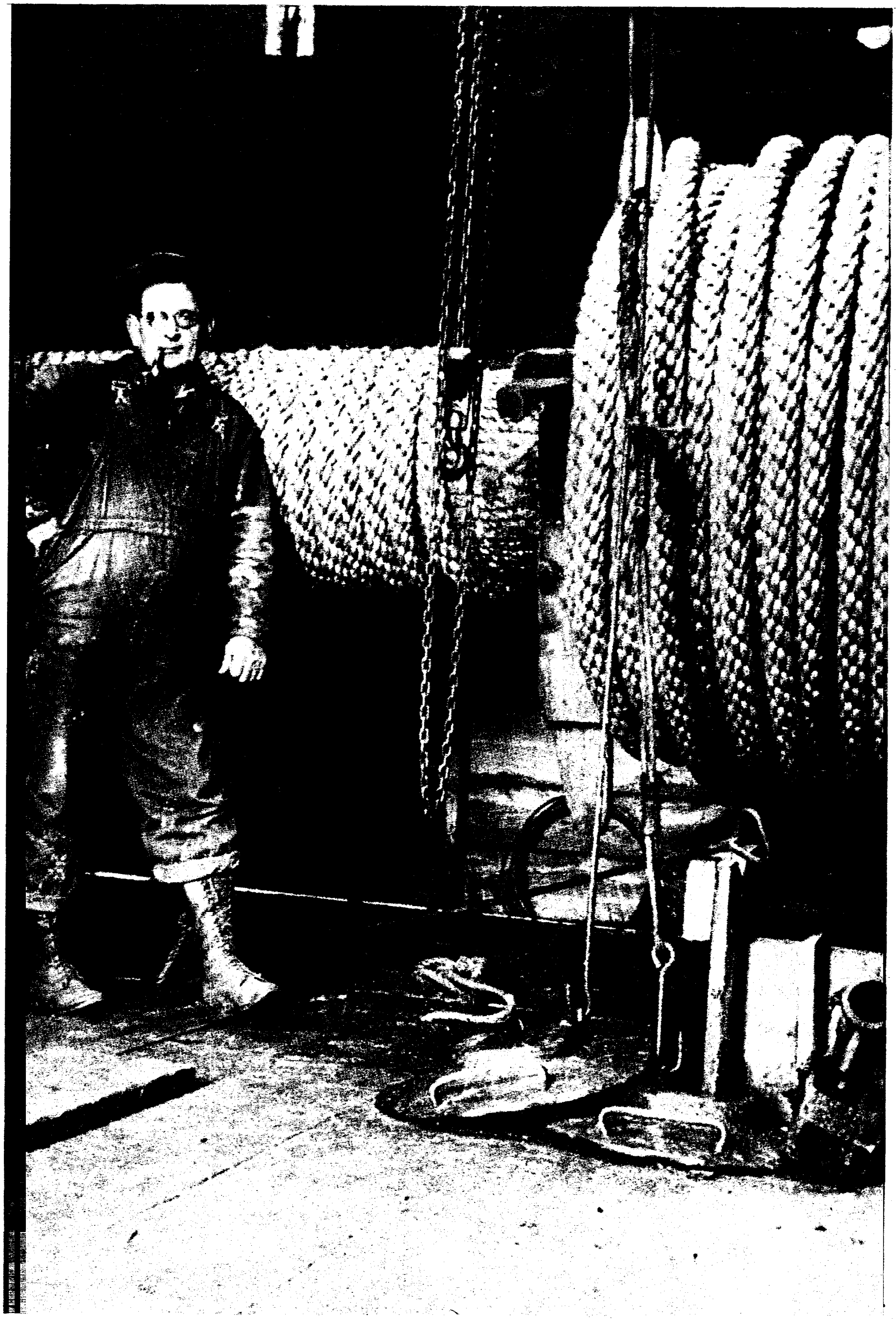
Figure 90. Kulthieth sandstone bed thickness distribution in the ARCO OCS Y-0211 No. 1 well. Histogram A displays bed thickness frequency of occurrence and histogram B displays percent of total sandstone thickness of each bed thickness category. Sandstones were identified from SP logs. Sandstone beds less than 5 feet were not counted.

Summary

Onshore, Kulthieth sandstones were deposited in a southwesterly prograding deltaic system. In the offshore, Kulthieth sandstones were deposited in relatively deep-marine environments apparently as submarine fans and/or outer shelf/slope break deposits. Sparse well and outcrop data suggest that Kulthieth sandstones may shale out in southwestern areas of the Paleogene basin of the Yakutat terrane. Stratigraphic trends from the limited control data suggest that Kulthieth sandstones may occur considerable distances offshore in a broad belt southwest of and paralleling the Dangerous River zone. In the single offshore well (OCS Y-0211 No. 1) to penetrate this inferred belt, an aggregate sandstone thickness of over 2,100 feet was encountered in the Kulthieth Formation. Kulthieth sandstone beds in the well range up to about 150 feet in thickness and have a mean thickness of 36 feet. The most prospective Kulthieth sandstones in the well occur near the top of the formation in a 1,100-foot sequence of sandstone beds with a net sandstone thickness of over 760 feet.

Kulthieth sandstones are predominantly fine- to very fine-grained, and many Kulthieth sandstones were fairly well-sorted during deposition, as they are relatively free of primary detrital clay or shale. However, Kulthieth sandstones are arkosic and micaceous and have undergone significant compaction and diagenesis. In the OCS Y-0211 well, compaction of ductile mica grains and the alteration of plagioclase feldspar to form pore-lining and pore-bridging authigenic kaolinite has significantly reduced primary porosity and permeability. Below burial depths of about 12,000 feet in the offshore, Kulthieth sandstones appear unlikely to exhibit any significant permeability. Sandstones above this burial depth display substantial porosity ranging from about 10 to 25 percent, but much of this is in the form of low-permeability microporosity in authigenic kaolinite clays and altered plagioclase grains and lithic clasts. Many Kulthieth sandstones at depths of less than 12,000 feet exhibit permeabilities less than 10 md and have poor to very poor reservoir potential. However, some of the thicker Kulthieth sandstones from the upper part of the formation can be expected to have moderate reservoir potential, with porosities of from 17 to 25 percent and permeabilities of 10 to 20 md.

***Opposite.** Chilcat Oil No. 20 well, Katalla field. The well was drilled with a cable tool rig. The large spool in the background is the bull wheel.*



THE KATALLA HERALD, SATURDAY, SEPTEMBER 21, 1907.

LOST LIFE ON RIVER

How John Davis Met His Death

BODY EATEN BY WOLVERINES

The Horrible Story of Death in the Arctic Winter, As Told By Emil Shubeck, a Hunter and Trapper in the Copper River Country.

After spending thirteen months continuously in the Copper river basin, at Abercrombie canyon, Emil Shubeck, blond and hairy, came into town this week none the worse for his long period of isolation.

Shubeck was formerly a guide for the survey parties of the Alaska Pacific Railway & Terminal company; later he became a hunter and trapper, and as such he has been employed for several months in the Copper river country.

In The Herald of August 10 was told a brief story of the finding of the bones of a man last February near a deserted cabin on Copper river. The dead man's name was given as Jones, but according to the statement made by Shubeck, who found what the wolverines had left of the body, the man was John Davis, an Australian of twenty years' residence, who went up to Childs Glacier in the employ of J. Stevens, of Valdez, who had located a homestead on the river. On Monday last Shubeck went to Judge Britton's office and formally notified him of his gruesome find.

According to Shubeck's story Davis came up to his (Shubeck's) camp near the rapids on Dec. 26 last year. The weather was cold and windy and Davis remained there eight days. Then he started down the river, despite Shubeck's advice to remain with him until the weather was better. This was the last seen of him alive.

On Feb. 26, last Shubeck left his cabin for Martin river. At an abandoned railroad cabin he saw two guns standing beside the door, and a sack was tied to a pole, evidently as a signal, but he saw no sign of human footsteps or life. He called but got no answer. Shubeck then started back to his own cabin, and when about four miles from Childs' glacier, he saw a black spot on the ice of the river; he looked again and saw several smaller spots. "It looked me not good", said Emil in relating his pathetic story. So he went over to the place and found poor Davis' body. The legs, back and hands and arms and a part of the head had been

FLOW OF CRUDE OIL

Five Barrels a Day On Mirror Slough

Out on Mirror slough Maj. S. L. Lovell, manager of the Alaska Coal-Oil Company of Portland, Ore., is conserving the flow of oil found some time ago on the Carless-Barrett-Sinclair property, which he has under lease, and he is saving about five barrels a day. This product he may use for fuel to operate the rig he is erecting or he may conclude to market it. Some of this oil was sent to Cordova to be tested for its value as a lubricant on the railroad, and Master Mechanic Van Cleave reported to Maj. Lovell that it answered the purpose quite as well as the imported refined article.

Maj. Lovell was in town this week from Mirror slough, looking for a boiler for use at his plant. Some parts of his drilling outfit were lost in a railroad wreck in California, while in transit, but he will be able to operate, with the machinery he was able to get here, including a boiler. The timbers and other ... for the plant are now ... at the Katalla camp 7, and have the drill

TWO MORE OIL RIGS FOR MARTIN RIVER

It is expected that within a short time three oil rigs will be drilling full blast on Martin river. Major ... is expected with a first class rig ... Portland, and C. F. Sinclair has been instrumental in organizing a company which will install two rigs and in the Martin river ... belonging to Sinclair, Carless, ... Cunningham. One of the rigs will be that of Cun... is now located near ...

THE DIGGINGS OF YAKATAGA

BIG NUGGETS ARE FOUND

Judge Thompson and Associates Lease Their Holdings, and the Judge and His Son Will Commence Practice of Law at Katalla.

The Yakataga beach diggings are producing considerable gold, according to a statement made by Judge Julius Thompson, who with Mrs. Thompson and Mrs. Arthur G. Thompson, arrived from Yakataga Sunday morning. With his son, Arthur G. Thompson, Judge Thompson has been engaged in placer mining at Yakataga for the past four ...rs, where they have large holdings, ... lease to other parties.

... as much as $48 have ...nds, and just ... is ...l. ... of ... y be ... thills ... skirt ...ry. ...thority ... believes ... developed ... and around ...siastic be... and for ..., with their ... locate in Katalla ... practice of their

TO-NIGHT

GRAND ATHLETIC EXHIBITION

...ment of the Katalla Athletic Club, C. L. Brock...

PIONEER HAL...

"The Ter... ROUND B...

ONLY LYNCHING IN ALASKA

The only lynching that ever took place in Alaska occurred in January, 1898, at Copper City, one mile from where the thriving town of Valdez now stands. The victim of lynch law was a man named Tanner, a desperado from Montana who, one evening, in cold blood shot and killed two men who had befriended him. There were some fifty men encamped at Copper City, and they quickly gave the murderer a "short shrift and a long rope," hanging him to the limb of a tree until he was dead.

According to Otto Hanson, now a ... Katalla, and who was a ... of Tanner, the lat... rope was ad... was: "You may ... but remember ...st shot that ever ...." Tanner died

MISS BENEDICT'S GRAVE CHARGES

Miss Mabel Benedict, a teacher in the Jessie Lee home at Unalaska, has made astounding statements to the Seattle Ministerial association concerning the manner in which women at Unalaska have been treated by the sailors attached to the United States revenue cutters and gunboats. She says that white women have been harassed and insulted and forced to defend their homes and virtue against these deep water invaders, while native women have been torn from their homes and ravished, and robbed and assaulted.

Capt. E. P. Bertholf of the ... cutter Bear, and Assistant ... torney Ray of Valdez ... dict story flatly, and ... that Miss Benedict ... attle ministers ... ges to the attention

BIG OIL SEEPAGE ON MARY'S CREEK

A fine flow of oil was found this week on Elaine claim No. 5, located on Mary's creek, near Redwood, while assessment work was being performed. This claim is one of a group owned by Judge Britton, A. C. Williams, William Carless, Walter Edkins and others. The seepage was found in an open cut which was run into a bank, and the ... rises at or near bedrock. Both ... where ... located.

... of Trade ... Flips, ... "of Katalla" ... Cin...

- AT THE SEATTLE AND N...

Northern Cafe and ... company from the ... al & Oil company, ... the Northern Oil ... at Redwood, was ... from Bering lake, ... located. The casing

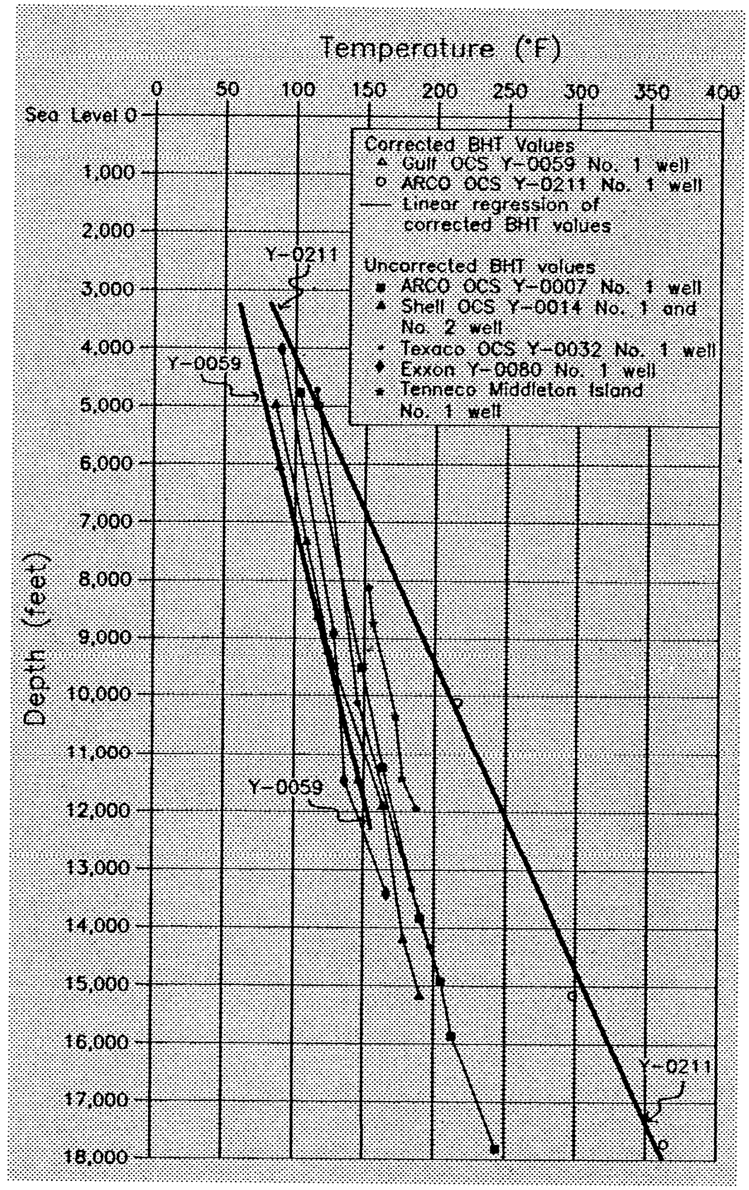
Portland ... Sailing ... dings From ... or about the 25th of each ... ALASKA ... For further information ... ject to Change Without ...

9. Temperature Gradients

The distribution of temperature varies with depth within the earth's crust. The first derivative of a continuous or very closely sampled temperature log, dT/dz, is termed the temperature gradient. If conduction of heat in directions not parallel with z, or the vertical axis, and convection of heat are ignored, dT/dz is directly proportional to vertical heat flow within the crust and inversely proportional to the conductivities of the crustal materials. At a given location, the heat flow can be regarded as constant over a short time interval. Therefore, the temperature gradient reflects changes in the conductivities of the lithologies penetrated by the drill and can be correlated with well logs such as spontaneous potential or resistivity logs. However, the temperature gradients computed for most drill holes are derived from temperature measurements made at widely spaced depth intervals and actually represent average temperature gradients ($\Delta T/\Delta z$). To add further complications, the drilling process alters ambient rock temperature (Bullard, 1947). Circulation time, the time during which the drill hole has been exposed to the relatively cool drilling fluids, is the most important factor in the alteration of ambient rock temperature. In practice, accurate circulation times are usually unavailable. Additionally, the mathematical corrections commonly used to eliminate or reduce this source of error have not been rigorously tested in shut-in wells where long-term temperature recovery was actually observed. Thus average temperature gradients are of questionable significance (Gretener, 1982).

Geothermal gradients vary across the Gulf of Alaska, and most probably have varied throughout geologic time at any single location. Average temperature gradients from selected wells are displayed in figure 91. The gradients for the ARCO OCS Y-0211 No. 1 well and the Gulf OCS Y-0059 No. 1 well are based on corrected bottom hole temperatures (BHT). The other temperature data represent maximum observed BHT's.

Figure 91. Corrected and uncorrected bottom hole temperatures (BHT) from selected wells in the Gulf of Alaska. The depths are corrected to sea level.



Corrected bottom hole temperatures can be estimated from observed BHT measurements by means of a technique suggested by Fertl and Wichmann (1977). This analytical extrapolation is accomplished by applying a linear regression to BHT observations versus the logarithm of the expression:

$$\frac{\Delta t}{t + \Delta t}$$

where for each temperature measurement, Δt = time from cessation of circulation of drilling fluid to the measurement of the BHT (hours), and t = the circulation time (hours). The projection of the line defined by these points to the temperature reached when $\frac{\Delta t}{t + \Delta t} = 1$ is considered to be the corrected or the true static formation temperature. This occurs when the recovery time (Δt) becomes large relative to the circulation time. The procedure is based on the observation that the temperature rise after the circulation of drilling fluids has ceased is similar to static pressure recovery and thus may be analyzed in a similar manner (Fertl and Wichmann, 1977). This technique is considered to yield true static formation temperatures until circulation times exceed 24 hours. The procedure for projecting the corrected BHT for the final drilling run in the OCS Y-0211 No. 1 well is illustrated in figure 92.

Clearly, very detailed drilling histories are required to compute such a correction. In the Gulf of Alaska wells, detailed records of circulation times are rare. The best information available is from the OCS Y-0211 No. 1 well, which was drilled most recently.

Temperature profiles for the OCS Y-0211 No. 1 and OCS Y-0059 No. 1 wells are illustrated in figures 93 and 94. These profiles were derived from linear regressions of the corrected BHT values. The repeat formation tester (RFT) also provided data for the OCS Y-0211 No. 1 well. However, because this tool samples only a tiny amount of formation fluid, probably derived from the annulus immediately surrounding the drill hole, these temperatures are generally considered to be less than true formation temperatures.

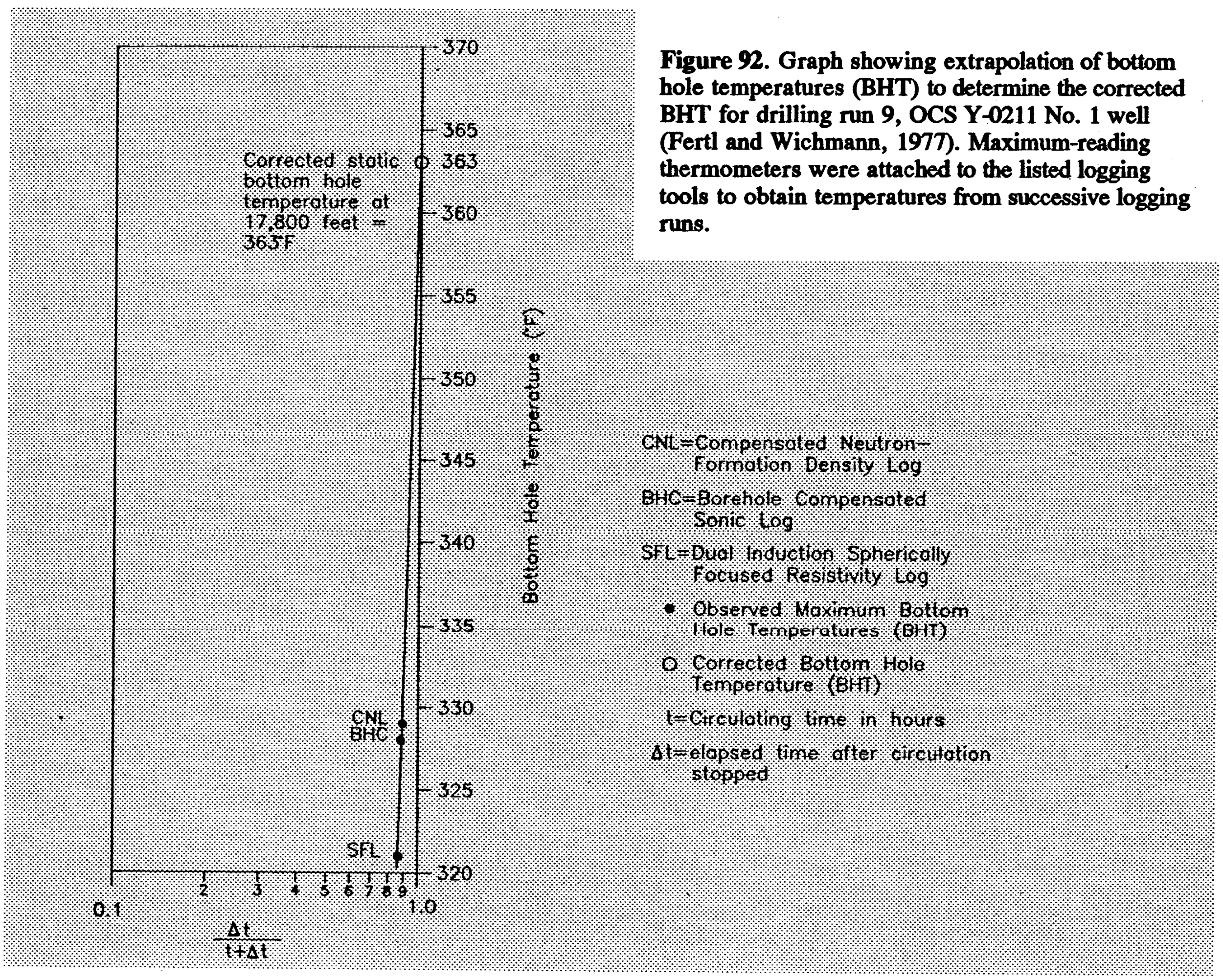


Figure 92. Graph showing extrapolation of bottom hole temperatures (BHT) to determine the corrected BHT for drilling run 9, OCS Y-0211 No. 1 well (Fertl and Wichmann, 1977). Maximum-reading thermometers were attached to the listed logging tools to obtain temperatures from successive logging runs.

Because adequate estimates of circulation times were not available for most of the Gulf of Alaska wells, corrected BHT values were plotted only for the OCS Y-0211 and OCS Y-0059 wells on figure 91. The profiles for the corrected BHT values from the two wells appear to define an envelope that contains most of the other available uncorrected maximum observed BHT data for the region.

The maximum BHT values and the temperature gradient from the OCS Y-0211 No. 1 well are significantly greater than those of the other wells. The temperature gradient from a linear regression of corrected BHT values for the OCS Y-0211 No. 1 well is 1.89 °F per 100 feet of depth (table 5). For uncorrected BHT values from this well, the temperature gradient drops to 1.64 °F/100 feet. Temperature gradients from linear regressions of uncorrected BHT data for the other wells range from 0.75 to 1.05 °F/100 feet. Although the temperature gradient for the Tenneco Middleton Island No. 1 well is low, temperatures in the depth range where they are available tend to be higher than those of the other wells except for the OCS Y-0211 No. 1 well.

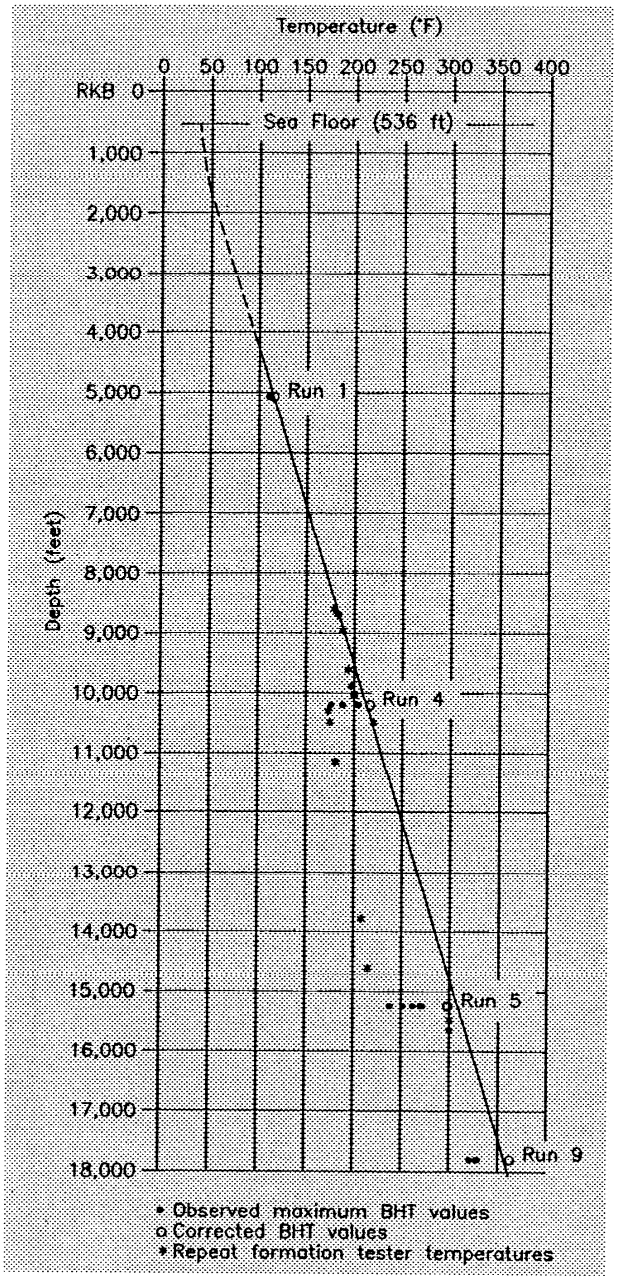
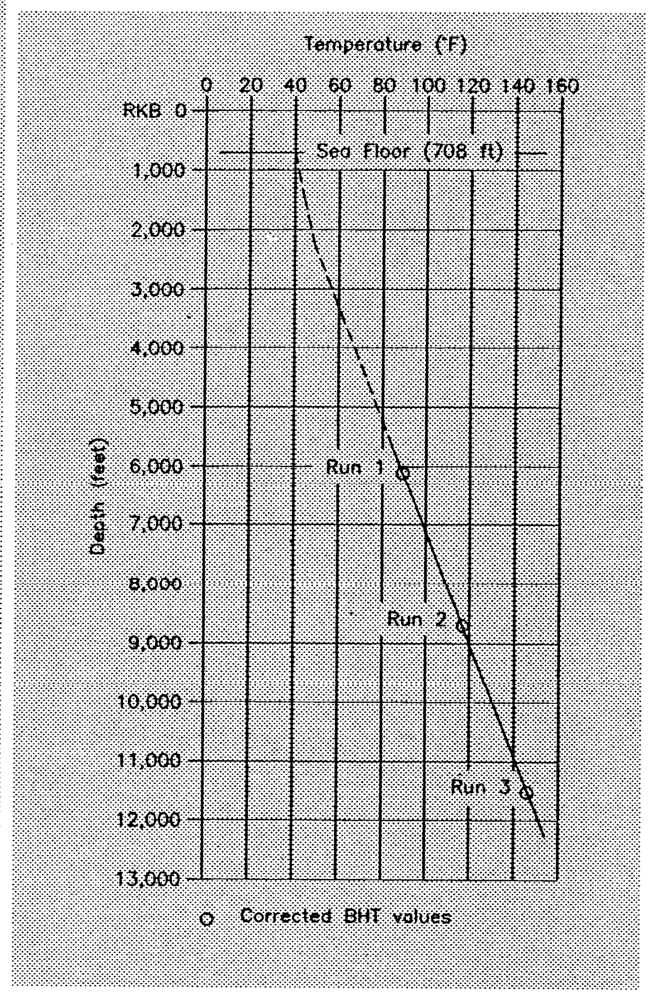


Figure 93 (left). Temperature gradient for the ARCO OCS Y-0211 No. 1 well. The depths are measured from the rig kelly bushing (RKB).

Figure 94 (below). Temperature gradient for the Gulf OCS Y-0059 No. 1 well. Depths are measured from the rig kelly bushing (RKB). Observed bottom hole temperatures (BHT) are so near the corrected BHT values that they are not shown.



Some of the factors that may have influenced these temperature gradients are:

- Drilling conditions such as circulation times and temperature recovery times probably changed from well to well and from drilling run to drilling run.
- Regional heat flow may vary in a tectonically active area the size of the Gulf of Alaska Tertiary Province. The heat flow in the vicinity of oceanic trenches associated with subduction zones tends to be low (Lee and Uyeda, 1965). Heat flow may also have varied with time. Plafker (1987) points out that regional heat flow during the early to middle Eocene was probably greater as a consequence of the emplacement of granitoid plutons throughout the Chugach and Prince William terranes.
- The late Miocene to Pleistocene Yakataga Formation is not as thick in the OCS Y-0211 No. 1 and Middleton Island wells, which penetrated significant thicknesses of Paleogene sediments. The thickness of the Yakataga Formation in these two wells ranges from 2,000 to 3,000 feet, compared to 8,000 to 13,000 feet in other Gulf of

Table 5. Selected bottom hole temperature values from Gulf of Alaska wells.

Well (measurements in feet)	Depth below sea level (feet)	Uncorrected maximum BHT (°F)	Corrected maximum BHT (°F)
OCS Y-0211 No. 1	4,985	113	116
RKB: 86	10,108	205	216
Depth of water: 450	15,161	272	298
	17,714	329	363
OCS Y-0032 No. 1	4,722	115	
RKB: 96	10,129	145	
Depth of water: 240	13,331	184	
	14,320	197	
OCS Y-0007 No. 1	4,755	103	
RKB: 95	9,537	148	
Depth of water: 250	11,250	163	
	13,850	190	
	14,917	205	
	15,862	213	
	17,810	244	
OCS Y-0014 No. 1 and No. 2	4,957	86	
RKB: 90	7,313	108	
Depth of water: 480	9,202	124	
	11,878	163	
	14,194	178	
	15,162	190	
OCS Y-0059 No. 1	6,027		89
RKB: 85	8,609	89	117
Depth of water: 623	11,442	116	146
		141	
OCS Y-0080 No. 1	4,016	90	
RKB: 82	8,920	128	
Depth of water: 448	11,465	136	
	13,410	166	
Tenneco Middleton Island No. 1	8,117	153	
RKB: 70.7	8,745	156	
Depth of water: Approx. 60±	10,354	172	
	11,438	177	
	11,942	187	

Alaska wells. Thick sequences of young, rapidly deposited sediments tend to exhibit depressed thermal gradients.

- The total thickness of sediments above acoustic basement in the OCS Y-0211 No. 1 well is about 17,000 feet. The total thickness of intensely folded and faulted sediments may be as great or greater than 30,000 feet in other parts of the region.
- Stress affects the thermal conductivity of rocks (Gretener, 1982). The deformation of sediments in the wells exhibiting lower temperature gradients suggests that they have been subjected to considerable amounts of tectonic stress that could have reduced porosity and resulted in an increase in thermal conductivity, thus decreasing the geothermal gradient.
- Water circulation in the upper few kilometers of the crust may be responsible for heat transfer if sufficient permeability is present in the sediments (Gretener, 1982). Faults and fractures can also alter permeability and affect heat transfer. Temperature projections involving the upper few thousand feet of sediments in wells are typically unreliable.
- Temperatures near the surface of the crust may not yet have equilibrated since the withdrawal of Pleistocene glaciers (Jessop, 1971; Majorowicz and others, 1988).

Present-day temperatures and temperature gradients in the Gulf of Alaska probably fall within the profiles exhibited by the OCS Y-0059 and the OCS Y-0211 wells (figure 91). The corrected BHT values from the Y-0211 well are currently the best estimate of the temperature distribution available from wells drilled in the Gulf of Alaska. A temperature function for this well can be derived from a least squares regression of the corrected BHT values in table 5. In the tectonically deformed area where most of the wells were drilled, near the convergence of the transform plate boundary and the subducting plate boundary, true ambient rock temperatures are probably greater than the observed bottom hole temperatures but less than the higher values from Y-0211. Temperatures farther west, near Middleton Island, appear to be slightly higher than those observed in the deformed area. Because the available drilling history for the Middleton Island well is particularly poor, it is possible that these differences may be apparent rather than real and a function of uncertainties in estimating circulation times. Various authors have presented hypothetical temperature gradients for the Middleton Island region (Bolm and others, 1976; Fisher, 1980; Fisher and others, 1984; Bruns, 1982b).

KATALLA HERALD

KATALLA, THE COMING METROPOLIS OF ALASKA, W

THE KATALLA HERALD, SATURDAY, SEPTEM

MANY OIL MEN ARE COMING TO KATALLA

That considerable outside interest is ing manifested in the oil fields of Ka- a is evidenced by the arrival on rday afternoon of A. F. Gwin, al manager of the Northern Oil y, a Seattle corporation; J. C. general counsel for the com- Ed Auld, son of the presi- e corporation. Accompany- ere a number of expert oil will operate the rig ob- he Anglo-American com- h will probably be placed ground recently pur- orthern Oil company Messrs. Gwin and 'e been inspecting lake and Mirror npany has bonded D. Gray, and r rig may be

BORING FOR OIL

Development Work Being Steadily Pushed

WELLS WILL SOON BE PRODUCERS

A Brief History of Oil Development in the Controller Bay Region---1600 feet the Deepest hole yet sunk---Oil Finest Quality.

A BOOM IN OIL

Preparing to Begin Active Work

The Katalla Anthracite company is making drill for oil ne has the machin for the equipme on hand, and Su busily engaged in bers for the derric claims north of tov hills.

The outlook now i will be more activity oil the coming year years past—in fact sin boom, when it was de actual development w is a promising oil field.

It is expected that the A leum & Coal company will drilling operations next ye this company shut down abou ago, owing to an accident to chinery, and to the financial good showing was being made, indications for striking a flow of the property the other side of K slough, were considered excellent hole had been drilled to a depth 1600 feet.

The Anglo-American people, it is r ported, will also resume drilling oper ations on Bering lake.

The Alaska Coal-Oil company ex- pects to be at work on Mirror slough

ASKA KNOCKERS

ored by Major John E Ballaine

HEN HE BEGINS TO KNOCK

Seattle-Seward Promoters Knock the Copper River & Northwestern Railway and Shake Guggenheim Bogey in Alaska Club, Seattle.

Seattle, Sep —Major J laine. the Ala

WAITIN TH

FOR VALDEZ

People Are Whether R ject Will Be veloping t

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TO DRILL FOR OIL

Rig to be Erected on Mirror Slough

An oil rig is to be erected at once upon the oil property on Mirror slough owned by C. F. Sinclair, C. Cunningham, William Carless and George T. Barrett. This is the ground on which a good flow of oil was found some weeks ago while doing assessment work, the discovery having been made by Col. Barrett.

Major S. L. Lovell, general manager of the Alaska Coal-Oil company, of Portland, Ore., has secured a twenty- lease of the property and will begin so soon as

A STRIKE OF GOLD QUARTZ

REPORTED ACROSS FROM BERING

Charles Doughton Makes a Sudden Journey to Seattle Taking With Him a Sack Filled With Rock---Gold Placers Said to Be Found.

What is believed to have been a rich gold quartz strike was made about six weeks ago across the divide from the Bering coal fields. The strike is said to have been made by Charles Doughton, who has been prospecting for coal and other minerals in that section for a number of years.

About six weeks ago Doughton returned from a trip which took him to the other side of the mountain range. He had a sack filled with rock which he refused to show anyone. He claimed the men who were backing him, Gov. McGraw and D. A. M Seattle should be first at discovery. So Doug Seattle taking his pr him. He told a fri Katalla, however,

PROGRESS OF MINING

Development Work Bering Lake

VENTILATION FOR

T. P. McDo

KATALLA'S OIL WELLS

And the Great Promise Which They Hold

Katalla people, whether they have lived a long or short time in this section know of the vast probabilities of the oil fields in and about the town, and stretching along the coast for a distance of 100 miles or more. This brief article, therefore, may not interest them, but it will be of interest to many persons, even in Alaska, outside of Katalla.

The oil fields of this region have experienced and are experiencing the same delays and vicissitudes that all oil fields have at first encountered. The oil fields of Texas and Oklahoma, of southern Kansas and southern California were long known to exist before their development was begun, in a practical way, and before they excited the attention and cupidity of the great oil trust.

The existence of oil deposits in this section of Alaska has been known to a few people for a good many years, but it was not until 1900 that any development work was begun. The Pacific Oil & Coal company, known locally as the "English company," was the pioneer in this work. Later they were followed by the Alaska Petroleum & Coal company, which, by the way, continued its explorations until last fall, and these will be resumed on a larger scale than ever early next spring.

The English company ing a large amount of

But it grumbles incessantly, and spits little sprays of oil. The pipe emits a continuous hissing duct of the earth beneath is doing best to burst through the iron shack by which it is confined. Two other rigs are within a short distance of others with pipes filled with oil, closely imprisoned as in the case of the other two.

And this will serve in a very imperfect way, to show the condition of development of Katalla's oil fields today. What they promise may also be gathered from this brief outline, at this one particular spot. Equally promising finds have been made at other points. Some day the oil fields of Katalla will be as well known as those of Pennsylvania, Ohio, Texas or Kansas or Oklahoma.

HANDICAPS OF OIL PROSPECTOR

Work on the Alaska Petroleum & Coal Company's well below the mouth of Katalla river has been shut down, owing to the breaking of the cable rope. The rope was 2600 feet in length, and after being in use but a short time it went all to pieces. Manager Davis has cabled for a new rope, and work will be resumed on its arrival.

The well is down 1600 feet. There is lots of oil sand, and the indications are entirely favorable for striking oil. "But what we want," said Mr. Davis yesterday, "is oil, not indications."

"An oil well supply house is needed here, where fishing tools, supplies such as are needed in drilling and all the other accessories could be found at all

10. Organic Geochemistry and Source Rock Potential

Introduction

During the first third of the century, small-scale oil production occurred in the Gulf of Alaska Tertiary Province (figs. 34b and 66; plate 8). Periodic attempts have been made since that time to discover additional petroleum resources in the region. This report summarizes and interprets the geochemistry that has resulted from these investigations.

Despite previous geologic mapping and carbon isotope studies that have identified the Poul Creek and Kulthieth Formations as sources of oil in the Gulf of Alaska, this study of the available organic geochemistry indicates that the Kulthieth Formation is the most probable source of petroleum in the Gulf of Alaska region. This conclusion is based on four types of evidence. First, detailed composition of the oil samples analyzed more nearly resembles heavy-hydrocarbon extracts from the Kulthieth Formation than extracts from Poul Creek sediments. Second, the Kulthieth Formation tends to be mature or overmature, while the Poul Creek Formation is thermally immature. Third, oil production and sample analysis indicate a predominance of light, low-sulfur, paraffinic and paraffinic-naphthenic hydrocarbons. Such hydrocarbons are generated by terrestrial or nearshore sediments such as those that compose the Kulthieth Formation. Finally, a crude oil sample from a well in the Katalla Oil Field exhibits biomarkers[1] characteristic of an oil generated from a terrestrial or nearshore environment.

The first section of this chapter, "Onshore Geochemistry," summarizes the results of early oil production at Katalla and later analyses performed on cuttings from exploratory wells and samples from surface outcrops. The second section, "Offshore Geochemistry," compares and evaluates results from offshore wells, dredge samples, and Kayak Island outcrops. The third section, "Origin of Petroleum in the Gulf of Alaska," uses chemical composition, carbon-isotope, and biomarker analyses to establish a correlation between the Gulf of Alaska hydrocarbons and their probable source.

While the Kulthieth Formation is suggested as the principal source of hydrocarbon, the limited amount and often poor quality of data make it apparent that these conclusions must remain tentative. The implications of the geochemistry considered here may depart from the conclusions of Miller (1975), Armentrout (1983a), and Magoon (in press). Some authorities believe the Poul Creek Formation contains very rich oil-prone source rocks (total organic carbon contents of 4 to 10 percent; type I and type II kerogen), and unpublished data held by the petroleum industry reportedly supports this claim (Turner, oral commun., 1992). This chapter does not dismiss such a claim, but rather concentrates on the relevant available public data.

Throughout the evaluation of potential source rock analyses, three precautions should be kept in mind. First, total organic carbon is a screening device. It helps to determine when further analyses are feasible and necessary. However, it generally does not discriminate between source and nonsource materials because the mean organic content of all shales is about 1.0 percent, and most source rocks are in the range of 1.0 to 2.0 percent organic carbon (Hunt, 1979). Second, transmitted light microscopy, a common evaluation tool, frequently identifies predominant populations of amorphous kerogen. Amorphous organic matter may

1 Organic compounds whose carbon structure, or skeleton, is formed by living organisms and is sufficiently stable to be recognized in crude oil or the organic matter of ancient sediments. Typical markers are the porphyrins, pristane, phytane, steranes, carotanes, and pentacyclic triterpanes. Biomarkers can convey information about the types of organisms contributing to the organic matter incorporated in the sediments and thus can be used for characterization, correlation, and/or reconstruction of the depositional environment (Hunt, 1979; Tissot and Welte, 1984).

come from algal debris or plankton, indicating a good petroleum potential. However, other sources may produce an amorphous or structureless kerogen. For example, precipitation or adsorption of dissolved or colloidal organic matter results in a structureless kerogen. Intense microbial reworking of organic debris may also destroy original biological structures. Based on these factors, Tissot and Welte (1984) conclude that identification of amorphous organic matter is by no means proof of good petroleum potential. Third, C_{15}+ extractable bitumens may indicate organic richness. If they were generated by the shales in which they occur, they are a legitimate measure of the shale's organic richness. If they were generated elsewhere and migrated into the shale, they yield a misleading measure of the shale's ability to generate hydrocarbons (Tissot and Welte, 1984; Waples and Machihara, 1991).

Organic richness and thermal maturity were used to evaluate available data for the Gulf of Alaska region. Generally, samples with total organic carbon (TOC) content of less than 1.0 percent were considered to have no petroleum source potential. Samples with TOC values of 1.0 percent or more were included in the study, subject to the above-mentioned precautions. For example, a single sample from the Exxon OCS Y-0080 No. 1 well yielded a TOC value of 1.97 percent, a predominant population of amorphous material, a C_{15}+ total extract content of 1,897 ppm, and a thermal alteration level of 1+ to 2- (Tybor, 1979). While these values point to a potential source of petroleum that is immature, there is no way to determine if the amorphous material truly comes from algal debris or if the bitumen migrated into the sediments and produced the high TOC value. Alternatively, where complete suites of geochemical data were available, such as for the ARCO OCS Y-0211 No. 1 well, described in "Offshore Geochemistry," the various sets of data are depicted in figures (see fig. 104, for example) and analyzed in the accompanying text.

Onshore Geochemistry

Produced Crude Oil and Petroleum Seeps

Abundant oil and gas seeps were discovered in the Katalla and Yakataga districts around 1896 by prospectors exploring for gold (plate 8). Detailed maps of the region have also been published by Plafker (1967), Miller (1975), Mull and Nelson (1986), and Plafker (1987).

At Katalla, approximately 154,000 barrels of oil were produced and refined from 18 wells between 1902 and 1933 before the refinery was destroyed by fire. Nearly all of the oil was produced from a narrow eastward-trending zone of about 60 acres total area. The field is believed to be located in a fault zone (Miller and others, 1959). The depths from which the oil at Katalla was produced ranged between 360 and 1,750 feet. The wells produced from faulted and fractured sandstone, siltstone, and shale of the middle Miocene to late Eocene Poul Creek Formation (then called the Katalla Formation), and from unconsolidated sediments overlying this formation (Miller and others, 1959; and Blasco, 1976).

In 1922, the Chilkat Oil Company owned 13 producing wells which fed their refinery on Katalla Slough. Production had peaked in 1919 at 10,853 barrels (Blasko, 1976) and over half the oil production of the Katalla field had been realized. The refinery utilized a simple fire-still process designed to produce the maximum amount of distillate. The crude oil being refined, according to a U.S. Bureau of Mines report of the period (George, 1922), consisted of 44° Baume gravity (44° API gravity) paraffin-base petroleum (Blasko, 1976). The drilling activities at Katalla were described by Martin (1921), Miller and others (1959), and Blasko (1976).

A narrow, east-west-trending belt of oil seeps occurs about 80 miles east of Katalla in the Yakataga district (plate 8). These seeps occur largely on or near the faulted crest of the Sullivan Anticline in rocks of the Poul Creek and the lower part of the Yakataga Formations. The Yakataga Formation has an age range of Pleistocene to late Miocene in this area.

A third, smaller area of oil seeps occurs in the Samovar Hills about 20 miles east-northeast of Icy Bay. It is slightly north of the trend of the Sullivan Anticline, isolated between the Malaspina, Seward, and Agassiz Glaciers on the northwest shore of Oily Lake. This area is intensely folded and faulted, and many of the seeps are mapped along stream beds which occupy fault zones (Blasko, 1976) (plate 8). Oil issues from Quaternary alluvium, from the Plio-Pleistocene portion of the Yakataga Formation, from marine and nonmarine sediments of the Oily Lake siltstone and Eocene Kulthieth Formation, and from interbedded argillite and graywacke of the Cretaceous(?) Yakutat Group (Miller and others, 1959, and Plafker, 1987).

The produced oil and the oil from seeps along the coast of the Gulf of Alaska are generally described in the literature as light, high-gravity, paraffin-rich, low-sulfur oils, considered to be reasonably mature and probably derived from a thermally mature source rock (Martin, 1921; Miller and others, 1959; Blasko, 1976; Lyle and Palmer, 1976; Plafker, 1987). Geologists who have observed these seeps have commented on their ephemeral nature and the lack of or limited amounts of surface residue associated with them. This may be due, in some measure, to the high rainfall in the area, but it is also consistent with seepage of light paraffinic crude oils. Blasko (1976), among others, commented on the transitory character of seeps in the vicinity of Oily Lake, and stated that "a yellow paraffin oil floated on top of the water and accumulated in the areas where flow was less rapid or impeded. A yellow paraffin material was also deposited on the streambeds and collected on rocks and moss."

In the summers of 1973 and 1974, the U.S. Bureau of Mines (USBM) investigated the Katalla area and the region from Cape Yakataga to Yakutat Bay to determine if previously reported seeps were still active, to assess the characteristics of seeping hydrocarbons, and to estimate the amount of bitumen in the drainages leaving seeps and entering the Gulf of Alaska (Blasko, 1976). This report contains standard USBM (Hempel method) distillation analyses for the seeps that were sampled. Such analyses are not particularly useful to geologists, but other information that is included with them can be helpful. Properties such as the density (expressed as API gravity), pour point, and sulfur content are both direct and indirect indicators of an oil's paraffin content. A classification system devised by Lane and Garton (1935) based on the API gravities of two key distillate fractions is summarized in table 6.

Highly paraffinic crude oils frequently have a high wax content which produces high pour points (Hedberg, 1968, and Hunt, 1979). Sulfur contents are usually less than one percent in paraffinic oils (Tissot and Welte, 1984). Table 7 summarizes pertinent USBM data. The first two analyses of crude oil from wells in the Katalla Oil Field have high API gravities, fairly high pour points, and low sulfur contents that are consistent with paraffin- and naphthene-base oils. The remaining oil and bitumen analyses from seeps in the region exhibit increasing sulfur contents as the oil becomes denser. It is possible that biodegradation, water washing, and oxidation selectively removed or destroyed lighter components of the crude oil. An alternative explanation, less likely according to Magoon (written commun., 1991), is that the oil was generated by marine sediments such as carbonates or phosphatic shales. It is not clear whether sulfur is added to the crude oil due to the action of the bacteria, or whether sulfur compounds are just selectively left over after bacteria have consumed parts of the lighter fraction (Tissot and Welte, 1984). However, marine sources such as the Monterey Formation produce much higher sulfur contents than the results shown in table 7 (Magoon and Isaacs, 1983).

The USBM (Blasko, 1976) found that the oils sampled from seeps ranged from 35.2° to 14.1° API gravity with sulfur contents of from 0.53 to 1.31 weight percent (table 7). Bitumen samples exhibited API gravities from 2.4° to 14.6° and the sulfur content ranged from 0.28 to 0.88 weight percent. Gas samples had specific gravities that ranged from 0.577 to 0.833 and caloric values from 724 to 1,427 British thermal units per cubic foot. Though water samples at some oil seeps contained as much as 246,000 milligrams per milliliter (mg/ml) of bitumen, the average amount of hydrocarbons reaching the Gulf of Alaska was less than 0.2 mg/ml.

Despite the fact that the Gulf of Alaska is one of Alaska's oldest petroleum provinces, few analyses of crude oil compositions have been published. Table 8 is a list of some published crude oil analyses.

Early analyses of oil from Katalla were distillation analyses performed to assess the nature of the petroleum products that could be refined from the crude oil

Table 6. Classification of petroleum according to its density (Neumann and others, 1981).

Petroleum Property	Degrees API Gravity (B.P.[1] 250 to 275 °C at 1 atmos.)	Degrees API Gravity (B.P.[1] 275 to 300 °C at 40 mm Hg.)
paraffin-base	≥ 40	≥ 30
mixed-base	33 to 40	20 to 30
naphthene-base	≤ 33	≤ 20

[1]B.P. indicates the boiling point range of the petroleum fraction. The 300-degree distillation end point produces a "good-grade" gasoline. Higher distillation end points yield "regular-grade" gasoline, and ultimately diesel fuel, fuel oils, and so forth (Blasko,1976).

Table 7. U.S. Bureau of Mines oil and bitumen analyses, Gulf of Alaska (from Blasko,1976).

Locality	Source/Description	API Gravity[1]	Pour Pt.[2] (°F)	Sulfur (weight percent)
Oil Analyses				
Katalla Oil Field				
Well No. 5		31.9	20	0.52
Redwood Well	Sample from open casing	35.2	-10	0.53
Sullivan Anticline				
Crooked Creek	Sample from bitumen surrounding oil seep	21.0	-15	0.90
Lawrence Creek	Oil seep	12.9	-10	0.82
Munday Creek	Oil seep	17.2	-15	0.96
Poul Creek	Oil seep	24.8	-20	0.68
Johnston Creek	Sample from lower seep pond	15.4	-15	0.73
Johnston Creek	Sample from upper seep area	19.0	-10	0.70
Samovar Hills				
Oily Lake	Sample from oil residue on water	14.3	N.D.[3]	1.08
Oily Lake	Sample from several small seep pools on old lake bed	14.7	-10	1.31
Oily Lake	Sample from seep in sandstone above old lake shore	14.1	-10	1.20
Oily Lake	Sample from seep in rock formation above old lake shore	14.9	-10	0.90
Bitumen Analyses				
Samovar Hills				
Oily Lake	Surface bitumen (solid) near Oily Lake	4.6	N.D.	0.29
Oily Lake	Surface bitumen (solid) near Oily Lake	2.4	N.D.	0.31
Oily Lake	Surface bitumen (solid) near Oily Lake	2.4	N.D.	0.31
Oily Lake	Surface bitumen (solid) near Oily Lake	5.7	N.D.	0.28
Oily Lake	Surface bitumen (solid) near Oily Lake	14.6	-10	0.72
Oily Lake	Surface bitumen (liquid) obtained from solid bitumen during warm weather (same location as preceding sample)	12.8	-10	0.88

[1]Gravity, $°API = \frac{141.5}{\text{specific gravity}_{60\ °F}} - 131.5$

[2]The pour point is the temperature below which oil will not flow under certain specified conditions. See Hunt (1979) and Hedberg (1968) for details about the determination of pour point and its use as a measure of an oil's waxiness.

[3]N.D. No data indicates that the pour point was not determined.

(table 8). Historically, crude oils were classified into two main groups, paraffin base and asphalt base, depending on the content of paraffin or asphalt in the petroleum residuum (Hunt, 1979). A high percentage of crude oils are actually mixed base; they do not belong distinctly to either the paraffin- or the asphalt-base type. Also, a simple distillation cannot adequately define the chemical composition of the oil fractions (Hunt, 1979). Detailed chemical compositions are needed to compare one oil with another, or an oil with its possible source rock. Tissot and Welte (1984) suggested a more rigorous method of crude oil classification derived from analyses of crude oils from 541 oil fields worldwide. It is based on the bulk composition of three fractions: (1) alkanes, (2) cycloalkanes (naphthenes), and (3) aromatics, plus nitrogen, sulfur, and oxygen (NSO) compounds (resins and asphaltenes). It also takes into account the sulfur content. Two of their diagrams have been combined in

Table 8. Some representative oil analyses from the coast of the Gulf of Alaska.

Produced Oil[1]	Density (g/cc)	API Gravity		Benzene (%)	Kerosene (%)	Lubricating Oil (%)	Residue Coke and Loss (%)
Katalla Slough Well No. 1	0.8280	39.4		21.0	51.0	28.0	
	0.7958	46.3		38.5	31.0	21.5	9.0
	0.7957	46.3		38.5	31.0	21.5	9.0
	0.800	45.4		34.2	34.4	16.5	14.5
	0.869	31.3			19.0	78.6	1.8
	0.914	23.3			9.0	87.6	2.7
	0.800	45.4		24.8	53.9	16.7	1.2

Surface Seeps[2]	Density (g/cc)	API Gravity	Volatiles on Drying (%)	Composition of Dried Crude Oil (%)				Sat.Hydc. / Arom.Hydc.
				Sat. Hydc.	Arom. Hydc.	Resins	Asphtn.	
Samovar Hills (N½ Sec.2, T21S, R27E)	0.9699	13.2	8.9	20.2	34.7	23.7	21.7	0.58
Sullivan Anticline (Johnston Creek)	0.9183	21.1	22.0	9.4	13.1	5.8	71.7	0.72

Surface Seeps[3]	Sulphur (%)	API Gravity	Non-volatile $C_{15}+$ at 40 °C	$C_{15}+$ Normalized (%)				CPI	Pr / Ph	$\delta^{13}C$(‰)	
				Sat. Hydc.	Arom. Hydc.		Non-hydc.			Sat. Hydc.	Arom. Hydc.
Samovar Hills (Hubbs Creek)	0.07	37.4	61.5	83.3	15.1		1.7	1.1	4.8 6.2	-26.9 -27.5	-25.5 -25.8
Wingham Island (South End)				67.0	23.0		10.0	1.2	5.7	-27.4	-26.3

[1] Extracted from a summary of analyses of petroleum from the Controller Bay region in Martin (1921).
[2] Analyses of altered oil samples obtained by Tenneco Oil Company for Lyle and Palmer (1976).
[3] Analyses of unaltered oil samples published by Plafker (1987) and Magoon (in press).

figure 95, and the six available oil analyses from the Gulf of Alaska were plotted on it. The locations of these samples and the specific analyses that were performed are listed in table 9. Because most Gulf of Alaska oil analyses did not include a breakdown of the alkanes versus the naphthenes, they were plotted on figure 95 as lines rather than as points, with each line representing a range of possible compositions bounded by the fields that Tissot and Welte (1984) consider to be characteristic of low-sulfur crude oils (less than 1.0 percent sulfur).

Application of the Tissot and Welte (1984) classification system to six crude oil samples from the region indicates paraffinic and paraffinic-naphthenic oils plus a biodegraded, oxidized product of one or both of the paraffinic and paraffinic-naphthenic oils. Descriptions of the six samples follow.

Phillips Petroleum provided the U.S. Minerals Management Service (MMS) with a crude oil sample in 1991 (point *a* on fig. 95). This sample came from a well identified as the Katalla No. 36, believed to be the Chilkat Oil Company No. 18 well drilled in 1921 (Miller, 1975), and is probably relatively unaltered. It was drilled to a depth of about 1,000 feet in 1921 in Section 36, Township 19 South, Range 5 East in the Katalla Oil Field. The sample was sealed and refrigerated, probably for more than 10 years before analysis. The chromatogram (fig. 96) and Tissot and Welte's crude oil classification (fig. 95) suggest an unaltered, mature, paraffinic-naphthenic crude oil.

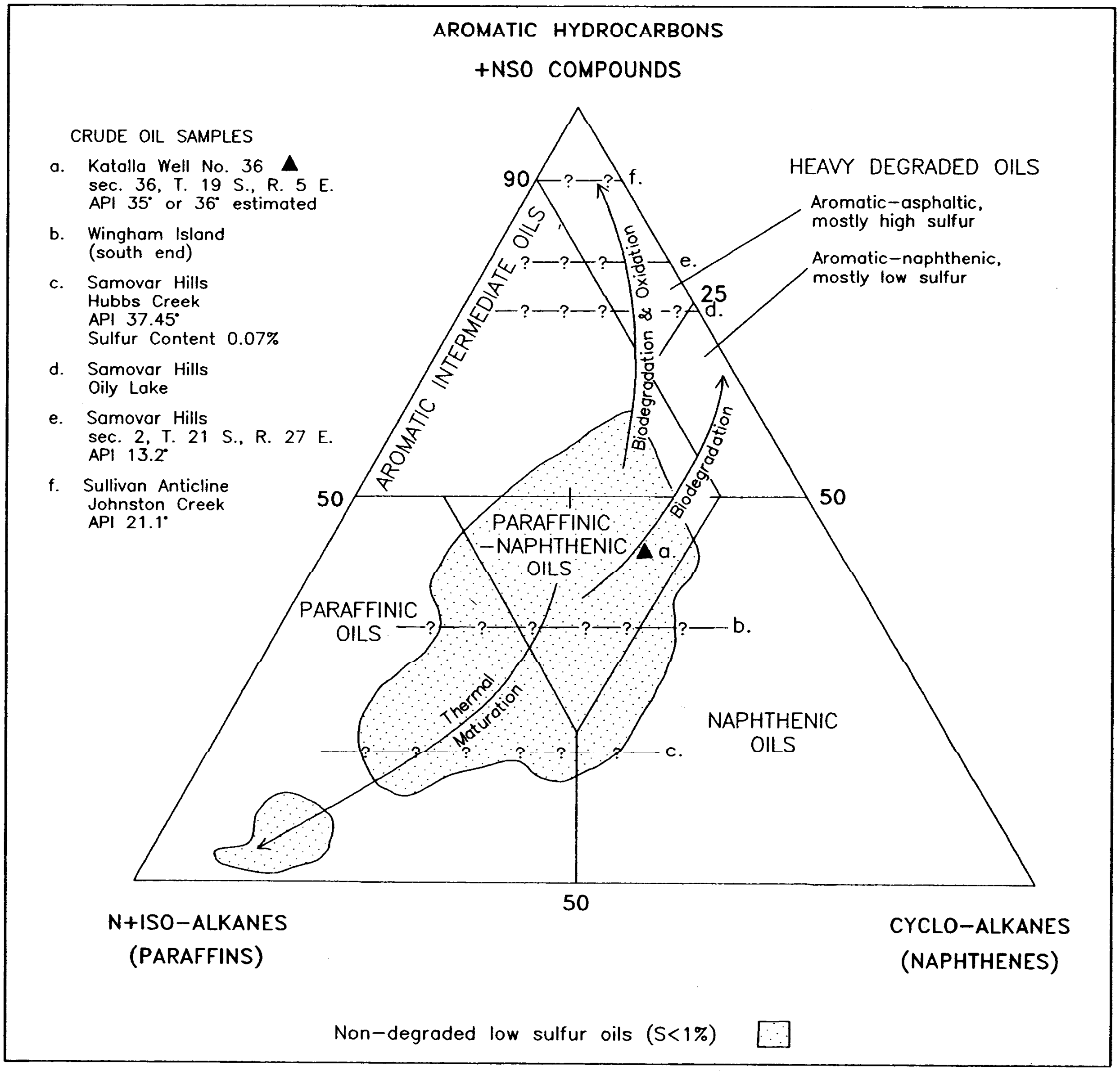
The U.S. Geological Survey (USGS) sampled and analyzed two petroleum seeps, one from an oil-stained rocky intertidal reef on the south end of Wingham Island (sample *b*, fig. 95), and the other from Hubbs Creek at Oily Lake in the Samovar Hills (sample *c*, fig. 95). The

Table 9. Analyses performed on oil samples plotted on figure 95.

Designation (fig. 95)	Location	Description of Sample	Laboratory	Type of Analysis
a.	Katalla Oil Field, sec. 36, T. 19 S., R. 5 E.	Crude oil sample from Katalla No. 36 well, originally Chilkat Oil Company No. 18 well, provided by Phillips Petroleum Company.	GeoChem Laboratories, Inc., Houston, Texas	Capillary gas chromatography. Gas chromatography and mass spectrometry analysis of the C_{15}+ paraffin-naphthene, sterane, and terpane biomarker compounds and carbon isotope ratios.
b.	South end of Wingham Island	Oil seep sample No. 81APr51C, Plafker (1987).	Global Geochemistry, Inc., and U.S. Geological Survey, Lakewood, Colorado	Gas chromatography and mass spectrometry analysis for carbon isotope ratios.
c.	Hubbs Creek, north shore at west end of Oily Lake in the Samovar Hills	Oil seep sample No. 80APr127, Plafker (1987).	Global Geochemistry, Inc., and U.S. Geological Survey, Lakewood, Colorado	Gas chromatography and mass spectrometry for carbon isotope ratios, also analysis for sulfur content and API gravity.
d.	West shore of the east end of Oily Lake in the Samovar Hills	Oil seep sample collected by ARCO Alaska, Inc., in July 1985. ARCO sample No. 85-KY-021-WKW.	GeoChem Laboratories, Inc., Houston, Texas	Gas chromatography.
e.	Samovar Hills, sec. 2, T. 21 S., R. 27 E.	Oil seep sample No. 84WL75, location No. 397, Lyle and Palmer (1976).	Tenneco Oil Company and the German Geological Survey	Gas chromatography and API gravity.
f.	Johnston Creek on the Sullivan anticline near the General Petroleum Co. Sullivan No. 1 well	Oil seep sample believed to be No. 89WL75, location No. 333, Lyle and Palmer (1976).	Tenneco Oil Company and the German Geological Survey	Gas chromatography and API gravity.

chromatogram of the seep sample (USGS sample number 81APr51C) from Wingham Island (fig. 97) exhibits a slightly bimodal distribution of both alkanes and naphthenes. Bimodality indicates thermal immaturity (Bayliss and Smith, 1980). The alkane distribution on the chromatogram of the seep sample from the Samovar Hills (USGS sample number 80APr127) exhibits only a single alkane mode with a maximum alkane content at C_{15}, characteristic of a mature crude oil (Hunt, 1979). Claypool of the USGS inferred that the sample from the Samovar Hills is "fairly mature" on the basis of the C_7 normal, iso-, and cyclo-alkane distribution (Plafker, written commun., 1989). The high API gravity (37.45°) and the low sulfur content ($S < 1.0\%$) of the Hubbs Creek sample (80APr127) are also characteristic of light paraffinic crude oils (Hedberg, 1968; and Hunt, 1979). Tissot and Welte (1984) observed that thermal evolution tends to shift the petroleum composition toward the lower left corner (the paraffin pole) of their ternary diagram (fig. 95). That is, paraffinic-naphthenic

Figure 95. Ternary diagram showing approximate compositions of Gulf of Alaska oil seeps (Lyle and Palmer, 1976; Plafker, 1987; sample 85-KY-021-WKW courtesy of ARCO Alaska, Inc.) plotted on Tissot and Welte's diagram of principal classes of crude oils. Point "a" is a sample of unaltered crude oil from the Katalla No. 36 well provided by Phillips Petroleum. See table 9 for the types of analyses done. Because most of these analyses did not include a breakdown of paraffins versus naphthenes, they are plotted as lines (b through f) rather than points. The diagram was adapted from Tissot and Welte (1984).



oils mature to paraffinic oils by a process of thermal evolution.

The three seep samples that appear near the top of the ternary diagram (fig. 95) have a compositional range that suggests degenerative alteration rather than thermal evolution. Degenerative alteration generally results in heavy oils of aromatic-naphthenic or aromatic-asphaltic classes (Tissot and Welte, 1984). Sample *d*, the seep sample provided by ARCO Alaska from the Oily Lake region (table 9), yielded 74.2 percent aromatics and NSO compounds, with no breakdown for paraffins and naphthenes (fig. 98). This is characteristic of biodegraded, oxidized hydrocarbons similar to the oil seep samples collected by Lyle and Palmer (1976).

Sample *e* (fig. 95) was collected from the north shore of the west end of Oily Lake in the Samovar Hills, and sample *f* from Johnston Creek on the Sullivan Anticline, approximately 19 miles east of Yakataga reef (Lyle and Palmer, 1976). These oil seep samples were analyzed by Tenneco Oil Company and the German Geological Survey (fig. 99). The normalized percentages of aromatics and NSO compounds with no breakdown of paraffins and naphthenes in the samples are 79.8 and 90.6 percent, respectively (fig. 95). Both laboratories concluded that the oil samples were thermally mature and biodegraded. They speculated that before biodegradation, both samples probably exhibited much higher API gravities and were derived from mature source rock. When deasphalted, the two oil samples are similar to one another in composition. It was suggested that their higher asphaltine content was probably due to biodegadation (Lyle and Palmer, 1976).

Oil seeping to the surface is usually altered by biodegradation and inorganic oxidation along the way. Biodegradation, the selective alteration of hydrocarbon compounds by microorganisms, occurs in both aerobic and anaerobic environments. This alteration roughly follows the sequence: n-alkanes (below C_{25}), isoprenoids, low-ring cycloalkanes, and aromatics. In addition, tetracyclic steranes are apparently preferentially attacked over pentacyclic triterpanes. Biodegradation often occurs when oil migrates into strata that have been invaded by meteoric waters and is nearly always accompanied by water washing, which tends to remove the more soluble light hydrocarbons, particularly the saturated alkanes and naphthenes and especially low-boiling-point aromatics such as benzene, toluene, and xylene (Tissot and Welte, 1984; Lafargue and Barker, 1988).

Figure 96. Crude oil analysis by GeoChem Laboratories, Inc., of sample provided by Phillips Petroleum from Katalla No. 36 well.

Well No. 36 (Miller, 1975, and Blasko, 1976) (Chilkat Oil Company No. 18 well) sec. 36, T. 19 S., R. 5 E. (Copper River Meridian)	Katalla Oil Field

GROSS COMPOSITION

Less than C_{15}+	37.0%
C_{15}+	63.0%

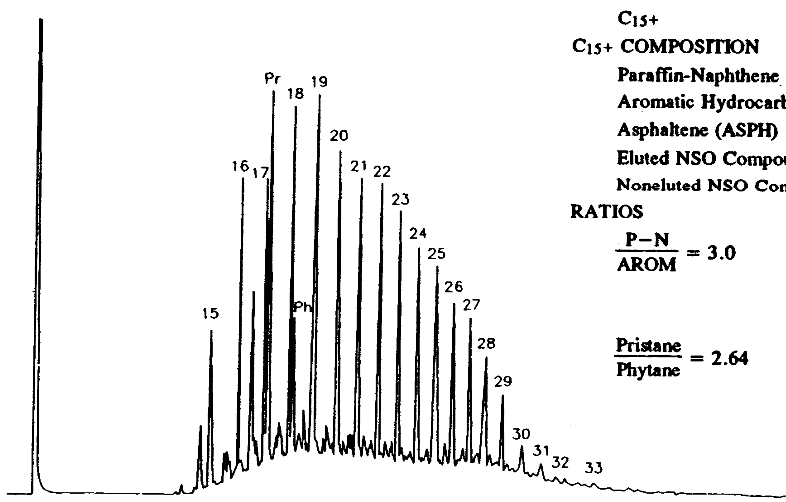
C_{15}+ COMPOSITION

Paraffin-Naphthene Hydrocarbons (P-N)	57.0%
Aromatic Hydrocarbons (AROM)	19.27%
Asphaltene (ASPH)	13.0%
Eluted NSO Compounds (NSO)	4.8%
Noneluted NSO Compounds (NSO)	6.0%

RATIOS

$\frac{\text{P-N}}{\text{AROM}} = 3.0$ $\frac{\text{ASPH}}{\text{NSO}} = 1.2$

$\frac{\text{Pristane}}{\text{Phytane}} = 2.64$ $CPI_{24-32} = 1.13$



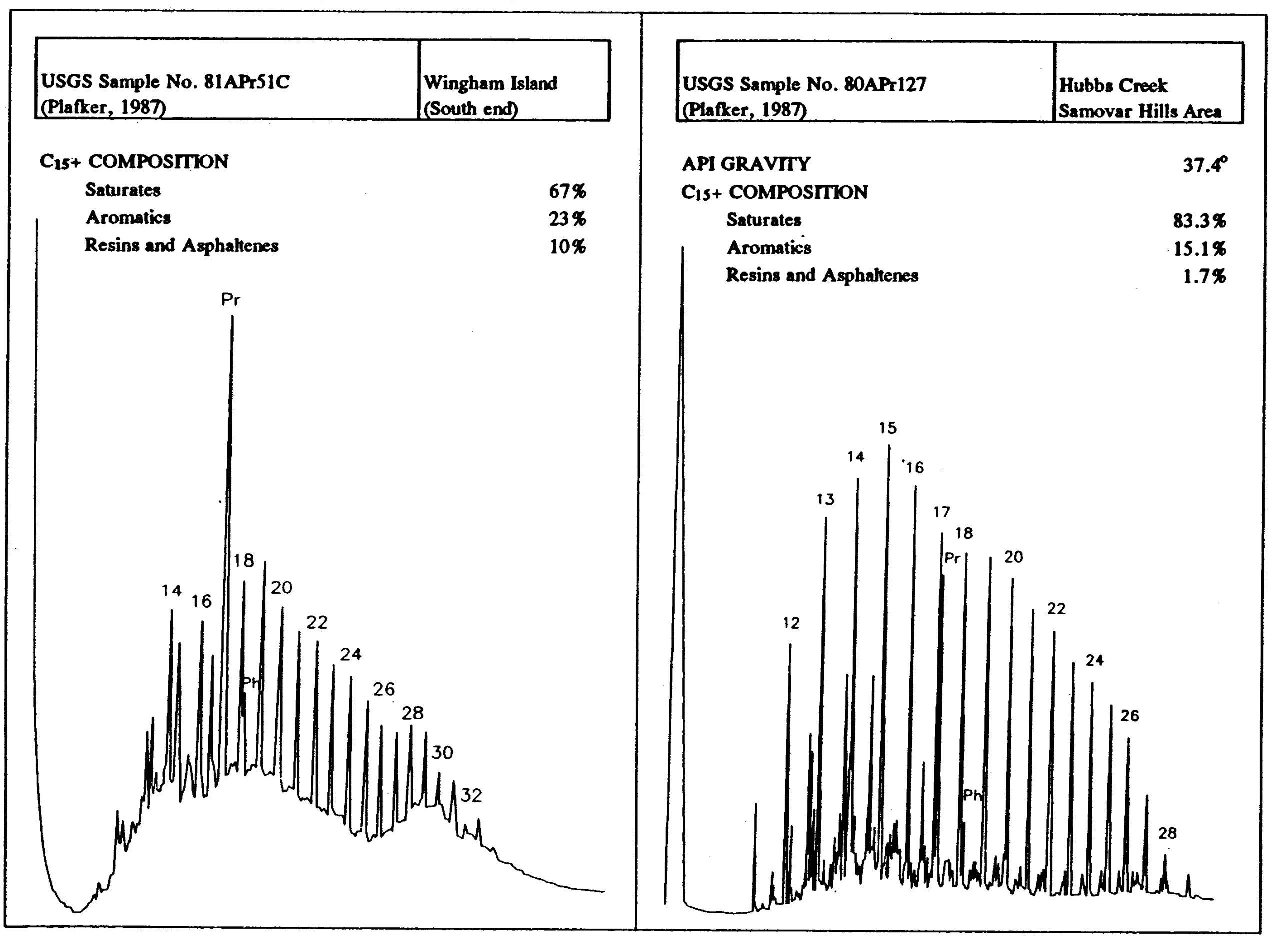
The cumulative result of biodegradation, water washing, and oxidation is that the bulk composition of the oil shifts toward the aromatic hydrocarbons plus NSO compounds pole of the ternary diagram (fig. 95). According to Tissot and Welte (1984), paraffinic and paraffinic-naphthenic oils are usually degraded into aromatic-naphthenic oils with "moderate" sulfur content (less than 1.0 percent), while aromatic-intermediate oils tend to degrade into aromatic-asphaltic oils with a "high" sulfur content (more than 1.0 percent).

The six crude oil analyses plotted on figure 95 appear to fall into three groups with distinct chemical characteristics. The first is an unaltered light paraffinic-naphthenic crude oil (point *a*, the Phillips Petroleum Company sample from the Katalla No. 36 well). The second is an unaltered light paraffinic crude oil (bars *b* and *c*, the USGS oil seep samples from Wingham Island and the Samovar Hills) that may have been derived from the thermal evolution of a paraffinic-naphthenic oil or from organic materials richer in waxy terrestrial kerogen than the organic material that produced the paraffinic-naphthenic crude oil. Crude oils of the first two types are frequently generated in deltaic or coastal sediments of the continental margins, or in nonmarine source beds (Tissot and Welte, 1984). The third group is composed of altered, aromatic intermediate or aromatic-asphaltic crude oil from seeps on the Sullivan Anticline (bar *f*) and from the Samovar Hills (bars *d* and *e*). This group of oil samples is probably a biodegraded, oxidized product of one of the first two groups, although it is possible that the aromatic intermediate oil was derived from a marine source rock.

Source Rock Geochemistry

Published and unpublished analyses of potential source rocks from onshore have produced relatively homogeneous results. Recycling of older kerogen and the apparent lack of preservation of fresh, unaltered organic material can produce a geochemistry that is very homogeneous. With few exceptions, there is little

Figure 97. Crude oil analysis by Global Geochemistry, Inc., and the U.S. Geological Survey, Lakewood, Colorado, of oil seep samples (Plafker, 1987).



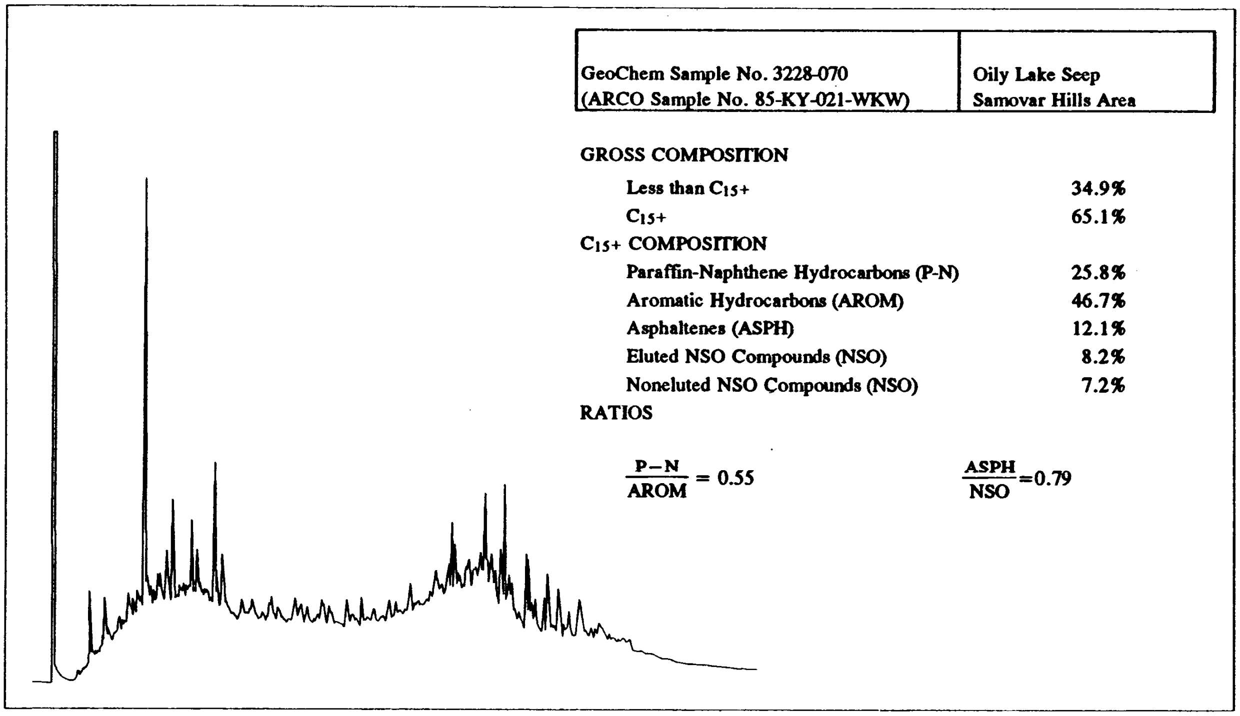
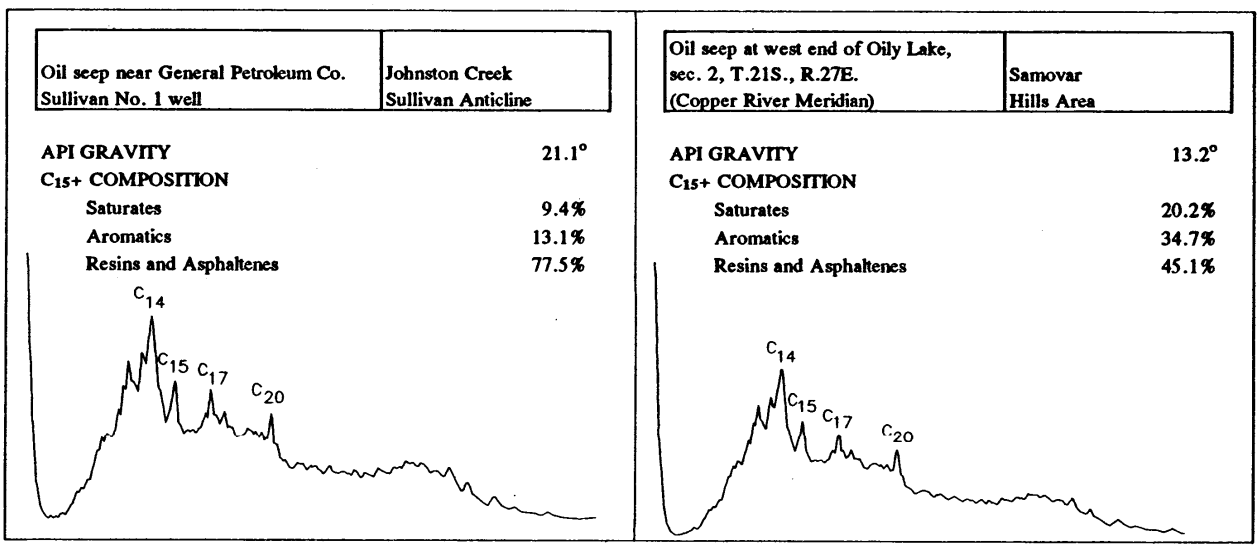


Figure 98. Crude oil analysis by GeoChem Laboratories, Inc., of oil seep sample provided by ARCO Alaska, Inc.

Figure 99. Crude oil analysis by Tenneco Oil Company and the German Geological Survey of oil seep samples (Lyle and Palmer, 1976).



detectable change in the levels of thermal alteration in the kerogens from rocks younger than the middle Eocene. For the most part, the amounts of pyrolytic hydrocarbons are consistently low (appendix G).

Table 10 contains a summary of pyrolysis and microscopy data from surface samples of organic material from the Katalla area and Kayak Island (Mull and Nelson, 1986). The table also includes four heavy hydrocarbon extract analyses obtained by the USGS from Kayak Island (Plafker, 1987). The Kayak Island samples are discussed later in this report in the context of the extract analyses from the OCS Y-0211 No. 1 well.

The analyses of organic material in table 10 represent most of the Tertiary formations exposed onshore. The predominantly herbaceous, woody kerogen in the samples is gas prone (Mull and Nelson, 1986). Seven

Table 10. FID (flame ionization detector) pyrolysis, microscopy, and heavy hydrocarbon extract analyses from outcrop samples from the Katalla area and Kayak Island.[1,2] The stratigraphic column is local (see fig. 33).

		Sample No.	TOC (wt. %)	Volatile Hydrocarbons (ppm)	Pyrolytic Hydrocarbons (ppm)	Pyro.Hcbns. / TOC (mg/g)	Temperature of peak II in FID pyrolysis (°C)	R_o (%)	Comments
KATALLA REGION[1]									
Miocene	Redwood Fm.	80AMH 181	0.32	78	222	69.4	434	0.5	Katalla Oil Field Yakataga Terrane
Miocene	Redwood Fm.	80AMH 179	0.49	108	292	59.6	432	0.6	
Miocene	Redwood Fm.	80AMU 69	0.62	136	564	91.0	429	0.6	
Miocene	Redwood Fm.	80AMH 180	0.67	92	508	75.8	430	0.5	
Miocene	Redwood Fm.	80AMU 68	0.50	98	302	60.4	435	0.6	
Oligocene	Poul Cr. Fm.	80AMU 60	4.83	3,070	9,300	192.5	430	–	
Oligocene	Poul Cr. Fm.	80AMU 61	1.42	184	1,015	71.5	434	0.5	
Oligocene	Poul Cr. Fm.	80AMH 193	0.50	128	272	54.4	442	0.7	
Oligocene	Poul Cr. Fm.	80AMU 67	0.58	171	129	22.2	435	0.8	
Oligocene	Tokun Fm.	80AMU 65	0.91	91	304	33.4	464	0.9	
Oligocene	Tokun Fm.	80AMH 194	1.22	196	404	33.1	484	1.8	Approx. 5 Mi. W. of Bering River Coal Field
Eocene	Tokun Fm.	80AMH 182	0.96	114	386	40.2	477	–	Approx. 5 Mi. W. of Bering River Coal Field
Eocene	Kulth-ieth Fm.	80AMU 90	1.61	209	691	42.9	472	1.3	Bering River Coal Field
Eocene	Kulth-ieth Fm.	80AMU 91	1.30	114	196	15.1	590	2.5	Bering River Coal Field
Eocene	Stillwater	80AMU 66	0.87	151	149	17.1	592	2.1	Ragged Mountain Fault Zone
Paleo-cene	Orca Group	80AMH 176	0.20	246	454	227	429	1.9	Prince William Terrane
Paleo-cene	Orca Group	80AMH 178	0.47	345	755	160.6	470	1.2	
KAYAK ISLAND[1]									
Miocene	Yakataga Fm.	80AMU 79	0.75	261	1,039	138.5	418	0.44	SE. side of island
Miocene	Yakataga Fm.	80AMU 77	0.56	255	645	115.2	427	0.47	
Miocene	Yakataga Fm.	80AMU 72	0.37	131	269	72.7	422	0.51	NW. side of island
Miocene	Yakataga Fm.	80AMU 76	0.91	274	2,026	222.6	407	0.50	
Oligo-cene	Poul Cr. Fm.	80AMU 84	1.09	642	1,558	142.9	431	0.71	E. Kayak Island
Oligo-cene	Poul Cr. Fm.	80AMU 86	1.20	568	1,632	136.0	430	0.67	

		Sample No.	TOC (wt. %)	Bitumen (ppm)	Total Extractable Hydrocarbons (ppm)	Saturates Normalized (%)	R_o (%)	Comments
KAYAK ISLAND[2]								
Oligocene	Poul Cr. Fm.	72APr 117A2	5.21	2,653	831	38	0.4	SE. side of island
Oligocene	Poul Cr. Fm.	72APr 117A3	4.56	2,426	750	37	0.4	
Oligocene	Poul Cr. Fm.	72APr 117B	6.76	2,113	873	34	0.4	
Oligocene	Poul Cr. Fm.	72APr 119	1.78	463	218	51	0.4	

[1]Mull and Nelson, 1986.
[2]Plafker, 1987; also personal communication, 1988.

samples collected from the Poul Creek, the Kulthieth, and the Tokun Formations had total organic carbon contents (TOC) greater than 1.0 percent. Thermal evolution analysis-flame ionization detector (TEA-FID) pyrolysis[2] yielded ratios of pyrolytic hydrocarbons to TOC that are characteristic of type III (gas prone) kerogen at their respective levels of thermal maturity.

In the Katalla-Kayak Island study, Mull and Nelson (1986) considered the zone of oil generation to extend from about 480 °C to over 680 °C for TEA-FID pyrolytic hydrocarbons. In contrast, T_{max} values from Rock-Eval pyrolysis are generally considered to reflect catagenetic alteration for type III kerogen between about 435 °C and 470 °C (Tissot and Welte, 1984; Peters, 1986).

Sample 80AMu 60 (table 10) from the Miocene part of the Poul Creek Formation is anomalous because of its high organic carbon content of 4.83 percent and high FID pyrolysis response. This sample may come from an organically rich facies of the Poul Creek Formation. But FID pyrolysis suggests that it simply contains migrated hydrocarbons. Mull and Nelson (1986) did not include the R_o value, but the temperature of peak II in pyrolysis (430 °C) indicates thermal immaturity. Although the sample is composed of both herbaceous and amorphous (structureless) organic material, the pyrolytic hydrocarbon to TOC ratio is relatively low (193 mg/g), suggesting, at this level of thermal maturity, a type III kerogen. Clementz (1979) has observed that large quantities of bitumen or migrated petroleum in rocks can affect the size and the maximum temperature of the S_2 peak (pyrolytic hydrocarbons) and can cause nonsource rocks to be misidentified as source rocks. This response occurs most frequently in the 350- to 450-°C range. The temperature of maximum pyrolysis yield for this sample is 430 °C. The high S_1 (volatile hydrocarbon) response suggests that this sample contains migrated hydrocarbons which may have affected the S_2 response. Because the sample was obtained from an area just east of Katalla and south of Bering Lake where oil seeps are common, the presence of migrated hydrocarbons in the sample is probable. If sample 80AMu 60 is considered to be potential source rock beause of its high organic carbon content, it is nevertheless immature and could not have generated the petroleum present in the area.

The thermal maturity of the samples from the Katalla area probably reflects the tectonics of the region as much as the relative ages of the sediments that were sampled. Mean random vitrinite reflectance values (R_o) increase to the north and east of the Katalla region in areas where tectonic deformation is more pronounced (fig. 100). The highest R_o value (2.5 percent, sample 80AMu 91) comes from Carbon Mountain in the Bering River Coal Field, about 30 miles northeast of Katalla. Sample 80AMH 194 (R_o 1.8 percent) was collected near the southwest end of the Bering River Coal Field.

This field contains coal ranging in rank from low-volatile bituminous in the southwestern part, to anthracite in the east (Barnes, 1967). The coal beds are tightly folded, locally overturned, and cut by many faults, including several thrust faults with large displacements. The coal beds are believed to be of middle(?) and late Eocene and Oligocene(?) age (Barnes, 1967). An analysis of anthracite coal cited by Barnes contained 5.0 to 13.3 percent volatile matter and 66.0 to 82.5 percent fixed carbon. Volatile matter is considered by coal petrologists to be a better indicator of coal rank than fixed carbon because it changes much more rapidly with rank. The volatile matter in this coal sample corresponds to an R_o range of 2 to 3 percent (Stach and others, 1982), which agrees with the 2.5 percent R_o value reported by Mull and Nelson (1986). Pressure is not considered to be as important a factor as temperature in the maturation of coal, but the degree of tectonic activity indicates that the rocks in the Bering River Coal Field may have been much more deeply buried and thus subjected to higher temperatures than equivalent less-deformed rocks. Regions of especially strong coalification are generally believed to have received additional heat from large intrusive igneous bodies at depth (Stach and others, 1982). A large aeromagnetic anomaly on the east margin of the Bering River Coal Field suggests the possibility that such an intrusive may be present (G. Plafker, oral commun., November, 1989).

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2 TEA-FID pyrolysis is not the same procedure as Rock Eval pyrolysis. MMS experience in other areas suggests that there can be reasonably good agreement between the ratios of pyrolytic hydrocarbons (S_2) to TOC for TEA-FID pyrolysis and the hydrogen index (S_2/TOC) from Rock Eval pyrolysis up to values of about 200 or 300 milligrams hydrocarbons per gram TOC. However, this generalization must be applied cautiously in areas where no basis for comparison exists.

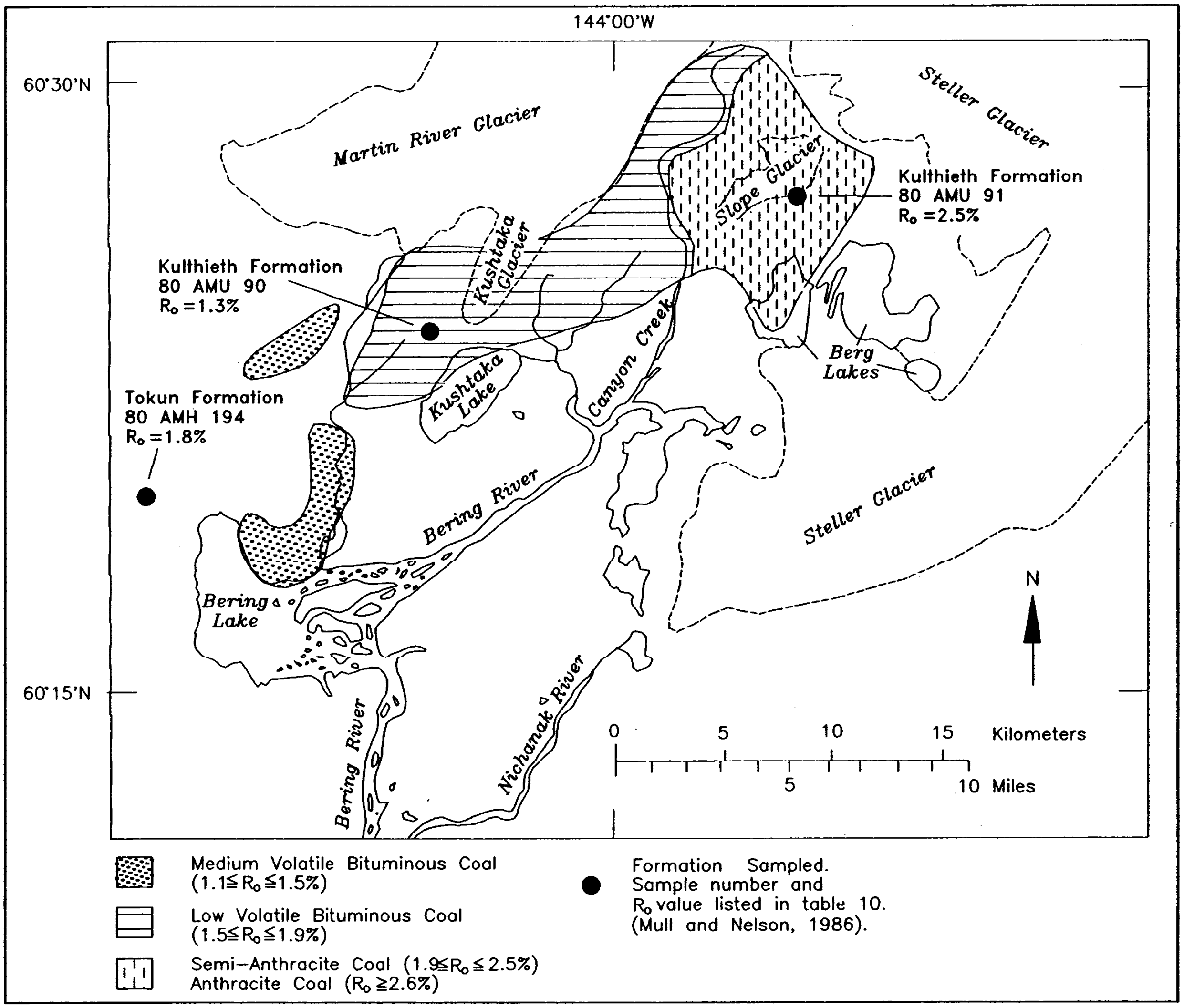

Figure 100. Generalized outcrop extent of the Stillwater/Kulthieth (formerly Kushtaka)/Tokun Formations of the Bering River Coal Field showing the increase in coal rank to the east-northeast (adapted from Merrit, 1986).

After World War II, petroleum exploratory wells were drilled to greater depths in prospective areas onshore outside of the Katalla Oil Field (plate 8). Some of the well samples collected were stored and later analyzed for total organic carbon content (TOC), mean random vitrinite reflectance (R_o), and by pyrolysis. Oxidation and loss of volatiles during storage may have affected these analyses. The results of the analyses for several of the onshore wells are listed in appendix G.

Flame ionization detector (FID) pyrolysis data for 10 onshore wells was provided by the State of Alaska (Alaska Geologic Materials Center Data Report 14, 1979). The FID pyrolysis was performed by Mobil Exploration and Producing, U.S., Inc. Rock-Eval pyrolysis was also performed for the MMS by Brown and Ruth Laboratories, Inc. (Jacobson Consulting, Inc., 1988) on selected cuttings from the Malaspina No. 1A well held by the State of Alaska. Unfortunately, none of the 15 samples contained more than 0.50 weight percent organic carbon and, as a result, produced only three pyrograms of questionable value. The S_2 response (pyrolytic hydrocarbons) for the three pyrograms was too flat to be meaningful. The only significant conclusion to be drawn from these results is that the organic matter analyzed did not constitute a potential source of petroleum.

Total organic carbon content and the S_1 and S_2 values from FID pyrolysis of sediments from the onshore wells are generally low. The ratios of pyrolytic hydrocarbons (S_2) to TOC are also low, suggesting that the organic matter is largely type III kerogen (Tissot and Welte, 1984) or that it is thermally very mature, an interpretation not supported by the petrographic studies. Mature kerogen would exhibit R_o values in excess of 0.6 percent (Dow and O'Connor, 1982).

Mean random vitrinite reflectance (R_o) was measured by Bujak Davies Group[3] (Report No. 88-0033, 1988) for the MMS on polished slides of organic matter from these wells. The slides were provided by the Geologic Materials Center. R_o measurements, generally less than 0.6 percent in Tertiary sediments from the onshore wells, indicate that the kerogen sampled was largely immature (appendix G). R_o values from the late Neogene glaciomarine Yakataga Formation in onshore wells are erratic, and Bujak Davies Group reports indicate that the kerogen has been extensively reworked.

In all onshore wells, the Poul Creek and the Kulthieth Formations exhibit nearly identical levels of thermal maturity. In fact, in some wells the Kulthieth Formation is slightly less mature on average than the overlying Poul Creek Formation. In most basins, R_o values normally increase with depth in response to the increase in crustal temperature with depth of burial. However, we see no change with depth, or possibly a reverse trend with onshore wells. These results suggest that the organic material analyzed from the onshore wells was originally derived from an exhumed source terrane onshore and redeposited with the sediments of the Kulthieth and the Poul Creek Formations. Autochthonous kerogen does not appear to have been preserved. Recycled or allochthonous kerogen contained in the Kulthieth Formation is less mature and may, therefore, be younger than the recycled or allochthonous kerogen contained in the overlying Poul Creek Formation. A progressive unroofing of deeper, more thermally altered sediments in the source terrane could then produce a retrograde R_o profile in the basin which received the products of this erosion.

The R_o profiles for these onshore wells (plate 8) resemble the thermal alteration index (TAI) profiles from an earlier study performed by Palmer (1976). The TAI values (Staplin, 1969) were determined for six onshore Gulf of Alaska wells: the Socal Rio Bay No. 1, the Richfield Duktoth River No. 1, the Tenneco Middleton Island No. 1, the Phillips-Kerr McGee Sullivan No. 1, the British Petroleum White River No. 1, and the Colorado Oil and Gas Yakutat No. 1 wells. These wells were drilled to depths of 10,000 to 14,000 feet and all bottomed in Kulthieth sediments except the Socal Rio Bay No. 1 well, which did not pass through the Yakataga Formation, and the Middleton Island No. 1 well, drilled in the Prince William terrane (fig. 3). TAI values ranged between 2 and 3, generally around 2.5, from the surface to total depth. They exhibited no apparent systematic increase with depth. This study assigned values of 2.5 to 3.5 to the zone of oil generation, which is approximately equivalent to an R_o range of 0.5 to 1.5 percent (Hood and others, 1975). Palmer (1976) assigned most TAI values in these onshore wells to the zone of catagenesis. The uniformity or lack of increase in the R_o and TAI values with depth suggests that the kerogen was probably recycled. The Colorado Oil and Gas Company Yakutat No. 1 and the Phillips-Kerr McGee Sullivan No. 2 wells provide additional supporting evidence for this hypothesis. In the onshore Yakutat No. 1 well, *Inoceramus* prisms were reported in the Eocene Kulthieth Formation (Rau and others, 1983) implying the possibility that Cretaceous–Jurassic sediments have been recycled.

In the Sullivan No. 2 well (appendix G-2), the strata are overturned (Larson and others, 1985a). The lowest observed R_o value (0.49 percent) occurs in one of the shallower sample intervals (4,240 to 4,300 feet, late Eocene Kulthieth Formation), and the highest R_o value (0.62 percent) was obtained from the deepest sample interval (11,600 to 11,680 feet, Miocene Poul Creek Formation). R_o values are erratic in this well, but it is noteworthy that the maximum and minimum values exhibit a normal increase with depth in overturned strata and that the highest R_o value occurs in the youngest sediments.

Cretaceous rocks of the Yakutat Group were sampled in the Malaspina No. 1A well and Dangerous River No. 1 well. Two Cretaceous samples from the Malaspina No. 1A well yielded R_o values of 0.73 and 0.80 percent (appendix G-3). Cretaceous rocks in the Dangerous River No. 1 well contained a vitrinite population that ranged in R_o from 0.95 to 1.49 percent. The R_o profile derived from this data increases with depth in a normal

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3 In the ARCO OCS Y-0211 No. 1 well, an offshore well, Bujak Davies R_o data tended to be slightly higher than GeoChem Laboratories R_o data for the same well (average Bujak Davies $R_o \cong$ average GeoChem Laboratories R_o + 0.14%). It is likely that Bujak Davies data represent maximum probable levels of thermal maturity for kerogen from this region.

manner (fig. 101). The kerogen from the Cretaceous sediments of the two onshore wells appears to have experienced catagenesis, and most R_o values fall within the generally accepted "oil window" for type III kerogen ($0.6\% \leq R_o \leq 1.35\%$).

Although surface exposures of Mesozoic rocks are frequently metamorphosed in this region, the indigenous kerogen in Cretaceous rocks in these two wells has apparently not been thermally metamorphosed. Metamorphism would result in R_o values of at least 4.0 percent (Tissot and Welte, 1984). The highest individual vitrinite reflectance observations recorded from these Cretaceous samples were 2.24 percent from the Yakutat Group in the Malaspina No. 1A well and 1.99 percent from the Yakutat Group in the Dangerous River No. 1 well. Bujak Davies Group reported that these measurements were made on vitrinite group fragments that were members of reworked populations (Bujak Davies Group Report No. 88-0033, 1988).

FID pyrolysis of samples from the Malaspina No. 1A and the Dangerous River No. 1 wells (appendix G-3 and G-6) yielded extremely low pyrolytic hydrocarbon contents (S_2 response). The organic matter obtained from these wells is classified as type IV kerogen or inertinite.

The geochemistry from onshore wells and surface samples did not reveal fresh indigenous kerogen in the Yakataga, Poul Creek, and Kulthieth Formations. Most kerogen contains less than 1.0 percent organic carbon and much of it less than 0.5 percent. All of the organic matter with the possible exception of two surface samples from the Katalla area is thermally immature. Kerogen from the Yakutat Group exhibits a normal increase in maturity in the Dangerous River No. 1 well which, along with two samples from the Malaspina No. 1A well, falls within the oil window. Pyrolytic response from these sediments, however, was unimpressive.

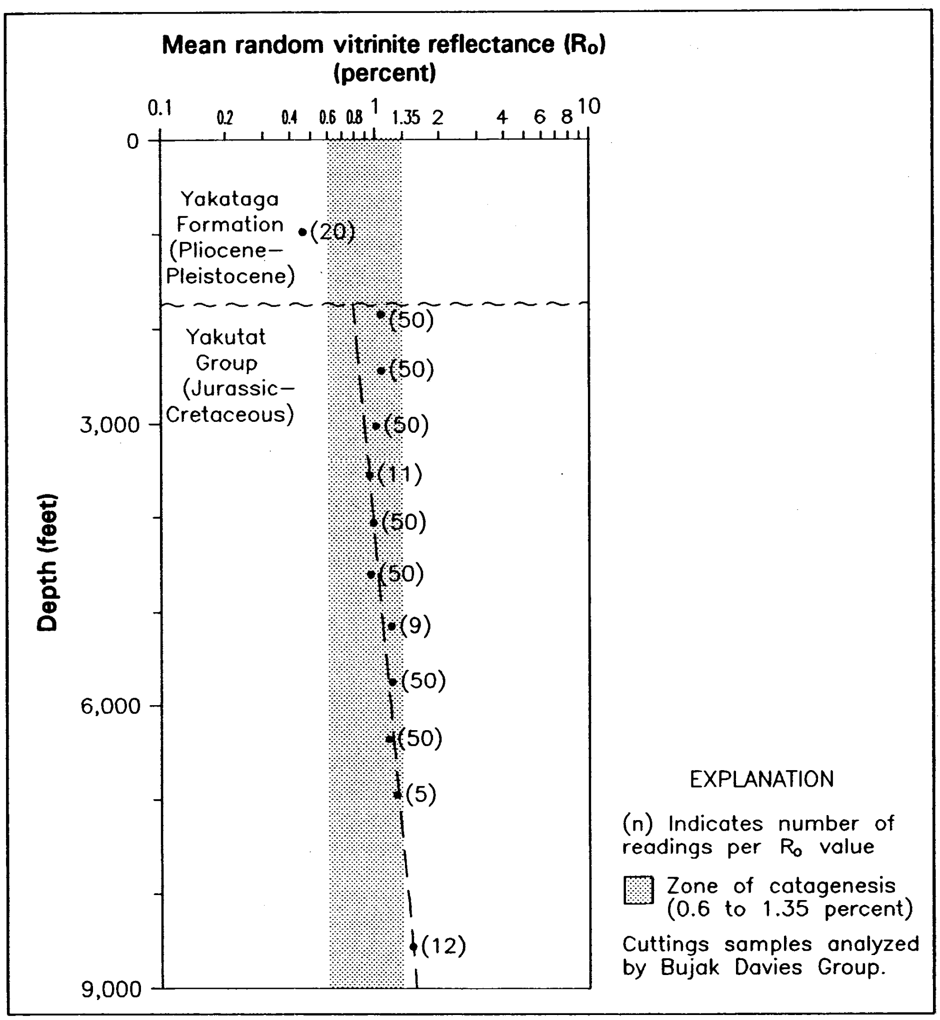

Figure 101. Mean random vitrinite reflectance, Colorado Oil and Gas Company Dangerous River No. 1 well.

Offshore Geochemistry

Organic geochemistry from late Eocene through recent sediments in offshore wells resembles the results from the onshore sediments of similar age. Armentrout (1983a) observed a dominance of terrestrial organic matter in Holocene and Neogene sediments despite the fact that the Gulf of Alaska has high marine productivity. He attributed this to the removal of marine organic carbon within the water column and at the sediment-water interface due to an oxidizing environment, which permitted the preservation of the terrestrial debris. Armentrout (1983a) went on to postulate that, during a transgressive interval, an upwelling seawater circulation system moved shoreward, producing deposition of organically rich sediment, where an oxygen-minimum zone intersected the continental slope and shelf (Demaison and Moore, 1980). Armentrout (1983a) supported his hypothesis with two TOC analyses yielding values of 2.39 and 1.64 percent from an outcrop of the Miocene part of the Poul Creek Formation at Munday Creek. Other geologists (Turner, oral commun., 1992) correlate this exposure with TOC values of 1.97 percent in the Miocene section of the Poul Creek Formation in the OCS Y-0080 No. 1 well (fig. 66 and plate 8) and 0.86 to 1.40 percent in the Miocene section of the OCS Y-0211 No. 1 well. Turner (oral commun., 1992) believes that in most offshore wells, this facies is absent due to an unconformity.

Because total organic carbon (TOC) alone cannot identify kerogen type or true genetic potential, additional geochemistry is required. Unfortunately, only the OCS Y-0211 No. 1 well produced meaningful geochemistry that identifies the kerogen type and its genetic potential. These results are consistent with the onshore findings, that is, an inertinite with some potential for gas but little or no potential for oil generation. Additionally, only sediments that are of middle Eocene age or older appear to have reached adequate thermal maturity to generate significant amounts of hydrocarbons.

ARCO OCS Y-0211 No. 1 well

The ARCO OCS Y-0211 No. 1 well provides the most thorough modern geochemistry currently available from the Gulf of Alaska (plate 8). Cuttings samples representing 60- to 360-foot intervals and sidewall core samples were analyzed by GeoChem Laboratories, Inc., for light hydrocarbons, C_{15}+ hydrocarbon extracts, and by Rock-Eval pyrolysis. Studies using both transmitted and reflected light microscopy were also done. Additionally, vitrinite reflectance analyses were carried out for 12 cuttings samples for the MMS by the Bujak Davies Group. All data are currently available for examination at the Anchorage office of the MMS.

All depths discussed in this chapter refer to depths below the Kelly Bushing (KB), 86 feet above mean sea level for the OCS Y-0211 well. The sea floor at this location was 450 feet below mean sea level.

Although total organic carbon content (TOC) values range between 1.0 and 2.0 percent over significant intervals in the OCS Y-0211 well (fig. 102), the genetic potential determined by Rock Eval pyrolysis (S_1+S_2) is generally unimpressive. Tissot and Welte (1984) consider genetic potentials (S_1+S_2) of less than 2,000 ppm to have some potential for gas but no potential for oil. Most of the samples from this well fall below 1,000 ppm (fig. 102). Though the genetic potentials of samples 227S and 229S are in excess of 2,000 ppm, their hydrogen indices (HI) are only 169 and 154 milligrams hydrocarbons per gram organic carbon, respectively. Samples 187S, 188S, and 189S were derived from sidewall cores that sampled sandstone lithologies and almost certainly contain migrated hydrocarbons. Solid bitumen and the "heavy end" fraction of petroleum are known to produce a measurable response (S_2) in the 350- to 450-°C range (Clementz, 1979). T_{max} values for these three samples were 436, 432, and 431 °C, respectively. Of the samples with genetic potentials in excess of 2,000 ppm, only sample 172 genuinely appears to exhibit a moderate potential for petroleum generation.

Several samples, indicated by sample numbers on the modified Van Krevelen diagrams (fig. 103), produced hydrogen indices that set them apart from the rest of the data. The Yakataga Formation is a glaciomarine unit that is thermally immature and an unlikely source of petroleum. The two samples from the Yakataga Formation with higher HI values (270 and 267 mg/g) contained less than 0.5 percent total organic carbon.

Cuttings samples were collected throughout the Poul Creek Formation at 60-foot intervals. Cuttings sample 071, a glauconitic shale from the Poul Creek Formation, (6,980 to 7,040 feet) had a TOC of 0.29 percent. R_o was not measured for this sample, but adjacent samples exhibited an R_o level of about 0.47 percent.

Cuttings sample 161, derived from the interval from 11,720 to 11,780 feet in the Kulthieth Formation, was composed of 60 percent sandstone and 40 percent shale.

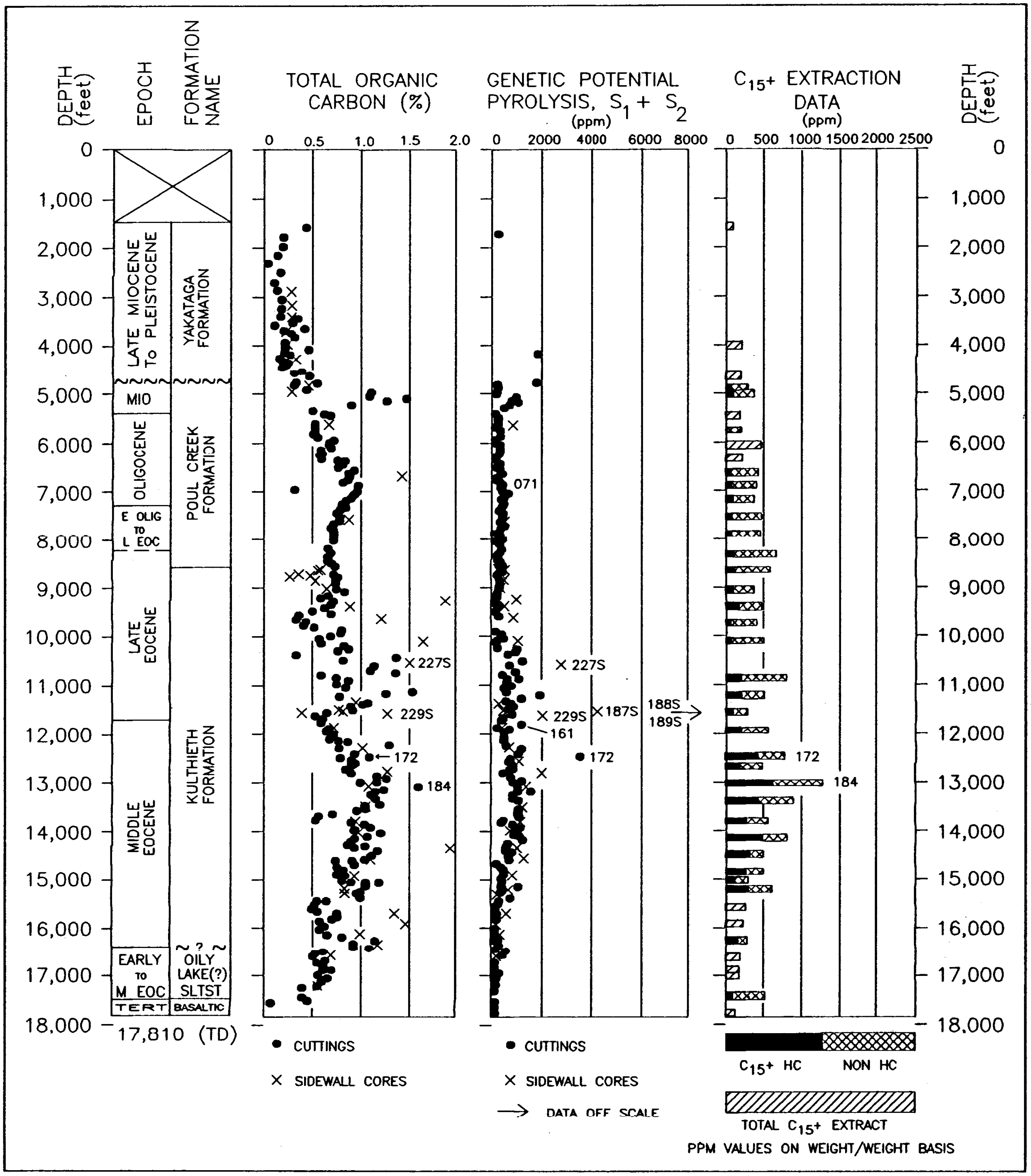

Figure 102. Organic richness and hydrocarbon potential from the ARCO OCS Y-0211 No. 1 well. Depths are measured from the kelly bushing. Data are from the GeoChem Laboratories, Inc. Numbered data points are discussed in text.

The shale contained 0.57 percent TOC. An R_0 was not measured for this sample, but cuttings samples immediately above and below sample 161 yielded R_0 values of 0.47 and 0.48 percent, respectively. Cuttings sample 172 represents the interval from 12,380 to 12,440 feet in the Kulthieth Formation. It was composed of 80 percent silty shale and 20 percent limestone and contained 1.04 percent organic carbon (Bond and Davis, 1981). The shale contained 60 percent amorphous material, 20 percent herbaceous kerogen, and 20 percent woody kerogen, which yielded a hydrogen index (S_2/TOC) of 330 mg hydrocarbons per gram TOC. It exhibited a mean random vitrinite reflectance (R_o) of 0.55 percent. At this R_o level, the low HI value of cuttings sample 172 indicates that it is not high in algal material, but rather a mixture of type II and type III kerogens (fig. 103). Though relatively immature, sample 172 is the most favorable source rock candidate observed in this well.

The maximum amount of heavy $C_{15}+$ hydrocarbons extracted from sediments in the OCS Y-0211 well was obtained from sample 184 at 13,100 to 13,460 feet (fig. 102). From 13,460 feet to total depth (17,810 feet), pyrolysis response and $C_{15}+$ extracts decline sharply, despite the fact that in this same interval the level of thermal alteration of the organic material reaches optimum levels for hydrocarbon generation (R_o approximately equal to 1.0 percent). Apparently, the organic matter required to generate hydrocarbons was not preserved below about 14,000 feet.

Several parameters used to evaluate thermal maturity are plotted on figure 104 for the OCS Y-0211 well. These include profiles of mean random vitrinite reflectance (R_o), T_{max} from Rock Eval pyrolysis, and heavy hydrocarbon $C_{15}+$ extract data. These data exhibit evidence of recycled kerogen and caving of cuttings which complicate the process of interpretation. The time-temperature indices (TTI) from a Lopatin model (fig. 105) are also included so that they may be compared with the empirical data. The TTI values represent a theoretical rate of thermal alteration that is based on the current temperature gradient derived from corrected bottom hole temperatures (BHT) recorded during the drilling of the OCS Y-0211 well (chapter 9).

An examination of the profiles in figure 104 suggests that for both R_o and T_{max} values, there are at least two populations of data. The R_o and T_{max} values are both nearly constant to a depth of about 11,000 feet. From about 11,000 feet to the total depth of 17,810 feet, the R_o and T_{max} values increase in a normal manner, and the percentage of paraffins and naphthenes (saturated hydrocarbons) in the $C_{15}+$ extracts also begins to increase (see fig. 104 for formation and age).

Measures of thermal alteration that are too high for shallow sediments and do not increase over a lithologic interval of almost 10,000 feet are problematic. An initial hypothesis was that a mud additive had contaminated the samples and produced the anomalous results. Several mud additives were examined petrographically to determine if they could have caused the problem. These studies, discussed in appendix H, did not confirm the hypothesis. The most common mud additives used in the top 10,000 feet of the OCS Y-0211 No. 1 well were unlikely to have been identified as vitrinite group macerals, and those that might have caused confusion either were not used or yielded R_o values that were too low.

Middle to late Eocene samples from 11,000 to 17,800 feet reflected the best indicators of a thermal alteration trend in the OCS Y-0211 well. That is, the R_o and T_{max} values increased systematically with depth in the normal manner. This trend is evident in R_o profiles constructed from both Bujak Davies data and GeoChem Laboratories, Inc., data (fig. 104). A profile with higher R_o values was derived from five cuttings samples analyzed by the Bujak Davies Group. Seven sidewall core samples analyzed by GeoChem Laboratories, Inc., produced a second profile that is consistently displaced toward lower values.[4]

Most GeoChem Laboratories R_o values from below 13,000 feet are mean values obtained from less than 15 measurements of reflectance. Ideally, mean random vitrinite reflectance should be computed from about 50 measurements of reflectance (Dow and O'Connor, 1982). In actual practice, 20 or 30 measurements are frequently the largest population available for an average, and 20 or 30 measurements usually produce good histograms (with low standard deviations and high kurtosis). However, the R_o values based on fewer than 15 reflectance measurements did not produce a linear profile at depths greater than 13,000 feet in the OCS

4 The offset between the two R_o data sets (Bujak Davies and GeoChem Laboratories, Inc.) is nearly the same throughout the well, about 0.14 percent. This offset in the data from the two laboratories may represent a systematic error such as a difference in the calibration of instrumentation, a consistent difference in the identification of the vitrinite populations, or the fact that GeoChem Laboratories, Inc., analyzed fresher samples (oxidation causes higher reflectances).

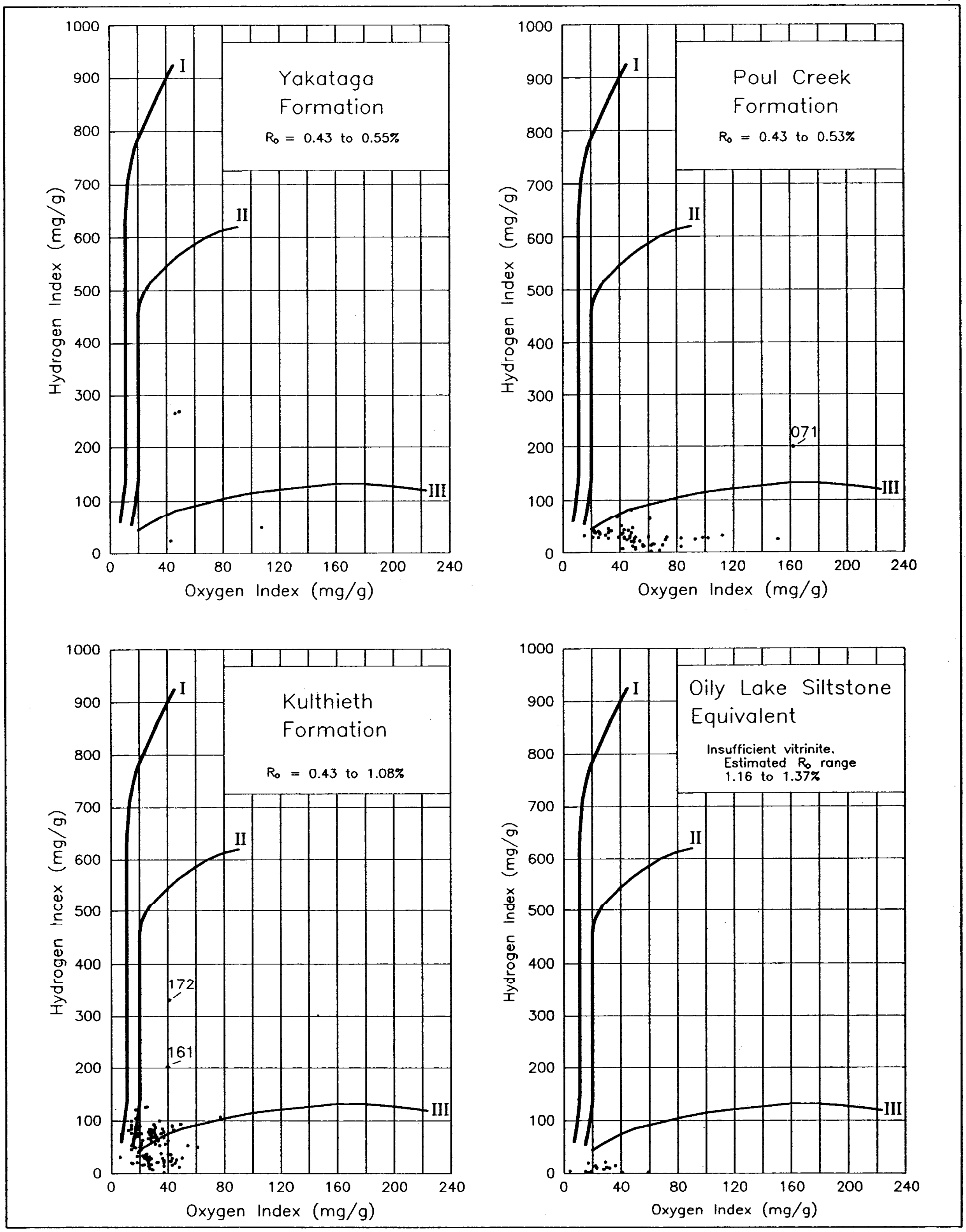

Figure 103. Modified Van Krevelen diagrams. Cuttings samples from the ARCO OCS Y-0211 No. 1 well (Yakutat well).

Y-0211 well. Insufficient vitrinite was available in the samples to yield reliable R_o averages.

The most satisfactory available petrography and geochemistry from this well occurs between about 10,000 to 15,000 feet. Both the vitrinite content and the pyrolysis response to organic material fall off below these depths (fig. 102). Because there was insufficient bituminous extract for gas chromatography below 15,000 feet, percentages of paraffins plus naphthenes are unavailable.

Several parameters are used to evaluate the level of thermal maturity at which hydrocarbons are likely to be generated. The parameters include mean vitrinite reflectance (R_o), the T_{max} value from pyrolysis, the increase in saturate content of hydrocarbons, and a Lopatin model based on the temperature gradient obtained from the well. The profiles constructed from these parameters show good agreement regarding the threshold for oil generation. In the case of the OCS Y-0211 well, sediments which produce an R_o of 0.6 percent ideally yield a T_{max} value of 435 °C, a time-temperature index (TTI) of 10, and a marked increase in the saturate content of extracted hydrocarbons. These values almost never occur simultaneously at exactly the same depth. However, as is shown below, these values exhibit very good agreement in the OCS Y-0211 well.

The R_o data from GeoChem Laboratories, Inc., is used to identify the zone of catagenetic alteration in this report because most of the GeoChem Laboratories, Inc., analyses were performed immediately after the drilling was completed, because their analyses included sidewall core samples, and because their data seem to be more consistent with other measures of thermal alteration. R_o values approach 0.6 percent, the generally recognized threshold for commercial oil generation (Hunt, 1979), at about 12,500 feet in the OCS Y-0211 well. T_{max} values from Rock Eval pyrolysis, the character of heavy hydrocarbon extracts, and calculated time-temperature indices (TTI values) also agree favorably with this interpretation (fig. 104). The chromatogram from 9,110 feet exhibits a low (< 1.0%) paraffin-naphthene/aromatic hydrocarbon ratio; a bimodal distribution of alkanes with an abundance of heavy, long-chain alkanes; plus the presence of steranes and pentacyclic terpane-related compounds (C_{25} - C_{31} spikes on the naphthene envelope). All of these are characteristic of immature hydrocarbons (Bayliss and Smith, 1980). The chromatogram from 13,100 feet does not exhibit a bimodal distribution of alkanes nor the presence of steranes and terpanes, but the long-chain alkanes are still present. The chromatogram from 16,340 feet exhibits the characteristics of a hydrocarbon approaching peak maturity. When a source rock has reached sufficient maturity to generate significant amounts of oil, the alkane distribution normally peaks between C_{13} and C_{18} and shows a steady decrease in the concentration of alkanes with longer chain lengths (Hunt, 1979).

The floor of the oil window is not clearly defined because of the low content of both kerogen and bitumen in the sediments below about 15,000 feet. R_o data are projected to 1.35 percent, the point at which liquid petroleum is converted to gaseous hydrocarbon at a significant rate. The GeoChem Laboratories R_o values projected to 1.35 percent at about 17,300 feet in the OCS Y-0211 well (fig. 104). This projection parallels the somewhat higher Bujak Davies R_o values reasonably well. At 17,390 feet, 50 Bujak Davies reflectances yielded a good histogram which produced an R_o value of 1.83 percent. Four reflectances were thought to represent reworked organic material.

A Lopatin model (fig. 105) was constructed from lithologic thicknesses, paleontological ages, and the temperature gradient derived from corrected bottom hole temperatures (Lopatin, 1971). The model was created to test the consistency of these parameters with empirical measures of thermal alteration in the OCS Y-0211 well. Waples (1980 and 1984a) calibrated Lopatin's time-temperature index values (TTI) with R_o values obtained from a worldwide sampling of sediments. In Waples' correlation, a TTI of 10 corresponds to an R_o of about 0.6 percent, a TTI value of 180 corresponds to an R_o value of about 1.35 percent, and a TTI of 900 corresponds to an R_o of 2.0 percent. The high values (R_o = 2.0 percent and TTI = 900) represent the extreme limits of catagenesis. Beyond these limits, only methane or graphite would be expected to survive as the rocks approach metamorphic grade.

In the Yakutat OCS Y-0211 well, the time-temperature index (TTI) reaches 10 at about 12,500 feet and 180 at 16,600 feet. At 17,300 feet, the floor for the oil window based upon projected R_o values, the computed TTI is 297. The inconsistency at the floor of the oil window between the computed TTI value (297) and the expected value (180) at a projected R_o value of 1.35 percent is insignificant for several reasons. There is uncertainty about fundamental information fed into the model, the most important being the distribution of temperature in the earth's crust over time. Additionally, the Lopatin model is less tenable at higher temperatures (Barker,

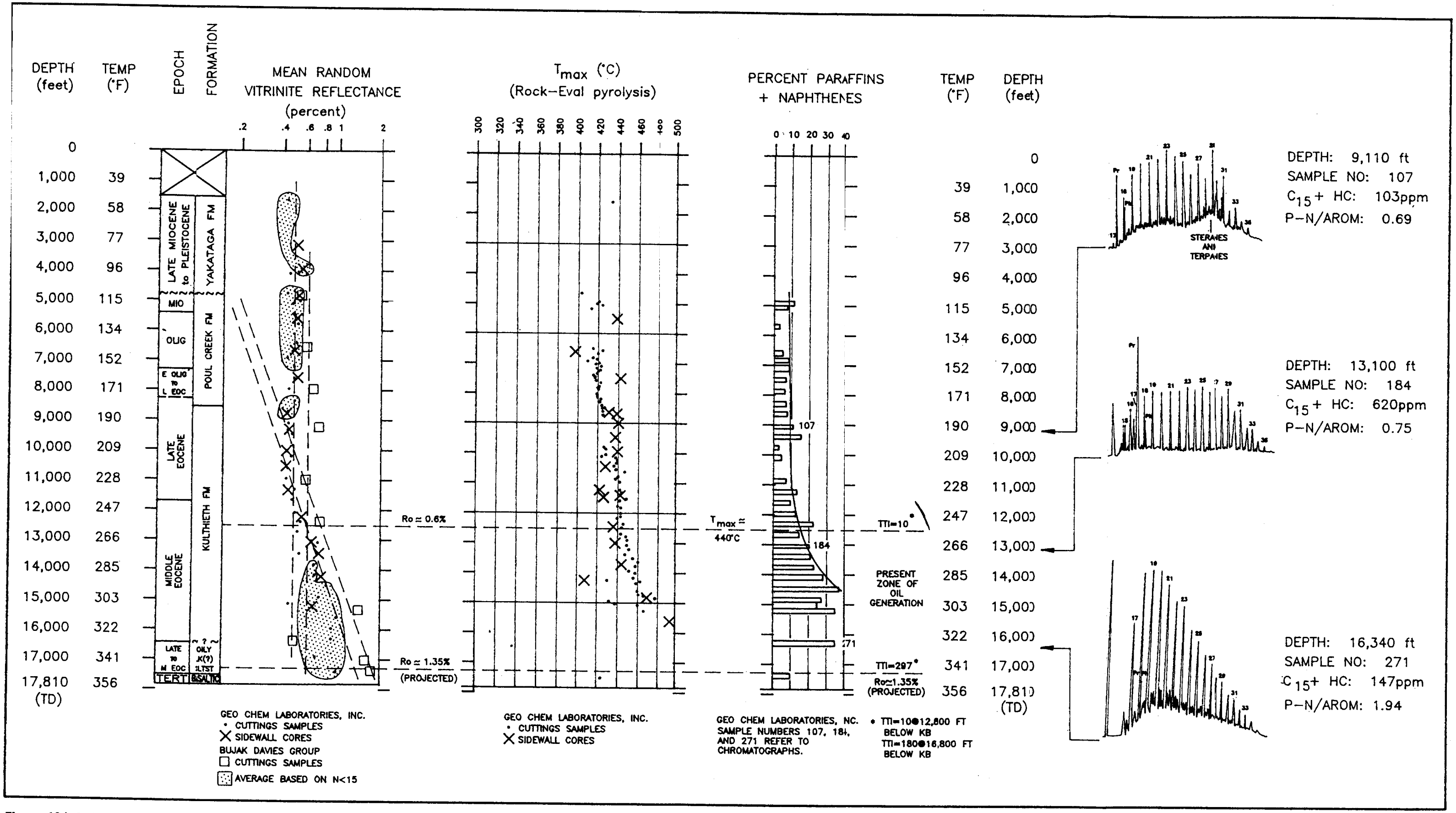

Figure 104. Indicators of thermal maturity from the OCS Y-0211 No. 1 (Yakutat) well. Depths are measured from the kelly bushing. Ambient rock temperatures are computed from a linear regression of corrected bottom hole temperatures (chapter 9).

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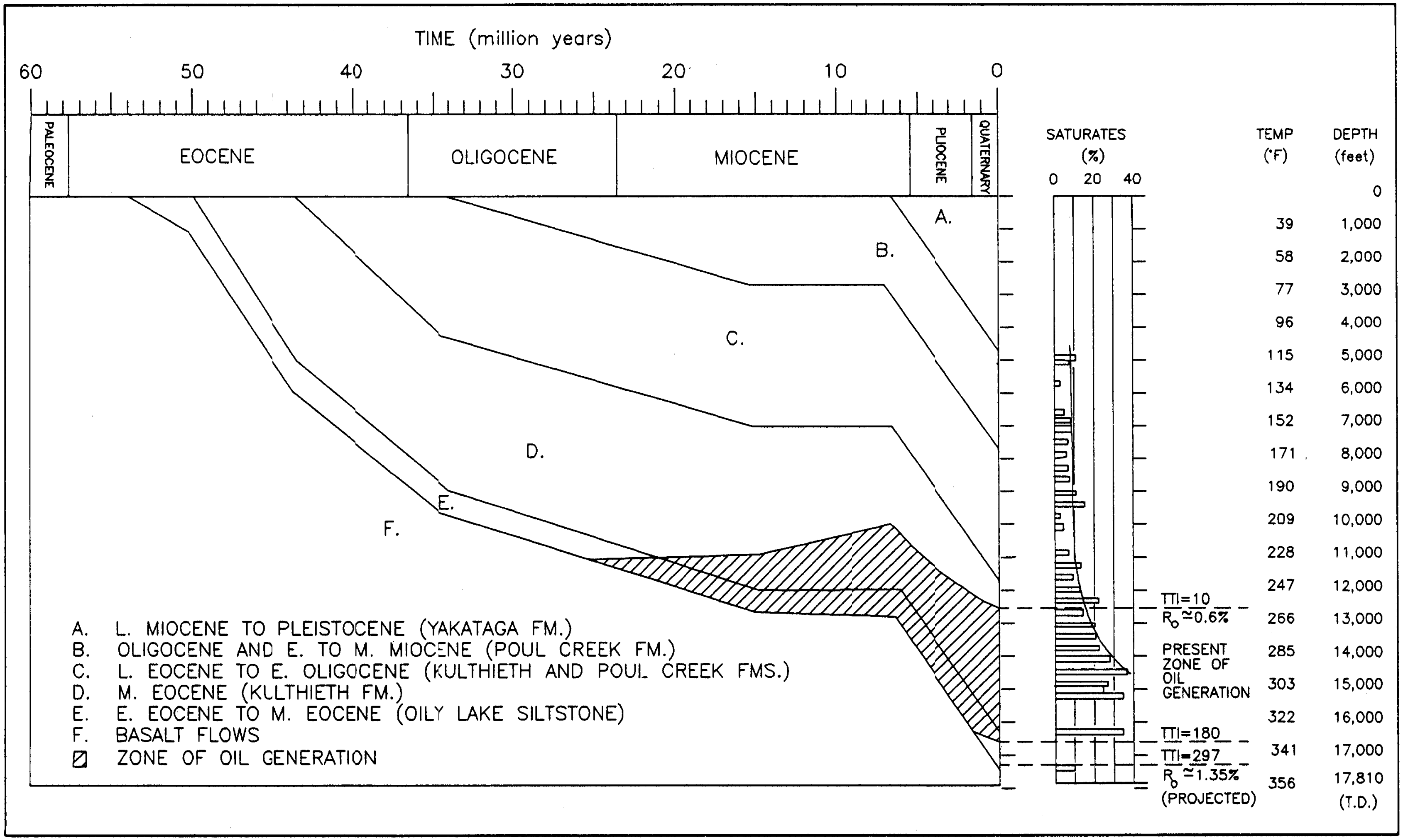

Figure 105. Lopatin model, OCS Y-0211 No. 1 well.

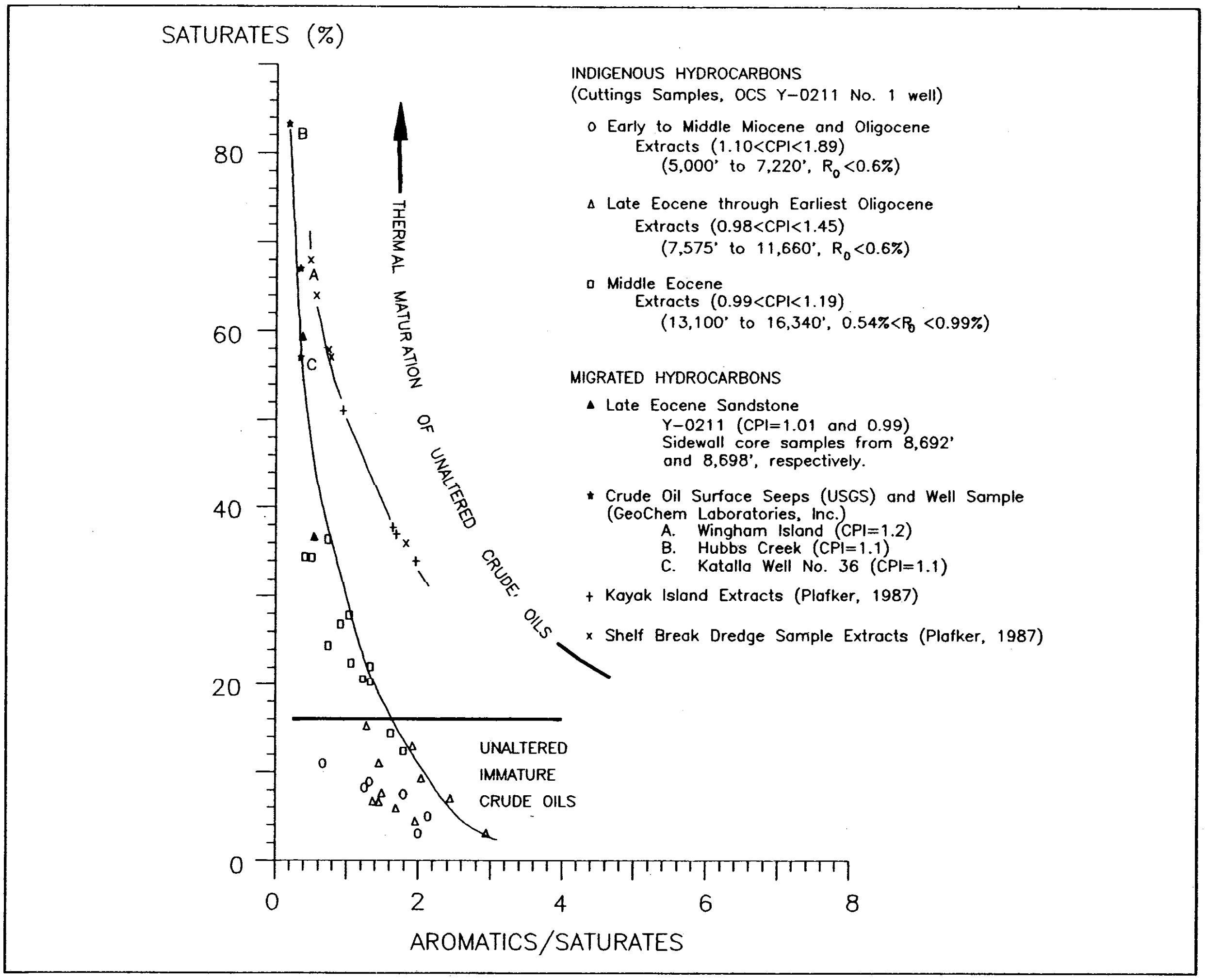

Figure 106. Effect of increasing thermal alteration (maturation) on the distribution of saturated and aromatic hydrocarbon composition from extracts from the ARCO OCS Y-0211 No. 1 well. C_{15}+ hydrocarbons have been deasphaltened. The term "unaltered" indicates that the samples have not been significantly affected by microorganisms, water washing, or oxidation. CPI signifies the carbon preference index. See plate 8 for sample locations. This diagram is adapted from Connan and others (1975).

written commun., 1991).[5] Finally, the observed measures of thermal alteration (R_o, T_{max}, and so forth) are less reliable because detailed data are unavailable below about 15,000 feet (fig. 104).

The Lopatin model (fig. 105) predicts that at the OCS Y-0211 well, oil first began to appear in rocks of middle Eocene age about 25 million years ago (Oligocene) and that younger rocks have not been exposed to sufficiently high temperatures for an adequate length of time to generate petroleum. The model yields a TTI of 0.3 at

5 The Lopatin model is based on the assumption that the reaction rate doubles for each 10 °C temperature increase from about 50 to 250 °C and that activation energies (E from the Arrhenius equation) range from about 10 to 30 kilocalories per mole. This assumption produced an infinite linear increase in ln TTI in contrast to a finite limit for ln k (the reaction rate coefficient from the Arrhenius equation) (Robert, 1988). It is possible that the kinetics of generation and destruction may have very different temperature dependencies (Waples, 1984a). Different kerogens with dissimilar reaction energies probably mature at different rates (Barker, oral commun., 1991). Waples (1984a) has suggested that the application of the Lopatin model to oil and gas preservation deadlines requires more sophisticated investigation.

7,760 feet, indicating virtually no thermal alteration has occurred in the early Oligocene to late Eocene Poul Creek sediments. The two R_o profiles in figure 104 project to 0.18 or 0.2 percent at the disconformity between the Yakataga and the Poul Creek Formations or perhaps in the Miocene Poul Creek sediments just below the disconformity. These R_o values are characteristic of thermally unaltered organic materials that have experienced only diagenetic alteration (Dow, 1977).

Figure 106 shows saturate contents versus the aromatic/saturate ratios of extracted hydrocarbons from the OCS Y-0211 well cuttings in addition to several miscellaneous analyses. The diagram is designed to evaluate the thermal maturity of unaltered oils and is based on the classical law of organic geochemistry that the most mature oils possess the largest quantity of saturates (Seifert and Moldowan, 1978). It was devised by observing changes in composition in a large number of crude oils and rock extracts of various origins and degrees of maturity (Bajor and others, 1969; Connan and others, 1975).

Extracts from the middle Eocene Kulthieth Formation rocks exhibit a systematic increase in saturate content with depth. Extracts from younger rocks do not. The increase in saturate content corresponds with an increase in vitrinite reflectance (R_o) and a decrease in the carbon preference index (CPI) to approximately 1.0. The increase in the saturate content of the extracted $C_{15}+$ hydrocarbons at 12,380 feet (fig. 104) probably represents the onset of catagenetic alteration of the heavy hydrocarbons in the OCS Y-0211 well. Mature, migrated hydrocarbons extracted from sandstone lithologies in the OCS Y-0211 well and mature, unaltered oil seep samples and the oil sample from the Katalla No. 36 well also fall along this projected trend.

Extract data from samples dredged from the continental shelf break just south of the OCS Y-0211 well and from outcrop samples from Kayak Island (plate 8) produce a second trend on figure 106. Connan and others (1975) note that petroleum is subject to two kinds of alteration: thermal alteration, which expresses the trend of any chemical system toward its state of equilibrium, and bacterial alteration, which results in the removal of certain classes of hydrocarbons and the generation of pentane- and chloroform-insoluble components (see discussion of the altered oil seep samples depicted in figs. 98 and 99). Bacterial alteration tends to reduce the saturate content and increase the aromatic to saturate ratio. The trend of the data from the shelf break dredge samples and the surface samples from Kayak Island is consistent with biodegradation.

The relatively high saturate content of the shelf break and Kayak Island samples suggests that they are at least as thermally mature as the extracts from the deepest cuttings samples (16,000 feet or more) in the OCS Y-0211 well. If the shelf break and Kayak Island samples are biodegraded, their original saturate content would have been even higher. The Kayak Island samples from which Plafker (1987) derived heavy hydrocarbon extracts (fig. 106) come from sediments exhibiting R_o values of 0.4 percent (bottom of table 10; Plafker, oral commun., 1987). These outcrop samples are not mature enough for a major portion of the kerogen to have been converted to liquid petroleum (Plafker, 1987).

Four of the dredge samples from which Plafker (1987) obtained heavy hydrocarbon extracts are thermally immature ($0.3 \leq R_o \leq 0.5$ percent). The fifth dredge sample yielded two vitrinite populations, one mature and the other immature. The thermal alteration index (TAI) and T_{max} values (2.6 and 439 °C, respectively) are consistent with the higher R_o value (0.90 percent). However, the saturate content of the $C_{15}+$ extract suggests that the bitumen is far more mature than bitumen from the OCS Y-0211 well, where R_o for the kerogen was about 1.0 percent (fig. 106). This implies that the bitumen from Kayak Island and shelf break samples has migrated into the sediments from which it was extracted. Large fault systems in the region, such as the Kayak Island fault zone, could have provided the avenue along which the hydrocarbons migrated.

ARCO OCS Y-0007 and Gulf OCS Y-0059 wells

The remaining offshore wells in the Gulf of Alaska provide significantly less useful information than the OCS Y-0211 No. 1 well. Two wells which provide some insight into the thermal alteration and organic richness of the sediment from this region are the ARCO (Salome) OCS Y-0007 No. 1 and the Gulf (Colleen) OCS Y-0059 No. 1 wells (plate 8).

All depths discussed for the OCS Y-0007 well were measured from the kelly bushing (KB), 95 feet above sea level. The water depth was 250 feet. Sediments to a depth of 11,580 feet belong to the Yakataga Formation. From 11,580 to 17,920 feet the section is equivalent to the Poul Creek Formation.

Twenty-two selected cuttings samples held by the MMS were sent to GeoChem Laboratories, Inc., to be

Table 11. Thermal alteration of USGS shelf-break dredge-sample extracts and kerogen (Plafker, 1987, and Plafker and Claypool, 1979). The shales and claystones are of middle to late Eocene age. Sample locations are shown on plate 8.

USGS Sample No.	Arom/Sat	Sat (%)	R_o (%)	TAI	Tmax (°C)	Sample Description
78-22D3	0.74	58	0.49/0.90[1]	2.6	439	Medium-gray silty shale; pre-Pliocene foraminifera; marine
79-39F	0.77	57	0.5	2.1	NA[2]	Medium-gray partly calcareous claystone; probable middle to late Eocene; marine
78-44D	1.82	36	0.3	1.9	421	Dark-olive-gray shale with silt-size grains; probable middle to late Eocene; marine (middle bathyal)
79-36C/D[3]	0.48	68	0.3/0.4	2.1	NA[2]	Yellow-brown partly calcareous claystone; probable middle to late Eocene; marine (bathyal with transported shallow, tropical fossils)
79-24B	0.56	64	0.3	1.9	NA[2]	Dusky-brown partly calcareous claystone; probable middle to late Eocene; marine (middle to lower bathyal)

[1]Two populations
[2]NA indicates data not available
[3]Two samples combined for extract analysis

analyzed for TOC, C_{15}+ extracts (no chromatography), visual kerogen, and R_o. The samples represent the interval from 2,980 to 17,880 feet and were taken at increments of from 20 to 180 feet. The analyses were performed in 1979, two years after completion of the well. Results of the analyses are given in table 12. Because chromatography was not performed, GeoChem Laboratories, Inc., estimated the concentration of C_{15}+ hydrocarbons by assuming that the hydrocarbons would have composed half of the nC_5 soluble bitumen.

TOC and total extract analyses do not indicate that promising source rock is present in this well. The high bitumen (total extract) contents are composed largely of asphaltenes (nonhydrocarbons).

Average R_o values (table 12) represent the dominant mode from each sample, and N is the number of observations averaged to compute the R_o value. Although there appear to have been sufficient vitrinite group macerals present to provide reliable R_o values, the values do not exhibit a normal logarithmic increase with depth but, instead, decrease from approximately 0.50 percent at 7,800 feet to about 0.40 percent at 17,900 feet (table 12 and fig. 108).

In the OCS Y-0007 well, the maximum uncorrected bottom hole temperature reached 244 °F at 17,810 feet below the KB. This implies a low temperature gradient compared with other Gulf of Alaska wells (fig. 91), but adequate to produce a distinct increase in thermal alteration of previously unaltered kerogen. The retrograde R_o profile present is characteristic of recycled organic matter.

The Gulf OCS Y-0059 well was drilled in 623 feet of water. The KB was 85 feet above sea level. Total depth of the well was 12,170 feet below the KB and the well penetrated Yakataga Formation sediments to total depth. Detailed geochemistry, performed by GeoChem Laboratories, Inc. (Van Delinder, 1977), is summarized in table 13. The subzones referred to in table 13 were identified largely on the basis of the light hydrocarbon content and the presence of coal debris in subzone A. GeoChem Laboratories, Inc., concluded that the sediments penetrated exhibit "a poor oil source character as a direct function of their organic leanness, kerogen type, and low geothermal history."

Several indicators of thermal maturity (Van Delinder, 1977) from the OCS Y-0059 well are plotted on figure 107. Microscopy in transmitted light revealed an extensive population of highly altered, recycled organic matter, as would be expected in a glaciomarine sediment. Van Delinder (1977) suggested that the four deepest visual kerogen alteration values from his indigenous population were too high. He estimated that if these same sediments persist with greater depth at this location, a mature level of thermal alteration (stage 2+) would not be reached above 20,000 ± feet. The trend produced by the visual kerogen alteration values contrasts with the trend of the R_o values. Average R_o values for the four subzones (table 13 and fig. 107) decrease with depth from 0.53 percent for the top subzone to 0.46 percent for the lowermost subzone.

A Lopatin model computed with a temperature gradient of 1.05 °F per 100 feet (chapter 9) and the probability of Poul Creek sediments below 14,000 feet based upon

Table 12. Selected geochemistry and mean random vitrinite reflectance (R_o) from shale and siltstone samples, ARCO Salome OCS Y-0007 No. 1 well (Tybor, 1979).

Series	Stage	Formation	Depth Interval (feet)	TOC (%)	Total Extract (ppm)	Preciptd. Asphaltene (ppm)	Est. Total Hcbs.[1] (ppm)	R_o, N[2] (%)
PLEISTOCENE	early	YAKATAGA FORMATION	2,980-3,130	0.37	439	159	140	
			3,850-4,030	0.27	308	57	125	
			5,330-5,360	0.30	334	139	97	
PLIOCENE	late		6,050-6,080	0.31,0.29	236	60	88	
			7,120-7,150	0.27	255	83	86	
	early		7,800-7,830	0.24	5,357	5,258	49	0.49, 27
			9,190-9,230	0.30	711	502	104	0.53, 18
			10,030-10,070	0.28	1,920	1,840	40	0.51, 37
			11,140-11,190	0.34	9,147	9,030	58	0.48, 36
OLIGOCENE	early(?) to late	POUL CREEK FORMATION	11,820-11,850	0.41	18,292	18,153	69	0.51, 30
			12,250-12,280	0.34	12,780	12,683	48	0.40, 39
			12,660-12,690	0.41	12,345	12,255	45	0.59, 16
			13,300-13,330	0.44	3,906	3,798	59	0.44, 33
			13,770-13,820	0.42	5,477	5,390	43	0.46, 36
			14,230-14,270	0.50,0.52	8,182	8,059	61	0.38, 37
			14,810-14,840	0.53	15,219	14,876	71	0.43, 30
			15,270-15,300	0.62	4,416	4,282	67	0.43, 32
			15,670-15,710	0.46	4,372	4,024	74	0.45, 9
EOCENE	late		16,230-16,260	0.67	4,046	3,939	53	0.36, 17
			16,790-16,820	0.56	7,146	7,002	72	0.50, 22
			17,340-17,380	0.90	10,241	9,771	235	0.42, 37
			17,840-17,880	0.73	4,914	4,702	106	0.42, 33

[1]Estimated total hydrocarbons (50 percent of nC_5 soluble bitumen).

[2]R_o values represent the first population of reflectance measurements. The first population contained the largest number of reflectance measurements and produced the lowest mean values for each cuttings sample. N is the number of reflectance values in the first population of measurements used to compute the mean reflectance values.

Table 13. GeoChem Laboratories, Inc., summary of main organic geochemical characteristics from cuttings samples, OCS Y-0059 No. 1 well (Van Delinder, 1977). The OCS Y-0059 well penetrated only sediments of the Plio-Pleistocene section of the Yakataga Formation. The four subzones were identified by Van Delinder on the basis of subtle organic geochemical differences.

Organic Geochemical Characteristics		Subzone A 0′ to 4800′	Subzone B 4800′ to 6600′	Subzone C 6600′ to 8800′	Subzone D 8800′ to 12180′
C_1-C_7 Light Hydrocarbon					
C_1 (methane) ppm*	Average	19243	12980	3586	2826
	Maximum	32397	26486	8648	7261
C_2-C_4 (ethane+) ppm*	Average	50	49	37	71
	Maximum	113	72	76	175
% Gas Wetness	Average	0.3%	0.4%	1.2%	2.7%
C_5-C_7 (gasoline-range) ppm*	Average	2	14	11	128
	Maximum	22	51	27	450
C_5-C_7 Detailed Analysis ppm*	Average	n.a.	n.a.	n.a.	121
	Maximum	—	—	—	341
C_{15}+ Soluble Bitumen Content					
Total C_{15}+ Extract ppm**	Average	276	317	242	202
	Maximum	804	732	359	290
C_{15}+ Hydrocarbon ppm**	Average	24 est***	29 est***	31 est***	39 est***
	Maximum	34 est***	41 est***	43 est***	120
P-N/AROM Ratio		n.a.	0.89	0.78	1.93
% P-N in Total Extract		n.a.	1.7%	4.8%	29.7%
Total Organic Carbon Content					
% of Rock	Average	0.44%	0.28%	0.30%	0.26%
	Maximum	1.08%	0.55%	0.39%	0.51%
Kerogen Composition					
Am-Amorphous; H-Herbaceous; W-Woody; C-Coal Debris; Al-Algal		W;H;Am (Al)	W-H;C; Am(Al)	H;W;Am-C	H;W;Am-C
Kerogen Alteration					
(1 to 5 Scale)	Top	1+	1+ to 2-	1+ to 2-	1+ to 2-
	Bottom	1+ to 2-	1+ to 2-	1+ to 2-	2 to 2+****
Vitrinite Reflectance (%R_o) Values					
	Average	0.53	0.51	0.48	0.46

Notes:
* Volumes gas per million volumes cuttings.
** Grams per million grams cuttings.
*** C_{15}+ hydrocarbon estimated on extract samples too lean for quantitative liquid chromatography.
**** High ? - see figure 107.

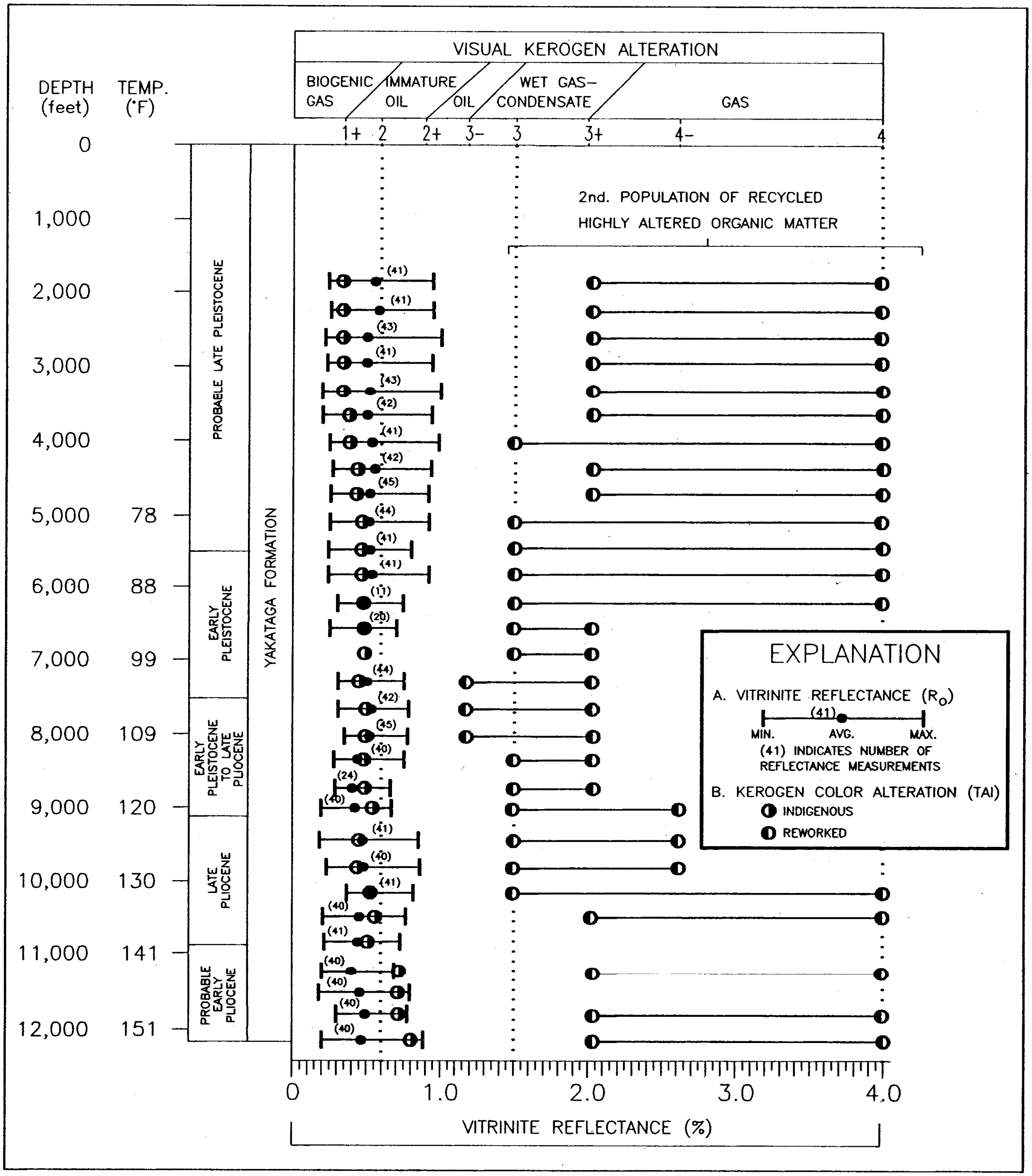

Figure 107. Mean random vitrinite reflectance and kerogen color alteration values for the Gulf Oil OCS Y-0059 No. 1 well. Visual kerogen alteration of 2, 3, and 4 equal R_0 values of 0.6, 1.5, and 4.0 percent respectively. Diagram modified from report of analyses by Geochem Laboaratories, Inc. (Van Delinder, 1977). Biostratigraphy from Anderson, Warren, and Associates (1977b). Ambient rock temperatures are computed from a linear regression of corrected bottom hole temperatures (see chapter 9).

seismic data suggest that Van Delinder's projected depth for the threshold of oil generation may be low. Even if the temperature gradient were 1.89 °F per 100 feet, the highest corrected temperature gradient observed for the Gulf of Alaska (chapter 9), the Yakataga sediments in the OCS Y-0059 well would, theoretically, be unaltered.

The complete suite of R_o data for the OCS Y-0059 well is plotted on figure 108 along with R_o profiles from the OCS Y-0007 and the OCS Y-0211 wells. These data were derived from sediments of Pleistocene to late Eocene age obtained from cuttings. The three combined wells produce overlapping R_o profiles representing more than 16,000 feet of sediment. The low amount of scatter of the R_o data plotted on the profile in figure 108 is striking. It would be impressive if only a single well were involved. The retrograde R_o profile plus the fact the that data from three wells exhibit so little variation suggest that the vitrinite reflectance, from sediments of Pleistocene to late Eocene age over an extensive area in the Gulf of Alaska, is virtually unrelated to formation, specific sample location, or age of the kerogen, provided the kerogen is derived from sediments that are no older than late Eocene.

The simplest way to explain the retrograde R_o profile is that most of the kerogen sampled from these offshore wells must have been recycled. This hypothesis would also explain the generally low hydrogen indices for the Poul Creek and the late Eocene Kulthieth Formations on the modified Van Krevelen diagrams (fig. 103) for the OCS Y-0211 well. Only unreactive organic material (inertinite) or very mature kerogens should exhibit such low hydrogen indices.[6] The regressive character of the R_o profiles suggests progressive unroofing in a source terrane. The first recycled kerogen to be deposited possessed an R_o of about 0.4 percent, and as deeper sediments were eventually exhumed, vitrinite with a reflectance of as much as 0.6 percent was recycled into the youngest Yakataga rocks. The result is an R_o profile that now decreases with increasing depth rather than one that increases in the usual manner. Where overturned bedding is present in the Phillips Kerr McGee Sullivan No. 1 well (appendix G-2) the highest R_o value (0.62 percent) was measured at the bottom of the overturned section rather than at the top.

The presence of altered, reworked kerogen and the virtual absence of fresh unaltered kerogen in sediments of the Poul Creek and possibly the upper Kulthieth Formations could be related to an oxidizing environment. In an unrestricted marine environment with free water circulation and little or no bacterial activity, the sea water–mud interface has the normal Eh and pH of the open ocean; that is, an Eh of +0.1 to +0.3 volt and a pH of 7 to 8. In this environment, ferric compounds characteristic of iron formations would be stable (Stanton, 1972) but organics would be readily oxidized. According to Krauskopf (1979), present-day environments of deposition where organic matter is accumulating exhibit oxidation potentials on the order of -0.1 to -0.5 volt. The nature of the preserved kerogen would depend on the kind of organic material that settled to the bottom, the environment of deposition, and the extent of the organic material's previous oxidation. If ocean bottom currents provided adequate water circulation, as Armentrout (1983a) has suggested for Neogene and Holocene sediments in the Gulf of Alaska, it is probable that the Eh of the sea water–sediment interface would be maintained between these extreme limits. If the Eh were near 0 but positive, possibly between 0 and +0.1 volt, fresh organic material would be oxidized, while recycled, previously oxidized kerogen might not be as susceptible to further oxidation and would consequently survive to be buried. Armentrout (1983a) also pointed out that marine organisms living in well-oxygenated sea water would be more likely to consume fresh, nutrient-rich organic debris than oxidized terrestrial and recycled organic matter transported along with the clastic sediments.

A few centimeters below the seafloor the pH can drop to 5 or 6. Glauconite and phillipsite (a potassium zeolite) are stable in this environment. In a basic solution in which iron and sulfur are present, pyrite would not be stable unless the Eh was less than -0.2 volt, but in an acid environment, pyrite can form up to an Eh of about +0.2 volt (Krauskopf, 1979).

To recapitulate, if a mildly basic oxidizing environment were present at the sea bottom when Poul Creek sediments were deposited, fresh organic material that survived to reach the sea floor would be oxidized. Recycled kerogen that had survived a much more rigorous oxidizing environment during erosion above sea level would no longer be as susceptible to oxidation and would, therefore, survive to be buried. If the pH in the sediment decreased as the sediments accumulated and if potassium, iron, and sulfur were present, glauconite and pyrite would become stable mineral phases. The resulting sediments would contain reworked organic

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6 Unpublished industry data from Kayak Island shows the Miocene part of the Poul Creek Formation to be an organically rich, oil-prone source rock (TOC of 4 to 10 percent) characterized by Type I and Type II kerogen (Turner, written commun., 1992). However, at the present time the data remain unavailable.

matter, glauconite, and pyrite but little or no detectable unaltered kerogen. Such a kerogen and mineral assemblage is present in the Poul Creek Formation and, with the exception of the glauconite and pyrite, in the upper part of the Kulthieth Formation in the Yakutat No. 1 well (Plafker, 1974) (see also chapter 5).

Tenneco Middleton Island State No. 1 well

The Tenneco Middleton Island State No. 1 well was drilled in 1969 west of the Yakutat terrane, which contains the other wells and the active oil and gas seeps of the Gulf of Alaska. The height of the KB was 71 feet above sea level and water depth was 60 feet. Total depth was 12,000 feet. Gulf Oil analyzed cuttings from this well in 1974 (Alaska Geologic Materials Center Data Report 8, 1974) using a pyrolysis-fluorescence process patented by Heacock and Hood (1970). This method is designed to detect and evaluate only thermally active organic matter and yields measurements in "fluorescent units" which are compared with data from organic shales from the western United States. Most of the Middleton Island well cuttings did not fluoresce. These cuttings do not appear to contain sufficient amounts of organic matter to be sources for economically significant amounts of petroleum.

Figure 109 shows mean random vitrinite reflectance (R_o) for the Middleton Island well (Alaska Geologic Materials Center Data Report 8, 1974, and Report 32, 1984). The interpretive profile suggests that the sediments penetrated by this well are thermally immature. This interpretation is supported by Lopatin modeling, even with the assumption of the high estimated temperature gradients (1.39 °F per 100 feet) needed to produce maximum likely TTI values.

In sum, the largest quantity of and highest quality data came from the OCS Y-0211 well. Few of the samples analyzed exhibit a high degree of organic richness. Samples with the highest genetic potential came from the middle Eocene Kulthieth Formation. Samples from Kayak Island have produced significant amounts of bitumen, but the bitumen is considerably more mature than the kerogen in the sediments from which the bitumen was extracted, suggesting that the bitumen migrated into the sediments.

Catagenesis in the OCS Y-0211 well begins to occur at about

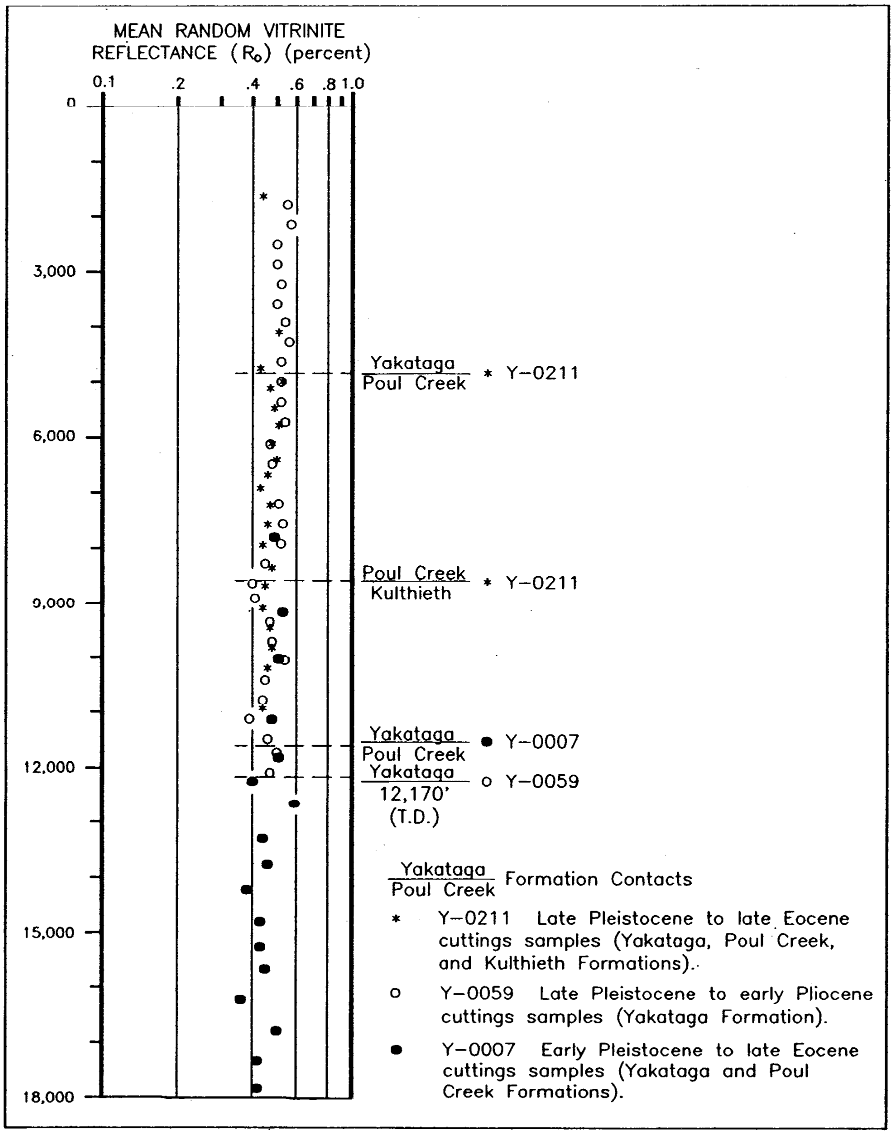
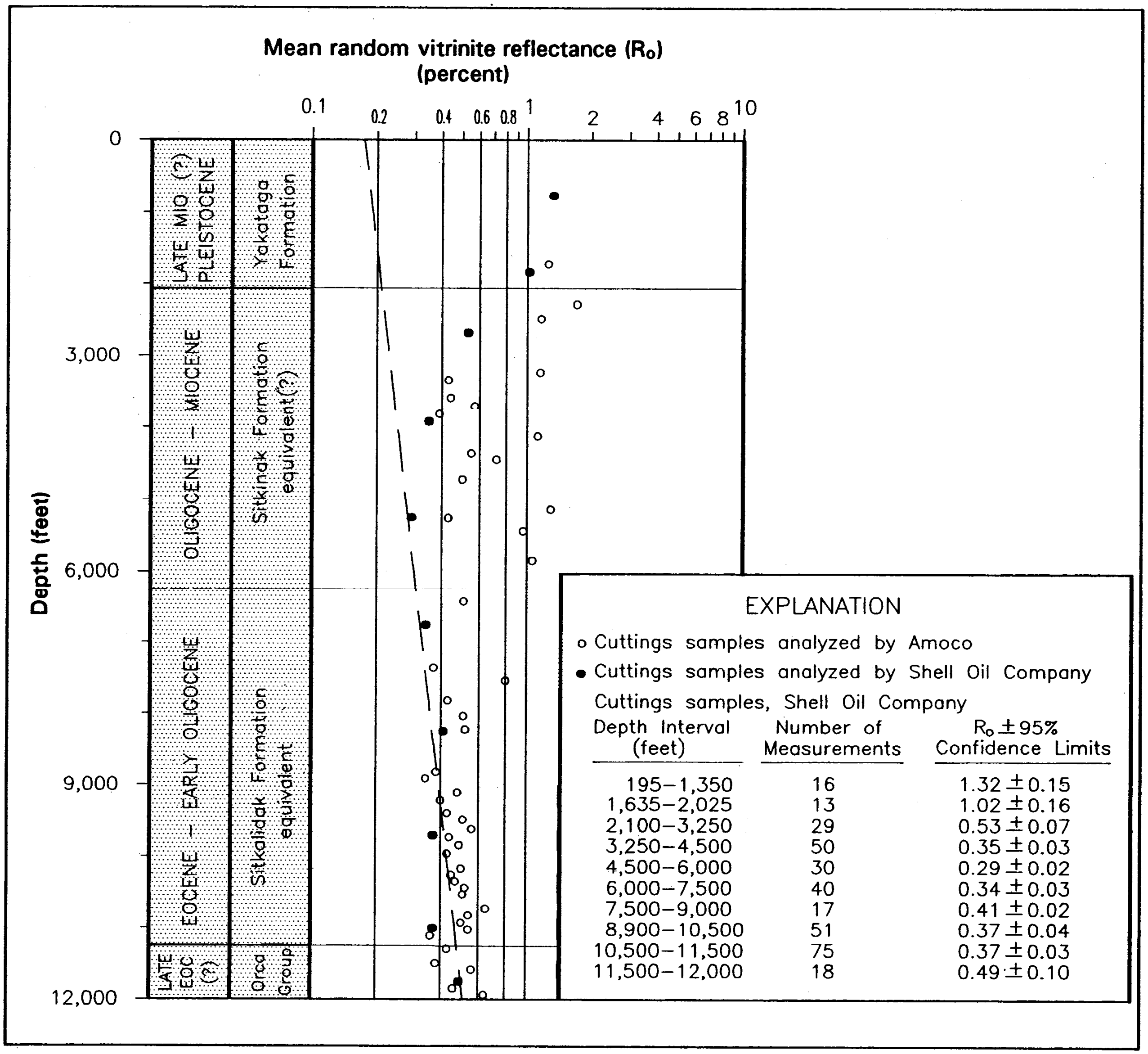


Figure 108. R_o values from cuttings samples from three offshore Gulf of Alaska wells measured in sediments of Pleistocene through late Eocene age. Data from GeoChem Laboratories, Inc.



Depth Interval (feet)	Number of Measurements	$R_o \pm 95\%$ Confidence Limits
195–1,350	16	1.32 ± 0.15
1,635–2,025	13	1.02 ± 0.16
2,100–3,250	29	0.53 ± 0.07
3,250–4,500	50	0.35 ± 0.03
4,500–6,000	30	0.29 ± 0.02
6,000–7,500	40	0.34 ± 0.03
7,500–9,000	17	0.41 ± 0.02
8,900–10,500	51	0.37 ± 0.04
10,500–11,500	75	0.37 ± 0.03
11,500–12,000	18	0.49 ± 0.10

Figure 109. Mean random vitrinite reflectance (R_O) values, Tenneco Middleton Island State No. 1 well. Biostratigraphy is from figure 58.

12,500 feet. In the Middleton Island well, catagenesis begins to occur at depths in excess of 13,000 feet. The normal R_o profiles that were obtained came from wells containing rocks of middle Eocene and older age. Other offshore wells which did not penetrate the Kulthieth Formation produced retrograde R_o profiles, suggesting the kerogen from late Eocene and younger rocks contained very little unrecycled organic material. The absence of indigenous kerogen is thought to be the result of an inhospitable depositional environment.

Origin of Petroleum in the Gulf of Alaska

The chemical composition of the three available oil samples suggests a correlation with the Kulthieth Formation. A single biomarker analysis points to a terrestrial or nearshore origin consistent with a Kulthieth source. Carbon isotope ratios indicate both marine and nonmarine sources for the oil, and Magoon (in press) suggests, on the basis of carbon isotope studies performed by A. N. Fuex, that both the Poul Creek and the Kulthieth Formations generated petroleum in the Gulf of Alaska.[7]

Chemical Composition of Crude Oil and Extracts

The most extensive analysis of Gulf of Alaska oil was the refining of crude oil at Katalla. Early reports indicate that the Katalla Oil Field yielded a predominantly paraffinic crude oil (Martin, 1921; Miller and others, 1959; Blasko, 1976). Analyses by the USGS of the two least altered oil samples from seeps (Plafker, 1987) support a light, low-sulfur, paraffinic oil (figs. 95 and 97).

The isoprenoids pristane (Pr) and phytane (Ph) have been used successfully as indicators of depositional environment and as biomarkers (Powell and McKirdy, 1973; and Lijmbach, 1975). There is no universal agreement regarding their usefulness for these purposes (Sofer, 1984; Moldowan and others, 1985), but they are readily available from standard gas chromatography procedures and, therefore, are frequently included in the literature. Pristane to heptadecane (n-C_{17}) and phytane to octadecane (n-C_{18}) ratios are also used because the pairs of compounds elute almost simultaneously from the gas chromatograph.

The Pr/Ph, Pr/n-C_{17}, and Ph/n-C_{18} ratios for extracts from the OCS Y-0211 well, two USGS oil seep samples, and a crude oil sample from the Katalla No. 36 well are given in figure 110. Pr/Ph ratios of less than 1 are characteristic of autochthonous marine or some lacustrine organic matter and reducing environments. Pr/Ph ratios greater than 3 are considered to be representative of terrestrial organic matter deposited in a marine setting and oxidizing environments (Hunt, 1979).

The Poul Creek and Kulthieth formations exhibit contrasting isoprenoid and isoprenoid n-alkane ratios (fig. 110). The Pr/Ph ratio for the Poul Creek Formation extract is characteristic of a marine sediment and the Kulthieth Formation of terrestrial organic matter deposited in a nearshore environment with a smaller marine component (Hunt, 1979). The high Pr/Ph values for the oil samples are more consistent with a Kulthieth extract than with a Poul Creek extract. Figure 110 (the isoprenoid n-alkane diagram) shows a clear separation of the two populations of $C_{15}+$ extract data from the Poul Creek and the Kulthieth Formations. Paleontological evidence indicates that the Poul Creek Formation was deposited in a deep-marine basin. The Pr/Ph ratios on figure 110 are consistent with that interpretation, but the isoprenoid n-alkane ratios indicate a peat-coal or transitional environment. Oxidation of the organic matter could have caused the shift in the locus of these data points out of the field where marine organic matter would normally be expected to plot. The isoprenoid n-alkane ratios from the three oil samples are also more similar to Kulthieth extracts than to Poul Creek extracts. The crossplot also indicates a lower level of thermal maturity for the late Eocene Kulthieth extracts than for the middle Eocene Kulthieth extracts. This is consistent with indicators of thermal alteration provided by microscopy, pyrolysis, and paraffin distribution (fig. 104). The two extracts from the late Eocene sandstones that plot near the center of the extracts from the middle Eocene shales are interpreted as representing migrated bitumen from much deeper lithologies. Because the bitumen came from sandstone, and because its high saturate content indicates high maturity (fig. 106), this interpretation seems reasonable. The composition of the two extracts most nearly resembles Kulthieth extracts.

Carbon Isotope Analyses

In addition to limited chemical analyses, a few crude oil and extract samples have been analyzed by mass spectrometry to determine carbon isotope ratios ($\delta^{13}C$):

$$\delta^{13}C_{PDB} = \left[\frac{(^{13}C/^{12}C)_{sample}}{(^{13}C/^{12}C)_{standard}} - 1 \right] 1{,}000$$

The most common standard used is the Peedee belemnite (PDB) of South Carolina (Hunt, 1979; Tissot and Welte, 1984).

In a poster session delivered at the Thirteenth International Meeting on Organic Geochemistry in Venezia, Italy, in 1987, A. N. Fuex (unpublished manuscript) described a systematic application of carbon isotope ratios for correlating oils with their source

7 Hunt (1979) points out the following difficulties in oil to source rock correlation. First, oil may fractionate during migration or expulsion from source rock. Second, source rocks do not yield oils of the same composition over time. Third, degradation processes can affect migrated oil, and processes such as mineral recrystallization, uplift, and erosion followed by reburial can affect source rock oil.

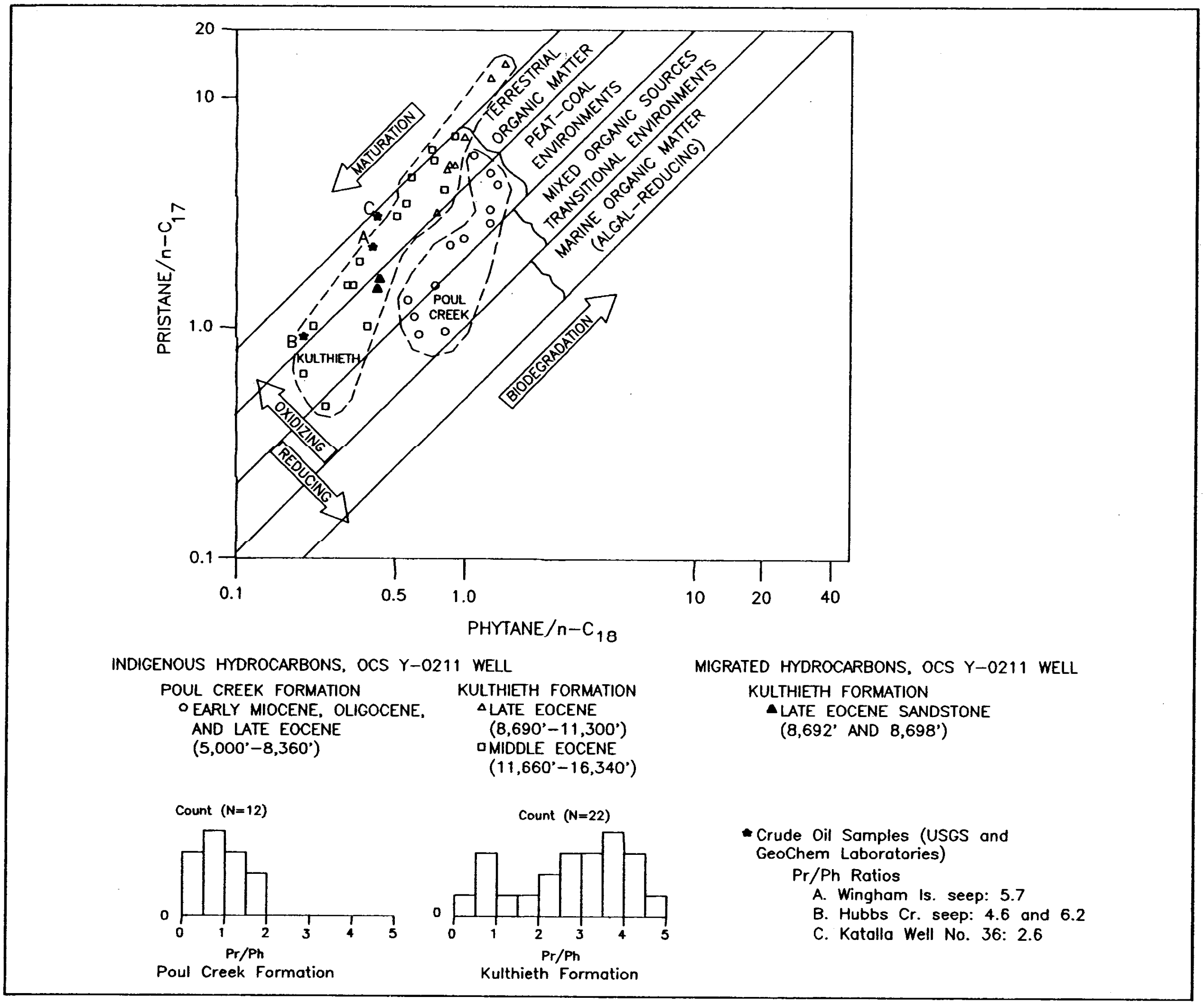


Figure 110. Plot of pristane/n-C_{17} versus phytane/n-C_{18} for Poul Creek and Kulthieth samples from the ARCO OCS Y-0211 No. 1 well. Two USGS oil seep samples and a crude oil sample from the Katalla No. 36 well provided by Phillips Petroleum are also shown. This diagram is adapted from a plot constructed by W. L. Orr in Shanmugam (1985) and is based on concepts proposed by Lijmbach (1975).

rocks. He concluded that his laboratory simulation experiments demonstrated the usefulness of the isotopic composition of carbon for such correlations. Data from the Gulf of Alaska were used to illustrate his procedure.

Fuex (unpublished manuscript) had previously established the probable source of the oils from the Gulf of Alaska utilizing C_{10} to C_{20} saturate composition and gross chemical composition of the C_{15}+ fraction (saturates, aromatics, NHC compounds, and so forth). These data were not included in the poster session. Most of Fuex's carbon isotope data along with $\delta^{13}C$ values acquired by the USGS (Magoon, in press) are illustrated in figure 111.

Fuex believes that a $\delta^{13}C$ correlation of oil with source rock extracts is more accurate than a comparison of $\delta^{13}C$ values for oil with kerogen because similar substances are being compared. To facilitate a comparison, crude oil samples are "topped" before analysis; that is, volatiles that evaporate below the boiling point of C_{15} compounds are removed because C_{15}+ extracts have usually lost these volatiles, either during storage or during the extraction process. Also, the C_{15}+ extracts must be obtained from kerogen within the range of thermal maturities representative of oil generated during the main phase of oil generation. According to Fuex, this should be within the R_o range of about 0.6 to 1.1 percent, which may entail heating an immature extract sample for about 20 days at about

330 °C. (The heat treatment is indicated on figure 111. For example the notation "18/330" means that the extract was heated for 18 days at 330 °C.)

On the basis of the carbon isotope data (fig. 111) for the saturated and aromatic hydrocarbons, Magoon (in press) suggests that two petroleum systems exist in the Gulf of Alaska: a Poul Creek system sourced by Poul Creek Formation rocks, and a Stillwater-Kulthieth system, based on an interpreted facies relationship between the Kulthieth, Tokun, and Stillwater Formations. Carbon isotope ratios for oil from the Katalla field are within 1.2 permill of extract from an artificially matured (heated) extract from Poul Creek rocks obtained from East Kayak Island (oil samples AKA-0-55 and 5006910026 and extract samples AKA-S-1163 and AKA-S-577 on fig. 111). Magoon suggests a match between an oil seep from Wingham Island and the Kulthieth Formation in the Samovar Hills (oil sample 81APr51C and extract samples AKA-0-56 and AKA-0-57 on fig. 111). These matches between oil and source rock obviously depend on the condition that the bitumen formed in the rocks from which it was extracted. Bituminous extracts from Kayak Island (fig. 106) are very mature, based on their saturate content, while the shales from which they were extracted are immature. This indicates that the bitumen probably migrated into the Poul Creek shales.

An alternate approach to the use of carbon isotope ratios was described by Sofer (1984). Sofer conducted a statistical study of $\delta^{13}C$ for $C_{15}+$ saturate and aromatic fractions of 339 oils which were believed to be derived from terrigenous sources (waxy oils) and marine sources (nonwaxy oils). The $\delta^{13}C$ values for the Gulf of Alaska oils are plotted with Sofer's linear regressions on figure 112.

Sofer derived a statistic, the canonical variable (CV), which discriminates between the two populations of carbon isotope data:

$$CV = -2.53\,\delta^{13}C_{sat} + 2.22\,\delta^{13}C_{arom} - 11.65$$

CV values greater than 0.47 correspond to oils derived from terrigenous sources and CV values less than 0.47 correspond to oils derived from marine sources. The CV values for the Gulf of Alaska oils are listed on both figures 111 and 112.

Three of Fuex's "Kulthieth oils" have positive canonical variables (CV), suggesting that they were derived from a waxy or terrigenous source (fig. 112). The two "Poul Creek oils" from the Katalla area have negative CV values, suggesting they are derived from a nonwaxy or marine source. The Wingham Island sample also has a negative CV value and plots very near the linear regression for nonwaxy (marine) oils (fig. 112). However, it has a high pristane to phytane ratio (Pr/Ph) ratio (5.7) and, on the basis of the isoprenoid n-alkane ratios (fig. 110), most nearly resembles the hydrocarbon extracts from the middle Eocene part of the Kulthieth Formation in the OCS Y-0211 well.

Three analyses fall midway between Sofer's (1984) linear regressions (fig. 112). These include two analyses of USGS sample 80APr127 from Hubbs Creek in the Samovar Hills (Plafker, 1987, and Magoon, in press) and an analysis of the Phillips Petroleum sample from the Katalla No. 36 well. Sample 80APr127 yielded CV values both greater and less than Sofer's discriminatory CV value of 0.47 (-0.20 and 0.64). The Pr/Ph ratios for these two analyses were 6.2 and 4.8, respectively. Although Pr/Ph ratios cannot be relied upon to discriminate between marine and nonmarine shales (Moldowan and others, 1985), high Pr/Ph ratios such as these suggest an oxidizing depositional environment (Powell and McKirdy, 1973) and are generally associated with terrigenous oils (Sofer, 1984). Both the Pr/Ph ratios and the isoprenoid to n-alkane ratios for these samples most nearly resemble similar ratios computed for middle Eocene Kulthieth Formation extracts obtained from the OCS Y-0211 well (fig. 110). The crude oil sample from the Katalla No. 36 well produced a CV value of 0.28, which is also very near to Sofer's discriminatory CV value of 0.47. Its Pr/Ph ratio is 2.6. Pristane to phytane ratios which fall between 1 and 3 are unreliable indicators of environment of deposition (Hunt, 1979; Sofer, 1984). However, both the Pr/Ph ratio and isoprenoid to n-alkane ratios resemble middle Eocene Kulthieth Formation extracts from the OCS Y-0211 well (fig. 110).

The data Sofer used to compute his linear regressions (fig. 112) exhibit a significant degree of overlap of the $\delta^{13}C$ values for waxy oils onto the linear regression for nonwaxy oils, particularly in the interval from about -29 to -25 parts per mill for the saturates. This is the interval into which all of the Gulf of Alaska oils fall. The carbon isotope ratios for the Gulf of Alaska oils are consistent with an oil generated by sediments containing terrestrial kerogen. The overlap in Sofer's carbon isotope data combined with the inconclusive results from the Gulf of Alaska carbon isotope analyses gives cause to question whether carbon isotope ratios alone, without other corroborative evidence, can be used to attribute oils

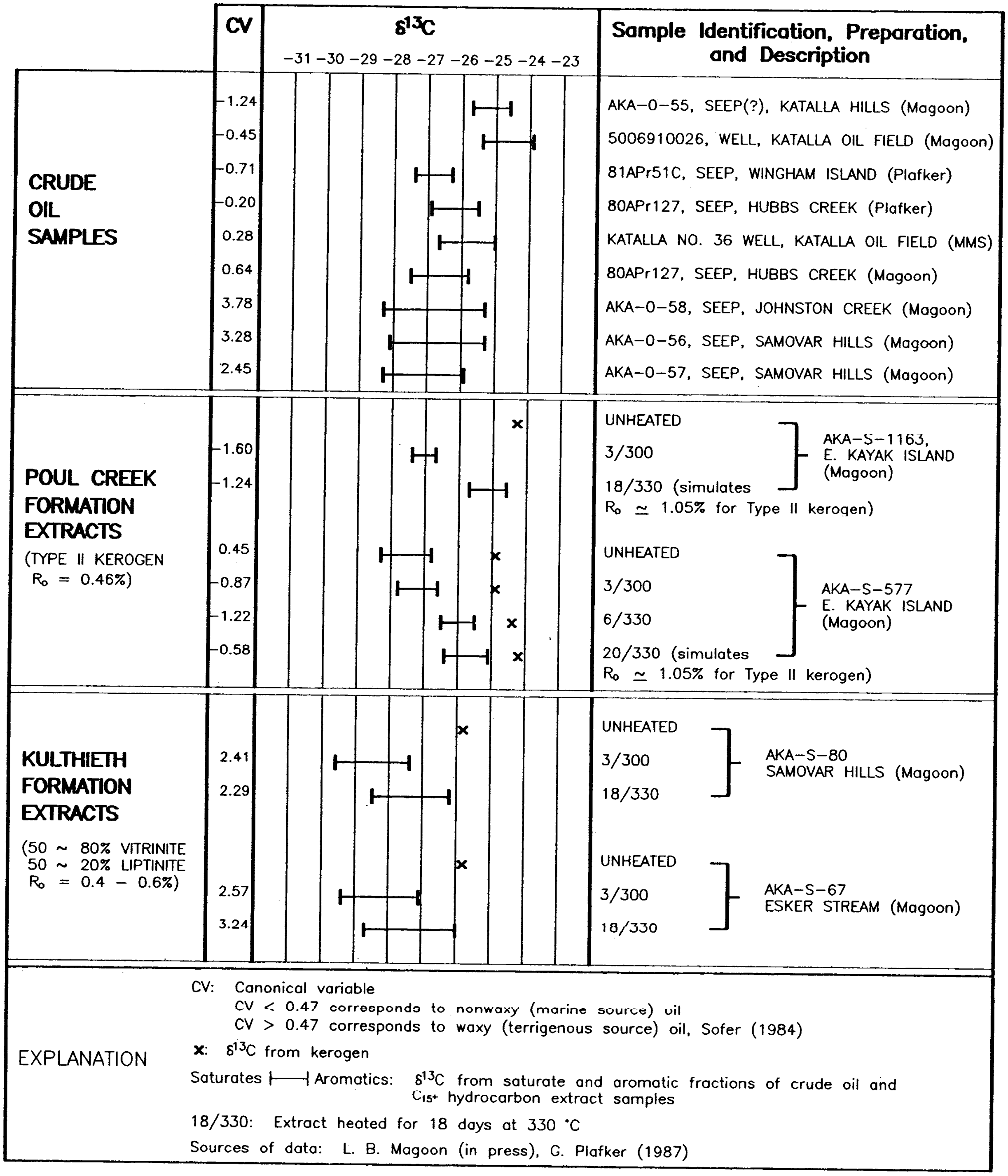


Figure 111. A summary of crude oil and extract carbon isotope ratio ($\delta^{13}C$) values from the Gulf of Alaska.

from this region to a marine source, a terrestrial source, or a specific source rock. If the carbon isotope values were obtained from migrated bitumen, they have no bearing on the rocks from which they were extracted.

Because migrated hydrocarbons are abundant along the fault zones of this region, the possibility of migrated bitumen in the carbon isotope studies cannot be dismissed.

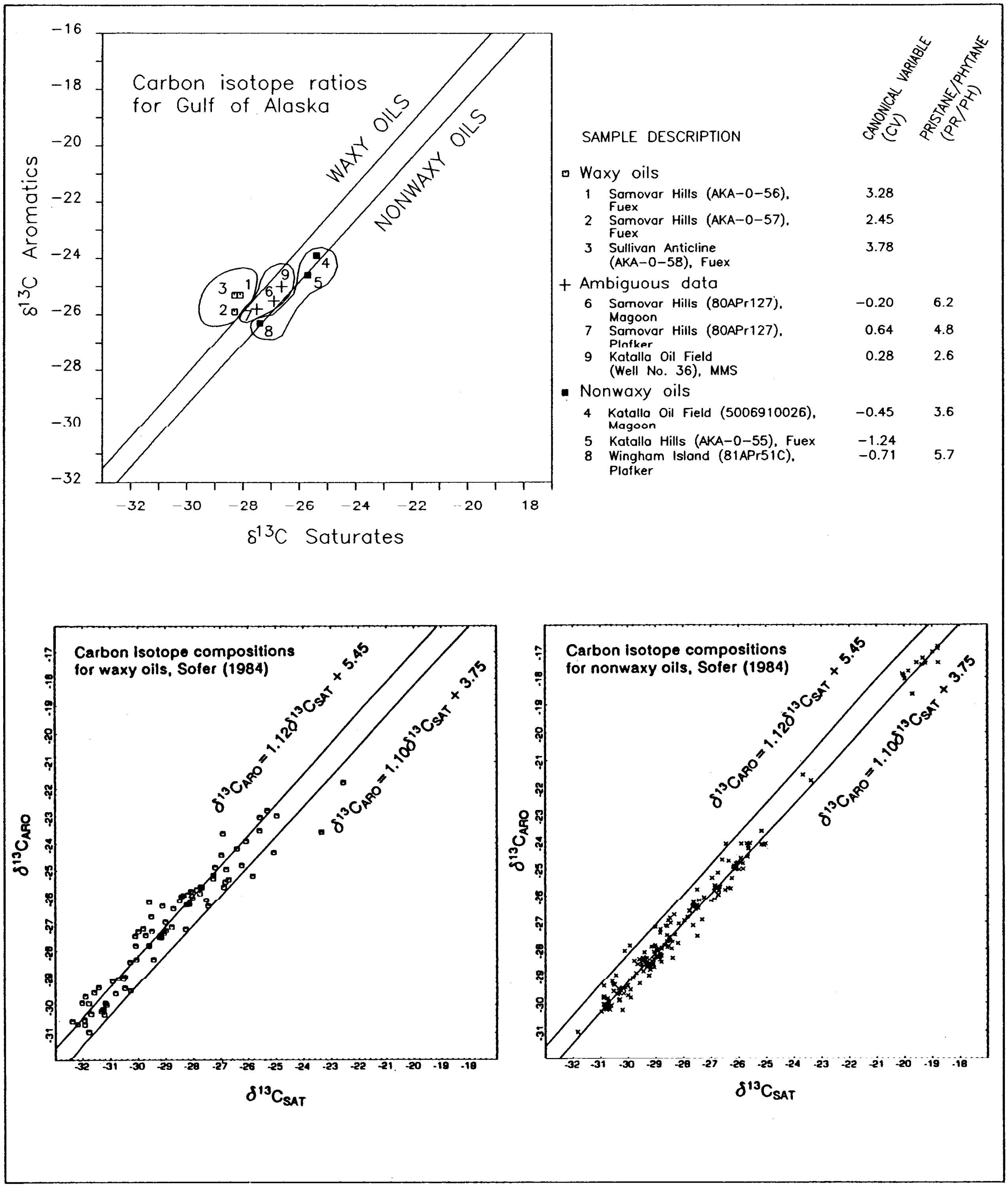


Figure 112. Carbon isotope compositions of C15+ aromatic versus saturate fractions of Gulf of Alaska crude oil samples with Sofer's (1984) statistical analysis of waxy versus nonwaxy crude oils.

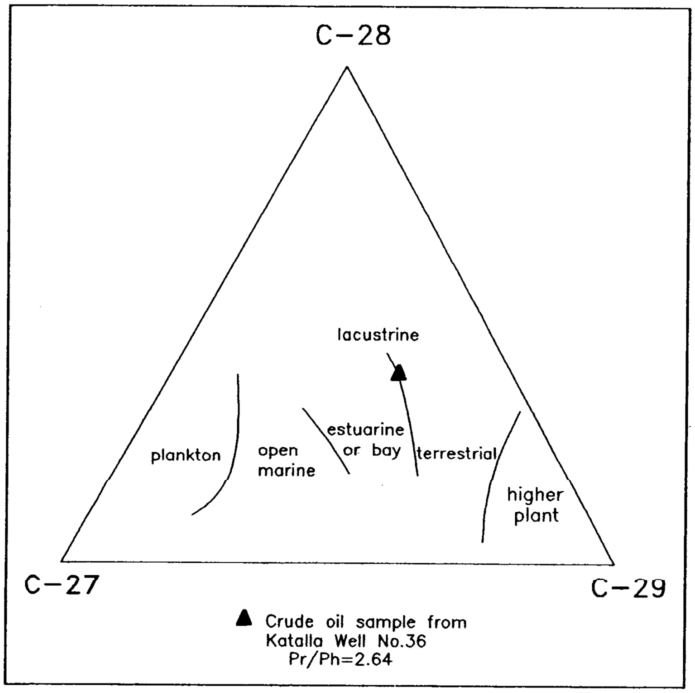


Figure 113. Sterane content of an oil sample from the Katalla No. 36 well plotted on a diagram showing the relationship between sterols from marine plankton, higher plants, soils, and lacustrine and marine sediments as ecological indicators (Huang and Meinschein, 1979).

Sterane-Terpane Composition, Katalla No. 36 Well

The crude oil sample from the Katalla No. 36 well was analyzed for steranes and terpanes using the gas chromatograph-mass spectrometer by GeoChem Laboratories, Inc. The complete results of this analysis are included in appendix I. Bayliss (1991) reported that the high terpane content (63.7 percent) compared with the sterane content (36.3 percent) calculated from the mass to charge ratio (m/z 217 and m/z 191 fragment ions) is characteristic of an oil generated from a dominantly terrestrial-source facies such as an inner neritic environment.

The C_{27}, C_{28}, and C_{29} sterane concentrations can be used as correlation parameters because of their direct dependence upon their precursor sterols (Waples, 1985). Huang and Meinschein (1979) plotted sterols from recent sediments on a ternary diagram as indicators of depositional environment. Their diagram has been reproduced in figure 113 and the C_{27}, C_{28}, C_{29} sterane contents for the oil sample from the Katalla No. 36 well is plotted on it. The C_{27}, C_{28}, C_{29} sterane content of this sample is suggestive of terrestrial source material deposited in a nearshore environment. This interpretation is also consistent with the Pr/Ph ratio of 2.6 and the carbon isotope ratios that plot midway between terrestrial and marine organic material (fig. 113).

Summary and Conclusions

The petroleum commercially produced at Katalla and crude oil recovered from seeps are predominantly light, paraffin-rich, low-sulfur crude oils probably generated from terrestrial source material. Biomarker compounds and carbon isotope ratios from saturate and aromatic fractions of Katalla oil indicate that it was probably generated from kerogen deposited in a nearshore environment that received a considerable amount of terrestrial organic debris.

The Poul Creek Formation and the upper part of the Kulthieth Formation are generally low in organic matter and thermally immature. More extensive sampling and analyses from offshore wells revealed a retrograde R_o profile (R_o decreases with depth) for organic material from the Yakataga (Miocene to Holocene), the Poul Creek (late Eocene to Miocene), and the upper Kulthieth Formations (late Eocene). These formations typically contain type IV kerogen. A possible explanation for the retrograde R_o profiles and for the very low hydrogen and oxygen content of the organic material from these sediments is that the kerogen was deposited in an oxidizing environment which consumed immature indigenous organic material and selectively preserved more mature, recycled, oxidized, organic debris.

Kerogen from the older middle Eocene Kulthieth Formation in the ARCO OCS Y-0211 No. 1 well exhibits a normal R_o profile (R_o increases with depth). At this location, catagenesis occurs between about 12,500 and 17,300 feet and hydrocarbon generation probably began about 25 million years ago in the late Oligocene. Onshore, the highly deformed Bering River Coal Field, part of the Kulthieth Formation, contains low-volatile bituminous to anthracite grade coals indicating levels of thermal alteration ranging from catagenetic to metamorphic. However, the very highest levels of thermal alteration are not a widespread phenomenon.

Cretaceous shales from the Dangerous River No. 1 and the Malaspina No. 1A wells exhibited R_o values characteristic of mature kerogen, mostly within the oil window, but with maximum values as high as 1.49 percent. The Cretaceous sediments penetrated by these wells are organically lean.

Oil samples from the Gulf of Alaska resemble heavy $C_{15}+$ hydrocarbon extracts from Kulthieth shales in the ARCO OCS Y-0211 well for which similar chromatographic analyses are available. Isoprenoid and isoprenoid to n-alkane ratios suggest a terrestrial or nearshore origin for both crude oils and the Kulthieth extract samples. Carbon isotope ratios suggest the presence of both marine and nonmarine petroleum. However, the carbon isotope data are not adequate, alone, to make this distinction. Carbon isotope ratios of saturated and aromatic fractions of oils are consistent with both Poul Creek and Kulthieth sources for the oil. This correlation, however, hinges on the premise that the bituminous extract from the candidate source rocks has not migrated into the rocks from which it was extracted. This is a questionable premise, given that the region is highly faulted and contains abundant oil seeps. Finally, biomarker data for an oil sample from the Katalla No. 36 well are consistent with a nearshore environment of deposition for the probable source of the oil.

On the basis of the available data, the Kulthieth Formation is the most likely source of petroleum in the Gulf of Alaska Tertiary Province. It contains both marine and nonmarine facies. It is thermally mature and on the basis of available analyses its extracts are chemically similar to the oil in the region.

If hydrocarbons generated by other marine source rocks are present, formations equivalent to or older than the Kulthieth Formation would constitute the most probable source of the petroleum. Candidates include the Tokun, the Stillwater, and the Haydon Peak Formations, and the Oily Lake siltstone. Of this group, the Tokun Formation is the most promising candidate because of its similarity and stratigraphic relationship to the Kulthieth Formation (Turner and Whateley, 1989). If parts of the Poul Creek Formation containing unoxidized kerogen are buried deeply enough in this region, they could be a potential source for petroleum. However, there is little geochemical support for this hypothesis. Lastly, the petroleum may have been sourced from unsampled Mesozoic rocks. However, the only known Mesozoic rocks are in the eastern part of the region, near Yakutat, and they are organically lean.

There is a worldwide correlation between oil seeps and seismicity, particularly adjacent to plate boundaries where earthquake activity is highest. Southern Alaska is a prime example of this kind of situation. Young sediments in tectonically active areas produce most oil seeps (Hunt, 1979). Migration of petroleum along faults can supply hydrocarbons to reservoirs if suitable reservoir rock and a trapping mechanism are present. The Trading Bay field in Cook Inlet is a system of stacked reservoirs fed by faults. The problem with the active faults along the Gulf of Alaska is that they appear to be delivering petroleum directly to the surface. The frequency of oil seeps, the high level of seismic activity associated with the high rate of plate movement, and the lack of exploration success suggest that hydrocarbons tend to escape in this region. Any exploration strategy for the Gulf of Alaska Tertiary Province must take into account the problem of entrapping the hydrocarbons that clearly have been generated. Because most large offshore structures have been explored, the more highly deformed, thermally mature onshore areas may offer the best opportunities for further exploration.

THE NEW PENNSYLVANIA

On account of the wonderful discoveries of high grade OIL and COAL, the Kayak District has been aptly so-called. We have:

COAL "There is no other coal with which it is likely to come into general competition with which it is to be compared, for **it is far higher in heating power and in purity than any coal that is mined upon the Pacific Coast, either in the United States, Canada, or Australia.**" (Bulletin 225, United States Geological Survey, p. 375.)

50 millions of tons of this coal above the creek level in our big 20-ft. vein. This is only one of our veins.

OIL The finest in the world. Read what the Government says about it:

Products—	Alaska.	Penn.	Ohio.	Beaumont.
Benzine	21	16½	10	2½
Burning Oil	51	54	50	40
Residuum	28	29	40	57½
Specific Gravity	39.1 B	..	..	22°B

(Bulletin 225, U. S. Geo. Sur. 370.)

This oil is worth $1.50 to $2.00 per barrel at the well—is a **pure paraffine oil.** A large flow of oil has been struck by our neighbors, the English Company. The best oil experts in the world have visited this field, many of them spending two seasons in the district. **BURLS** of London, **SCHUMAN** of New York, **ARATA** of California, **WORTHINGTON** of the Standard Oil Company, **DR. MARTIN** for the United States government, and many others are all agreed that the indications point to immense deposits of this high grade oil.

TOWNSITE In this entire district there is just once place for a town. This particular piece of land was occupied by old settlers in the district, who had lived there for twenty years. This company purchased their rights, and have since covered the land with soldier's additional homestead scrip, also the riparian rights to the water front. Eighteen months ago we had at this place a couple of log cabins and a few tents. Today we have about forty houses, the population varying from two to five hundred, besides a deputy United State's marshal's office, recorder's office, hotel, stores and quite a community. The company owns a two-story, eight-room frame headquarters building in the town, and lots are selling at two hundred dollars each.

ASSETS:

1. 12,000 Acres of oil land
2. 1,800 Acres of coal land
3. Townsite of Catalla
4. 8 roomed headquarters building in Town
5. 12 other buildings on properties
6. Two complete drilling outfits on ground
7. Tug, Lighter and small boats
8. Scores of big oil seepages
9. Millions of Tons of Coal in sight
10. Best drill crew in Alaska
11. Men now at work on coal
12. Coal Veins 20 feet thick
13. As high grade of both Coal and Oil as was ever discovered
14. Mild Climate. Plenty of Timber
15. Thorough, reliable business management without salary

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W. J. Hotchkiss, Capitalist, San Francisco ..... Trustee

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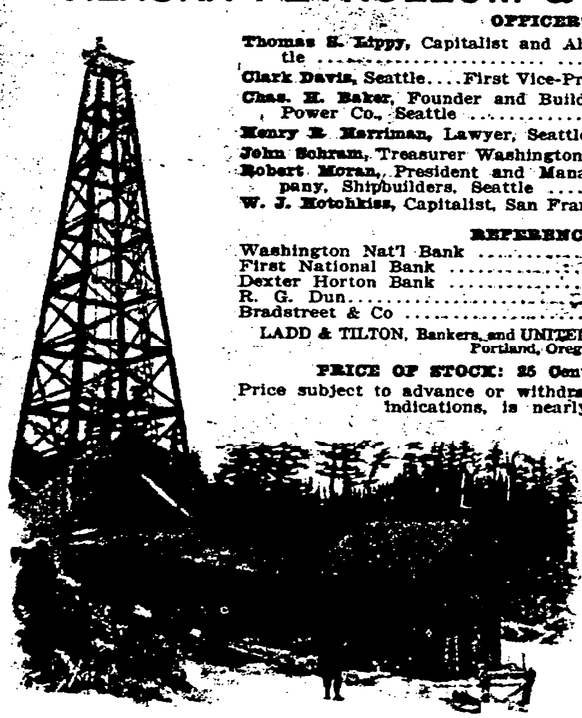
LADD & TILTON, Bankers, and UNITED STATES NATIONAL BANK, Portland, Oregon

PRICE OF STOCK: 25 Cents per Dollar Share

Price subject to advance or withdrawal, as our well, with fine indications, is nearly completed.



ALASKA PETROLEUM & COAL CO.'S RIG NO. 2.

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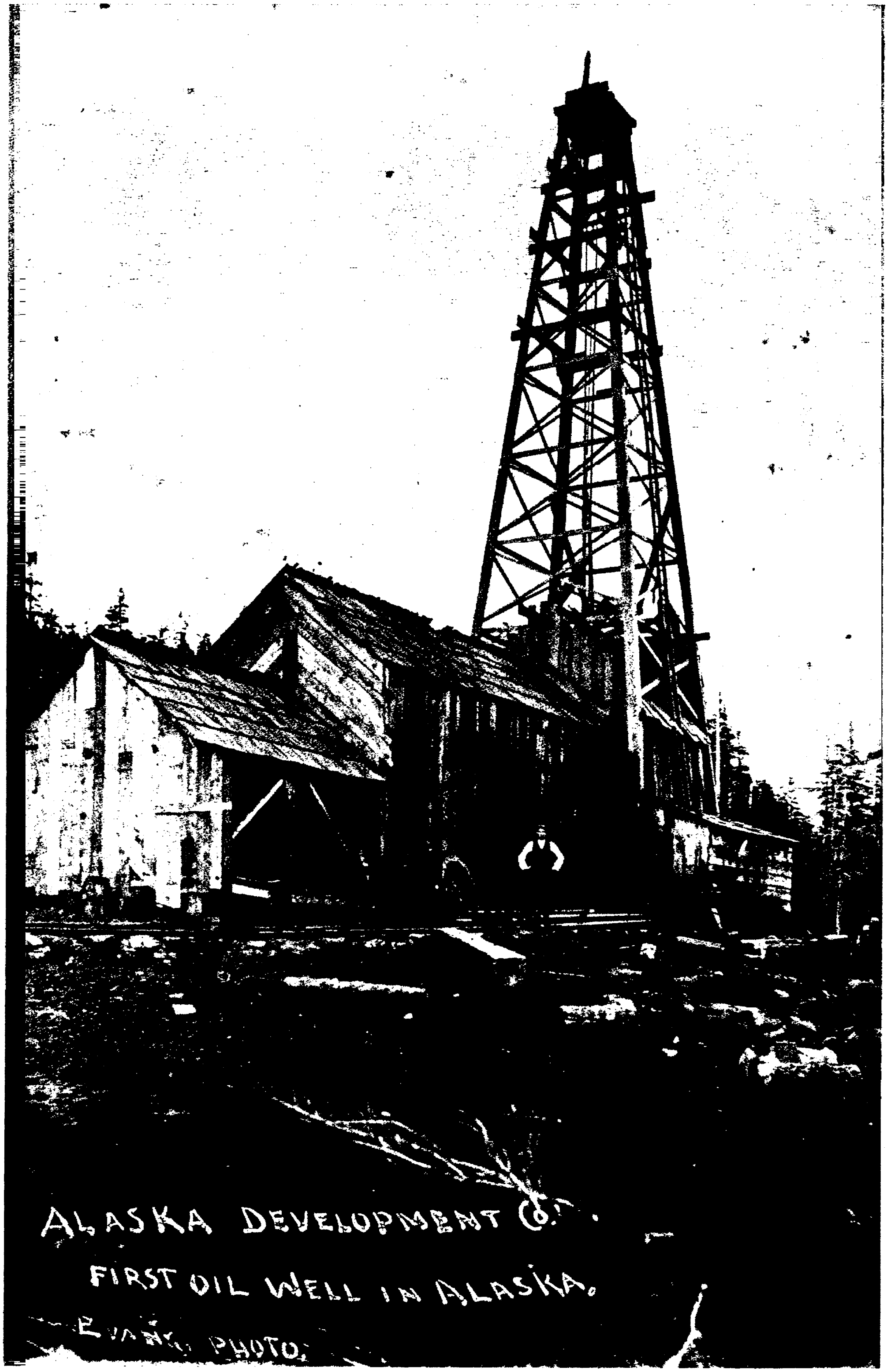
Pleased to make appointment for evening conferences.

Above. Advertisement for Alaska Petroleum and Coal Company stock (1905)

Opposite. The first oil well in Alaska was drilled by the "English Company" for the Alaska Development Company. The well flowed 1,600 barrels per day.


ALASKA DEVELOPMENT CO.
FIRST OIL WELL IN ALASKA.
PHOTO.

THE KATALLA HERALD

KATALLA, THE COMING METROPOLIS OF ALASKA, WHERE THE RAILS MEET THE SAILS

VOL. 1. No. 18. KATALLA, ALASKA, SATURDAY, NOVEMBER 2, 1907. PRICE TEN CENTS

Pacific Steamships to Make Test of Katalla Coal

WIRELESS, NO CABLE

Katalla To Be Connected With Sitka

Katalla may have a wireless system within a short time, according to the statement of attorney V. G. Frost, who returned Thursday on the Saratoga from a trip which took him as far east as Washington. As told in a recent issue of The Herald, Sitka is now connected with Puget Sound by wireless telegraph and the distance to be spanned between Sitka and Katalla is not great.

While in Washington Mr. Frost called on Gen. Allen, chief of the United States Signal corps, and had a talk with him concerning the Katalla cable. Gen. Allen stated positively that nothing would be done towards laying the loop this year, due Mr. Frost thinks to knocking that has been done by enemies of this place. Gen. Allen stated however that the war department contemplated erecting a number of wireless stations to connect all the principal points in Alaska with Sitka and Puget sound. He also intimated that the work would be done at an early date.

In the meantime, R. S. Ryan who was largely instrumental last winter in getting Congress to pass the appropriation for cable extensions in Alaska, is furious at the failure of the department to make the loop, which it was tacitly understood was to form a part of the cable extensions. Delegate Cale, too, does not like the turn the matter has taken and he says that unless Katalla gets cable connection the cable appropriation next year will be held up.

KATALLA COMPANY STARTS A LIBRARY

The Katalla company has started a library for the benefit of its employes. The library has quarters in the general offices building. It contains some 200 volumes of excellent books and about 20 of the magazines will be received each month. The idea is an excellent one and meets with great favor among the company's employes. Geo. Stewart, a bright young man is the librarian, and he also acts as the company's postmaster.

FINANCIAL SITUATION IN NEW YORK CITY

Telegraphic dispatches from New York of date Oct. 24, state that John D. Rockefeller is not afraid of a crash among the Gotham banks. He said that instead of withdrawing any of his money from the banks he was co-operating with others in helping to meet what he firmly believed to be only a temporary crisis. There was a heavy run on the Trust company of America, which up to that time had been successfully withstood.

The collapse of the Knickerbocker Trust company had a tendency to start runs on other banks, the Knickerbocker having been regarded as a strong institution. Frank Vanderlip, vice president of the National City Bank, and a former assistant secretary of the treasury stated that Secretary Cortelyou would place enough funds in New York banks to meet any emergency.

In the New York offices of the seven Guggenheim brothers, the depreciation of the price of their stocks was laughed at. "It's merely an attack by the bears," it was said, "and the bears will have to pay for it." American Smelting and Refinery company's shares fell almost ten points; and a drop of almost fifty points in the price of Guggenheim Exploration stock was recorded on Oct. 19.

For colds, coughs and all lung troubles the only remedy is Piso's Cure at P. J. Brusards.

A practical test of the coal mined by T. P. McDonald at Bering lake will be made in the near future by one of the steamers of the Northwestern Steamship company. The steamer will take enough coal here to steam to Seattle.

Mr. McDonald is confident that the result of the test will be entirely satisfactory and next summer the coal will be in demand by steamship companies, for steaming purposes, as it is fifty per cent better than Washington coal now used by most of the steamship fleets.

Mr. McDonald returned from Seattle on the steamer Portland. In speaking of his proposed operations in the future Mr. McDonald said:

"I have been operating under the name of T. P. McDonald & Co., but had not formed any company as yet, and in view of existing conditions and many little delays incident to the opening and development of the property I have arranged to operate alone, and I will proceed to develop the mine and operate it in a small way until such time as conditions are more propitious, when I hope to associate sufficient capital to operate a coal property of some magnitude.

"Development work at the mine in my absence has progressed very favorably and the coal is showing up quite satisfactorily, but we have many adverse conditions to contend with so far as marketing the coal is concerned, until such time as we are properly equipped to lighter the coal from the mine to deep water and load it on ships which means the investment of a large sum of money: and owing to the depressing financial condition existing throughout the country at this time, the matter of getting the mine into active operation may be delayed somewhat longer than I had anticipated.

"I may say that from tests made of the coal we are fully convinced that we have a coal that is worth at least fifty per cent more to steamship companies operating on this coast than the coal they are now using and in an effort to demonstrate this fact I have arranged for a test on one of the ships operated by the Northwestern Steamship company in the near future."

Mr. McDonald brought in supplies to last him until next June, and in the meantime the work of developing the mine will proceed throughout the winter. Coal is being brought down daily from the mine to Chilkat and from thence it will be brought to Katalla.

COAL ROAD TO BERING LAKE BY JAN. 1ST.

It is expected that by Jan. 1, the Copper River & Northwestern Railway company's coal line will be completed to Bering lake. Coal from McDonald's coal mine will then be shipped to town by way of railroad. This will necessitate a haul by teams of three miles, but a road can easily be constructed, and the teams will be available.

More Goods Lost.

A consignment of groceries etc., to P. J. Brussard is believed to have been lost on the barge which became waterlogged Monday morning while being towed from the Portland. The goods were listed on the Portland's manifest but as they were not delivered the presumption is that they were lost.

BANK OF KATALLA AWAITS ITS BOOKS

Everything is in readiness for the opening of the First Bank of Katalla, except the books and stationery, which however are expected on the first steamer. The books and stationery were shipped on the Yucatan, and were taken back to Seattle when that vessel pulled out of the harbor on the approach of a squall.

The bank building is completed, the furniture and fixtures are all in; the cash is on hand and so is Cashier W. G. Smith, and shortly after the much wanted books are received the bank will open its doors for business. This may be on Monday next, should a steamer reach port before that time.

Just received at P. J. Brussard's, a complete line of Gents' Underwear, Shirts and Shoes.

MARTIN BARRETT FIRES POLITICAL BUMS

The meeting billed for last Saturday night and which was called for the ostensible purpose of organizing a political labor party, or a labor political party failed to materialize. It was to have been held in the Pioneer saloon, but Martin Barrett, who owns the building figuratively if not literally kicked the "politicians" who foregathered there into the street, and they have given no signs of life since. The "labor" leader was one Jess Morrison.

STEAMER PORTLAND ARRIVED SUNDAY

Steamship Portland, of the Alaska Coast company, arrived from Tacoma and Seattle Sunday afternoon with a cargo of 200 tons, 100 tons of which was for T. P. McDonald, the coal operator. Early Monday morning a barge in tow of the Corsair, which had sprung a leak during the night became waterlogged and a quantity of hay and oats, 25 cases of tomatoes and some other goods belonging to Mr. McDonald were swept off, but a quantity of the hay and some other articles were recovered in fair condition. The Katalla Improvement company also lost five tons of hay and three tons of oats, part of which was also recovered. The total loss was not very heavy.

The Alaska Coast company is now owned by Tacoma people and hereafter vessels of this line will make regular calls here. The Portland's trip at this time into Katalla was due to the efforts of M. A. Green, the well known coal operator, who arrived on the steamer.

Line Crew Returns.

William Wallington, who has been in charge of telephone line construction for the Katalla company, reached town from Martin river, accompanied by W. Briggs, Robert Isaacson, Harry Sullivan, Ed. Connor, J. Delfel and George Sooland. Work for the season has been abandoned. About fifteen miles of line was constructed.

FUTURE IS ALL RIGHT

A Big Influx of People Next Spring

"While Katalla is being knocked hard in Seattle, still there is much interest evinced in this section, and I have never felt more confident of Katalla's future, said attorney V. G. Frost, who returned on the Saratoga, as told elsewhere in The Herald. "While I do not think there will be much of a movement this way during the winter months, there will be a big influx of men with capital early next spring. They have money and will invest it. In fact I had to do some rather skillful maneuvering to keep some of them from coming with me. But you may look for a big rush here commencing next spring. Some of the people I talked with want to get into the copper mines, others want business opportunities of various kinds.

"The Alaska Pacific Railway & Terminal company has not sold out to the Copper River & Northwestern, as has been reported, nor do I believe they have any intention of doing so. Mr. Hawkins of the latter company was in New York but I heard absolutely nothing as to his mission."

Mr. Frost went to Washington in connection with some threatened local litigation between the Alaska Petroleum & Coal company and P. J. Brussard and O. L. Willoughby, but the matter has been amicably adjusted.

Katalla has the best people in the world and we are going to have the best buildings for the best people.

CARPENTER.

Expects to Get Both Oil and Gas In Commercial Quantities

Work on drilling for oil on the Alaska Petroleum & Coal company's property below the mouth of Katalla river will be renewed with the arrival of a cable, which is expected on the first steamer. General Manager Davis of the company believes that oil in commercial quantities will be struck at a depth of 1800 or 2000 feet. [illegible]

"If we get oil with a pressure of 400 pounds we will be able to save the gas [illegible]

[illegible]

STOLE FROM KATALLA CO

[illegible]

(Continued on Page 4.)

PLANS FOR LIGHTERAGE

[illegible]

Steamer Hourly Expected

[illegible]

Will Open Sunday School

[illegible]

A Notable Housewarming

[illegible]

Carpenters Increase Scale

[illegible]

ALASKA CLUB FOR TEDDY

[illegible]

INTEREST IN CONVENTION

Considerable interest is being manifested in southeastern Alaska in the Republican territorial convention which takes place on Nov. 14 at Juneau. [illegible]

Left For New York.

[illegible]

11. Play Concepts

The geology of the continental shelf in the northern Gulf of Alaska reflects a diversity of tectonic settings and depositional processes. Because of this, particular attention must be given to regional variations in stratigraphy, structure, and geologic history when assessing the hydrocarbon potential of this area. Five major hydrocarbon plays have been recognized within this region: (1) the Middleton fold and thrust belt play, (2) the Yakataga fold and thrust belt play, (3) the Yakutat shelf play, (4) the subducting terrane play, and (5) the Southeast Alaska subbasin play.

Middleton Fold and Thrust Belt Play

The Middleton fold and thrust belt play encompasses the segment of the continental shelf west of the Kayak zone and east of approximately 148° W. longitude (fig. 114). The prospective section in this area overlies rocks of the Prince William terrane, and reflects a different depositional, structural, and maturation history than the Yakutat terrane to the east. Strata within the Middleton fold and thrust belt play are folded and disrupted by zones of Pleistocene structural deformation that strike generally to the west and southwest (figs. 7 and 25) creating numerous structural trapping possibilities. The most common trapping configurations are elongate, asymmetric structural closures on the northern, upthrown sides of high-angle thrust or reverse faults.

The source rock potential of the Middleton fold and thrust belt play appears poor to marginal based on available stratigraphic and geochemical data. Well cuttings from the Tenneco Middleton Island No. 1 well (fig. 66), located just southeast of Middleton Island, were analyzed subsequent to drilling in 1969 using pyrolysis-fluorescence, a technique that measures thermally active organic carbon content (Alaska Geologic Materials Center Data Report 8, 1974). Low levels of fluorescence were detected over four intervals: 2,100 to 2,250 feet (early to middle Miocene siltstone), 3,250 to 5,000 feet (late? Oligocene siltstone), 7,000 to 7,500 feet (early? Oligocene interbedded siltstone, sandstone, and conglomerate), and 9,000 to 12,000 feet (Eocene interbedded siltstone, shale, and conglomerate).

Conversion charts developed by Heacock and Hood (1970) were used to convert pyrolysis-fluorescence values from the Middleton Island well to total organic carbon (TOC) and C_{15}+ extractable hydrocarbon values. Estimated TOC values for the four intervals ranged from 1 to 2 percent, and C_{15}+ extractable hydrocarbon values from 50 to 200 parts per million (ppm). These values suggest that the organic matter in the sedimentary section at the well is probably not capable of generating economic quantities of hydrocarbons. Organic carbon values derived from stratigraphically equivalent strata in the KSSD No. 2 well and from outcrops on Kodiak Island, 100 and 275 miles to the southwest, respectively, are correspondingly low, with maximum TOC percentages of about 0.5 percent in the KSSD No. 2 well (Turner and others, 1987) and 0.7 percent in the Eocene-Oligocene Sitkalidak Formation on Kodiak Island (Fisher, 1980).

Analyses of kerogen type on the Middleton platform and adjacent areas indicate that sediments in the Middleton fold and thrust play are generally more gas prone than oil prone. Turner and others (1987) reported that the kerogen in Eocene and younger strata tested by the KSSD No. 2 well was predominantly herbaceous and woody (gas prone). Kerogen from the Sitkalidak and Sitkinak Formations of Eocene to Oligocene age on Kodiak Island is mostly coaly and herbaceous (Fisher, 1980), indicating a terrestrial origin. Kerogen type was not reported in detail from the Middleton Island No. 1 well. However, a report prepared from an examination of drill cuttings described the kerogen type as predominantly structured, and containing numerous cuticle and wood fragments (Alaska Geologic Materials Center Data Report 49, 1984). The Eocene interval between 9,000 and 11,000 feet contains a slightly higher percentage of amorphous material and appears to have the highest potential within this section for generating liquid hydrocarbons.

Vitrinite reflectance studies and Lopatin modeling indicate that the sediments penetrated by the Middleton Island No. 1 well are thermally immature (Organic Geochemistry and Source Rock Potential chapter) (fig. 109). The top of the oil window is projected to occur at about 13,000 feet, or 1,000 feet below total depth. Seismic-reflection data reveal that the thermally immature Paleogene section encountered in the well is present within the oil window in many of the structurally low areas on the Middleton shelf. Preliminary estimates suggest that a sufficient volume of potential Eocene source rocks have reached thermal maturity to generate economically recoverable amounts of hydrocarbons, provided that the section is moderately kerogen rich.

Sandstones and conglomerates constitute about 15 percent of the Yakataga Formation in the Middleton Island well as determined from spontaneous-potential (SP) and gamma ray logs. Density porosity of coarse-grained facies in this section averages about 13 percent. Using this average porosity, the relationship between porosity and permeability of sandstones and conglomerates in the Yakataga Formation (fig. 76) provides an average permeability value of 6.0 millidarcies. These values suggest that the Yakataga Formation in the vicinity of Middleton Island has reservoir potential, although it is of marginal quality. However, individual beds in this formation have density porosities as high as 18 percent and estimated permeabilities of 65 millidarcies, well within the range of a good reservoir rock.

Paleogene and early Neogene strata underlying the Yakataga Formation on the Prince William terrane appear to have negligible reservoir potential. In the Middleton Island well, porous, coarse-grained facies are sparse in the Sitkalidak and Sitkinak Formation equivalents, and absent in underlying Eocene rocks, possibly of the Orca Group. Based on the poor reservoir quality of Paleogene and early Neogene strata observed in the Middleton Island well, and on similar findings in the Kodiak shelf stratigraphic test wells to the east (Turner and others, 1987), it appears unlikely that sufficient quantities of coarse-grained facies of this age are present on the Middleton shelf to represent prospective reservoir targets.

In summary, the Middleton fold and thrust belt is characterized by a sedimentary section that is thermally immature and has poor source rock potential. However, Eocene rocks present in the oil window in the deeper parts of the basin may be capable of generating hydrocarbons if TOC levels are sufficiently high.

Reservoir rocks appear to be limited to the Yakataga Formation (late Miocene and younger). Interbedded fine-grained clastic sediments within the Yakataga Formation are potential seals to hydrocarbon migration if individual beds are areally extensive. High-angle thrust and reverse faults may provide a pathway for migration of hydrocarbons from underlying source rocks to large anticlinal and fault traps within zones of Pleistocene structural deformation.

Yakataga Fold and Thrust Belt Play

The Yakataga fold and thrust belt play consists of intensely folded and thrust-faulted strata overlying the western portion of the Yakutat terrane between Icy Bay and the Ragged Mountain-Kayak zone (fig. 114). A variety of structural and stratigraphic traps are present in this play, although the primary traps are areally extensive fault-bounded anticlinal structures of late Pliocene and younger age that strike southwest across the continental shelf and upper slope (fig. 27). To date, ten exploratory wells have tested offshore anticlinal structures in the Yakataga fold and thrust belt play. The results have been unfavorable.

The source rock potential of the Yakataga fold and thrust province was evaluated using data from the ARCO OCS Y-0007 No. 1, Texaco OCS Y-0032 No. 1, and Exxon OCS Y-0080 No. 1 wells. These wells penetrated the Yakataga Formation and sampled upper Paleogene to early Neogene strata of the Poul Creek Formation. Rocks underlying the Poul Creek Formation were not tested by drilling in the Yakataga fold and thrust belt. The source rock potential of strata underlying the Poul Creek Formation is extrapolated from data acquired from the ARCO OCS Y-0211 No. 1 well, located 75 miles southeast of the Pamplona zone on the eastern, relatively undeformed segment of the Yakutat terrane.

The Yakataga Formation does not appear to be a possible source rock in the offshore Yakataga fold and thrust play. Organic material in the Yakataga Formation is immature to moderately immature with respect to hydrocarbon generation, with thermal alteration index (TAI) values of 1^{+} to 2^{-}. The kerogen present is predominantly reworked and recycled humic organic material. The TOC content of the formation is poor, ranging from an average of 0.25 percent in the eastern part of the play (OCS Y-0032 No. 1 well) to 0.47

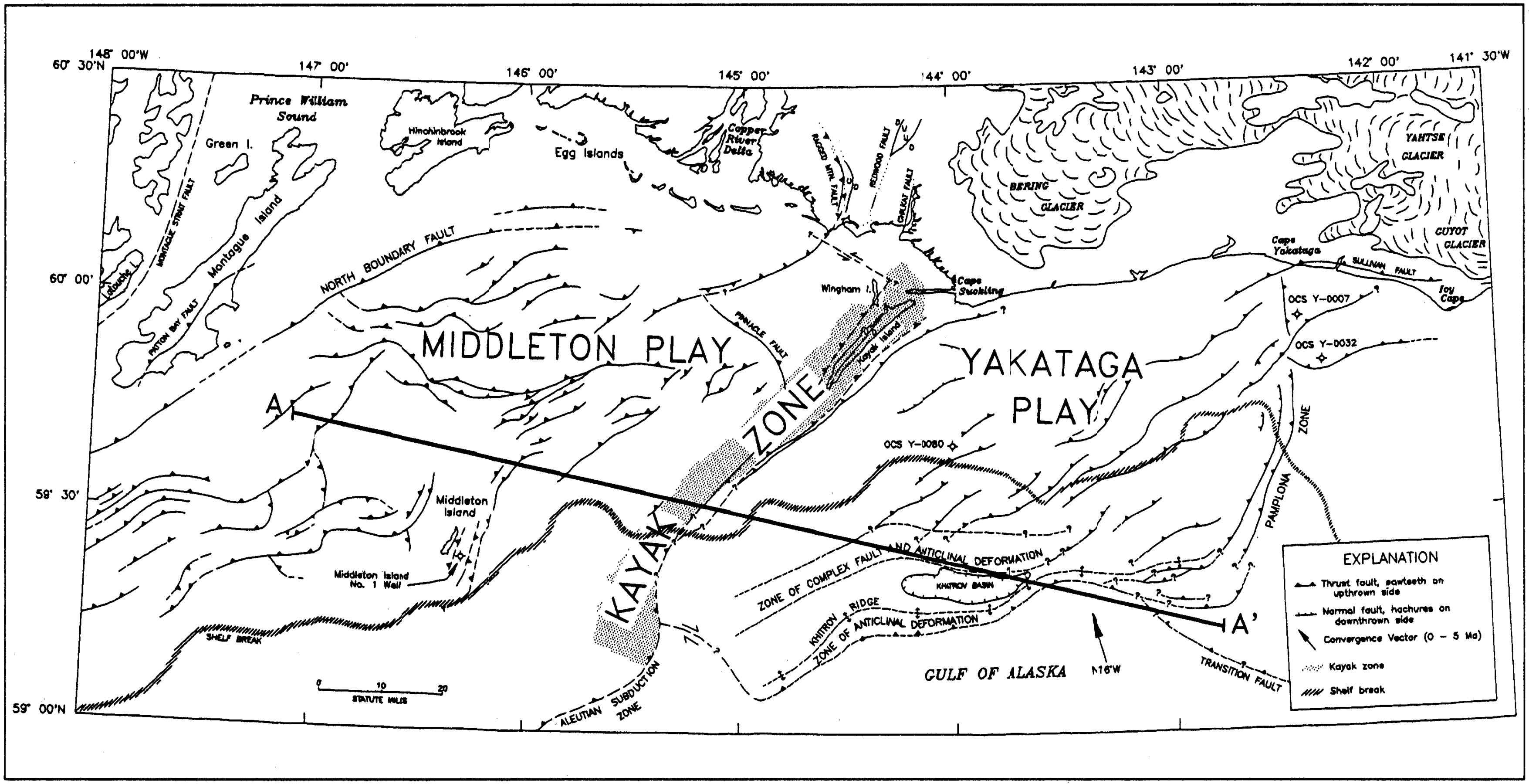


Figure 114. Location and tectonic setting of the Middleton and Yakataga fold and thrust belt plays. The Middleton fold and thrust play lies west of the Kayak zone and overlies rocks of the Prince William terrane. The Yakataga fold and thrust play encompasses intensely folded and faulted strata of the western part of the Yakutat terrane. The Kayak zone, which separates the two plays, delineates the surface suture between the two terranes, but may be underlain at depth by underthrust Yakutat terrane rocks (Brocher and others, 1991). Cross section A-A' is illustrated in figure 116.

percent in the OCS Y-0080 No. 1 well seaward of Kayak Island.

Analyses of Poul Creek Formation well cuttings for source rock potential have been generally disappointing. The thermal maturity is generally low, and TOC values are poor to marginal (0.5 to 0.6 percent). The kerogen recovered from this deep-water marine deposit appears to be largely recycled humic organic material. However, late Miocene strata between 9,100 and 9,160 feet in the OCS Y-0080 well exhibit fair to good source potential. A cutting sample from this section contained 1.97 percent TOC and exhibited a generative potential of 1,897 ppm of $C_{15}+$ total extract. The kerogen includes amorphous, herbaceous, and woody material, and is moderately immature to moderately mature (TAI = 2^- to 2). This interval may be equivalent to a middle to late Miocene organic-rich Poul Creek facies described by Armentrout (1983b) in the Robinson Mountains proximal to the Yakataga shelf, and to a late Miocene organic-rich facies reported from outcrops on Kayak Island and the adjacent Katalla district (Plafker, 1971, 1974; Miller, 1975; Rau and others, 1977). Unpublished industry data show high TOC (>4) and type I and II kerogens onshore (Turner, personal commun., 1992). The stratigraphic section equivalent to this organic-rich interval is not present in the OCS Y-0007 and OCS Y-0032 wells, but some may be present at the unconformity in the OCS Y-0211 well.

The middle to late Eocene Kulthieth Formation or equivalent strata, including the Tokun, Stillwater, and Haydon Peak Formations, appear to be the most likely hydrocarbon source beds in the Yakataga fold and thrust belt. Although untested on the Yakataga shelf, Kulthieth Formation strata penetrated in the OCS Y-0211 well on the adjacent Yakutat shelf contained many organic-rich intervals with TOC values of 1.0 to 2.0 percent (fig. 102). The genetic potential was relatively low for most of this section, although several samples had S_1+S_2 potentials greater than 2,000 ppm, a value considered necessary for oil generation (Tissot and Welte, 1984). Maximum $C_{15}+$ extractable hydrocarbons of 650 ppm were obtained from middle Eocene strata between 13,100 and 13,460 feet. The organic material in the Kulthieth Formation appears to be a mixture of recycled organic matter, type III kerogen, and less abundant type II kerogen (fig. 103).

A critical uncertainty with respect to the generation and expulsion of hydrocarbons from organic-rich facies of the Kulthieth Formation in the Yakataga fold and thrust belt is the thermal maturity of these sediments. Poul Creek and Yakataga strata (late Eocene and younger) sampled to a depth of 17,921 feet in the OCS Y-0007 No. 1 well are immature to marginally mature, indicating that the top of the oil window is relatively deep. The stratigraphic relationship of the Kulthieth Formation to these younger units provides a lower limit on the degree of maturation of Kulthieth strata, and suggests that this formation is at least moderately mature, and could be mature to overmature at depth. However, because of the structural complexity of the Yakataga fold and thrust belt, thermal maturity is expected to fluctuate areally within all of the lithologic units.

Strata of early to middle Eocene age which are assumed to underlie the Kulthieth Formation are unlikely to be potential source rocks in this play. These rocks are tentatively correlated to the Oily Lake siltstone onshore, and to early to middle Eocene deep-water marine strata in the OCS Y-0211 well on the Yakutat shelf to the east (Lithostratigraphy chapter). Although the Oily Lake siltstone has been considered a source for large hydrocarbon seeps onshore in the Samovar Hills (Plafker and Miller, 1957; Plafker, 1987), offshore, in the OCS Y-0211 well, it appears to have very low genetic potential. Pyrolysis of cuttings from these strata yielded S_1+S_2 values that average less than 250 ppm (fig. 102).

Potential reservoir rocks in the offshore Yakataga fold and thrust belt occur primarily in the Yakataga and Kulthieth Formations. Although coarse-grained facies are present locally within the Poul Creek Formation, it appears unlikely that these coarse-grained units are of sufficient volume and distribution to represent prospective reservoir objectives.

The distribution of potential reservoir strata within the Yakataga Formation on the Yakutat terrane varies generally as a function of the distance from source areas in the coastal mountains to the northeast (fig. 72). In offshore wells in the Yakataga fold and thrust play, coarse-grained sediments make up from 3 percent (OCS Y-0059 No. 1 well) to 29 percent (OCS Y-0035 No. 1 well) of the total volume of these strata. Porosities calculated from density logs are high, ranging up to 35 percent for shallow sandstones (<3,000 feet), and as high as 15 to 25 percent for deeper reservoir strata (7,000 to 12,000 feet). Permeabilities derived from conventional cores display moderate to good reservoir potential, with typical values of 100 to 500 millidarcies for coarse-grained sediments with 20 percent or greater porosity. The most prospective reservoirs are found in the lower Yakataga Formation, where the beds are also in close proximity to underlying potential source rocks. The lower Yakataga Formation contains a high percentage of primary and reworked marine sandstones which have higher porosities and permeabilities than the glaciomarine sandstones of the upper Yakataga Formation. However, the porosity of the lower Yakataga sandstones has been diminished by the physical and chemical alteration of unstable mineral grains with increasing depth of burial.

The reservoir potential of the Kulthieth Formation and equivalent facies of the Tokun and Stillwater Formations, which were not penetrated by wells on the Yakataga shelf, is inferred from cores and log measurements from the OCS Y-0211 well on the Yakutat platform, and from onshore wells and surface exposures. Onshore stratigraphic relationships indicate that sandstone facies of the Kulthieth Formation give way to the west to shale facies of the Tokun-Stillwater-Haydon Peak Formations (fig. 89). This trend is in agreement with a northeast onshore provenance for these sediments (Lithostratigraphy chapter). Extrapolating this relationship offshore, the reservoir potential of Eocene rocks underlying the Yakataga fold and thrust belt is assumed to diminish to the southwest. The relative abundance of coarse-grained sediments is estimated to range from 25 percent in the vicinity of Icy Bay, to less than 5 percent in the southwestern two-thirds of the play.

Kulthieth sandstones are typically fine grained, arkosic, and micaceous. In the OCS Y-0211 well, diagenesis and compaction have significantly reduced primary porosity and permeability (Reservoir Rocks chapter). These sandstones have good porosity down to 12,000 feet, but permeabilities are commonly less than 10 millidarcies. Below 12,000 feet, permeability in Kulthieth sandstones is effectively absent. If a similar relationship between permeability and depth exists in deeply buried Kulthieth equivalent sandstones in the Yakataga fold and thrust belt, the reservoir potential of these strata in this play would be negligible. However, the potential for secondary porosity from the dissolution of feldspar and volcanic lithics allows for the possibility of local reservoir-quality facies.

Large, fault-bounded anticlinal structures provide more than 200 square miles of structural closure at the base of the Yakataga Formation and constitute the primary potential trapping mechanism in the Yakataga fold and thrust play. Development of these structures appears to have occurred primarily in latest Pliocene and Pleistocene time, in part concurrent with the estimated time of expulsion of possible hydrocarbons from underlying Eocene source beds. Lopatin modeling using estimated paleogeothermal gradients indicates that hydrocarbon generation is most likely to have begun by middle to late Neogene time. The migration of such hydrocarbons would be controlled largely by thrust faulting. This model is supported by the relationship between seeps and faults in the onshore extension of this play (Bruns, 1988).

In summary, Yakataga Formation sandstone reservoirs within thrust-faulted anticlinal structures remain the most promising exploration target in the Yakataga fold and thrust belt play despite the lack of success of wells drilled in these structures to date. The quality and distribution of potential source rock, reservoir rock, traps, and seals appear favorable for the entrapment of hydrocarbons. The timing of thermal maturity and subsequent migration of hydrocarbons with respect to trap formation is not tightly constrained by available data, but also does not appear to be a constraint. The lack of exploration success in this play may be due in part to the extreme structural complexity of the area. Large imbricate thrust faults that may serve as migration routes for hydrocarbons also may be conduits for hydrocarbon escape via seafloor and surface seeps.

The Eocene sandstones of the Kulthieth-Tokun-Stillwater system constitute a secondary exploration objective in the offshore Yakataga fold and thrust belt play. Possible structural and stratigraphic traps within this interval are obscured beneath a thick Oligocene and younger clastic sedimentary section, but are assumed to include many of the same trapping mechanisms observed in the overlying Yakataga Formation. The potential for the migration of expelled hydrocarbons into Kulthieth reservoir rock is high, as source and reservoir rock are found within the same stratigraphic interval. The quality and areal distribution of reservoir rock may limit the potential of this exploration target. In addition, Eocene exploration targets are present at depths that are presently unfavorable because of logistics and drilling costs.

Yakutat Shelf Play

The Yakutat shelf play encompasses the eastern, relatively undeformed offshore segment of the Yakutat terrane, and extends 230 miles from the Pamplona zone on the west to the seaward extension of the Fairweather fault at the entrance to Cross Sound (fig. 115). The prospective strata of the Yakutat shelf play were

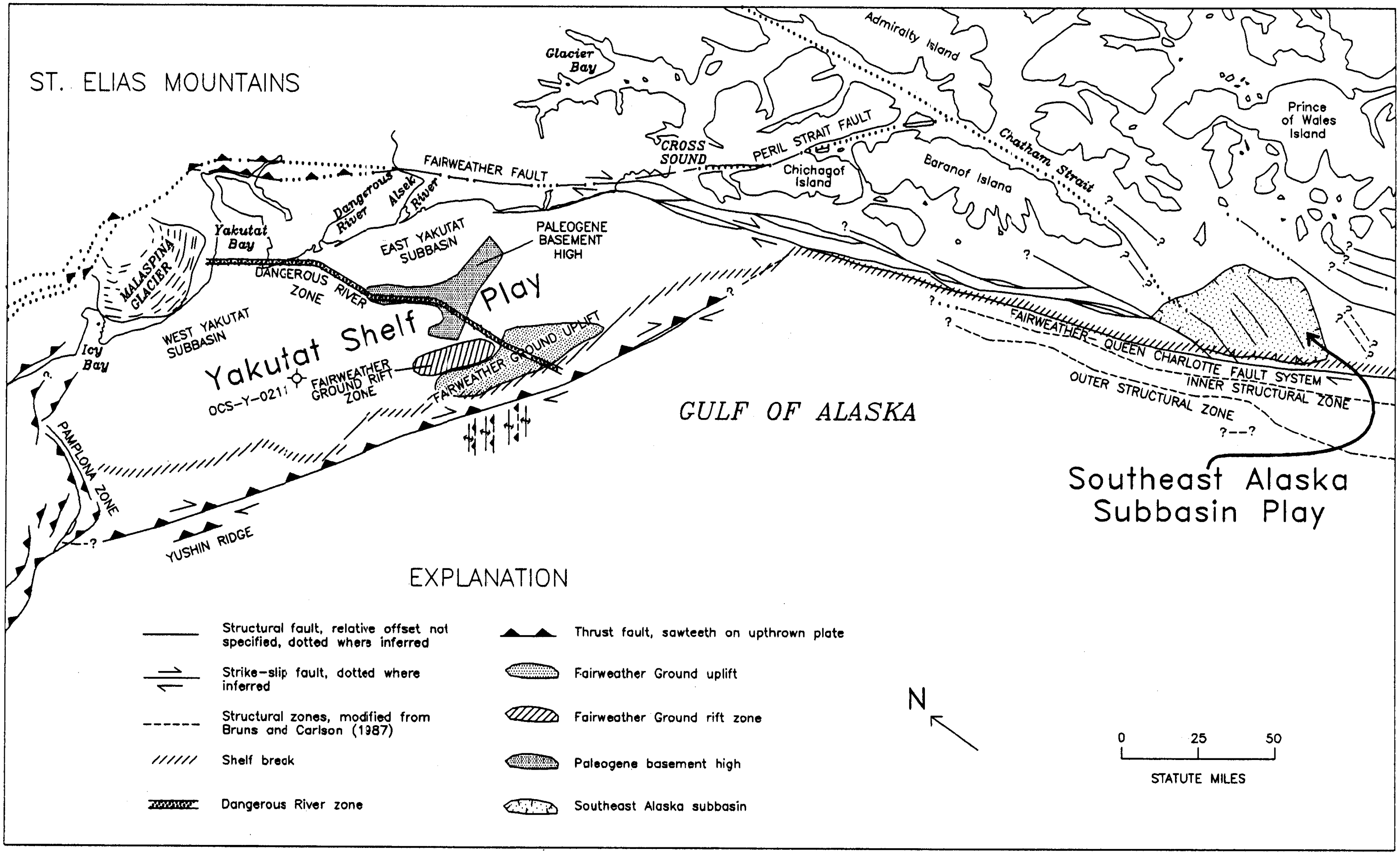


Figure 115. Location and tectonic setting of the Yakutat shelf play and the Southeast Alaska subbasin play. Potential hydrocarbon targets in the Yakutat shelf play include the Dangerous River zone, the Fairweather Ground rift zone, and the West Yakutat subbasin. The hydrocarbon potential of the Southeast Alaska subbasin is limited because of the small volume of possible mature source rock and an apparent lack of significant trapping structures.

sampled by the ARCO OCS Y-0211 No. 1 well, which was drilled on a Paleogene high on the central shelf south of Yakutat Bay. The OCS Y-0211 well penetrated 17,450 feet of Eocene to Quaternary clastic sedimentary strata and bottomed in igneous rocks that mark economic basement. Although not a commercial success, the OCS Y-0211 well demonstrated that strata are present that possess moderately favorable characteristics for the generation and entrapment of hydrocarbons under the Yakutat shelf.

Early Pliocene and younger strata of the Yakataga Formation do not appear capable of generating hydrocarbons within the Yakutat shelf play. Organic matter from the Yakataga interval in the OCS Y-0211 well is largely recycled and is thermally immature. The TOC content is less than 0.5 percent, and the genetic potential as indicated by pyrolysis is low. The Yakataga Formation attains a maximum stratigraphic thickness southwest of Icy Bay, at the northwestern margin of the play, where seismic-reflection data reveal a 16,000-foot-thick section (fig. 15). Lopatin modeling of this expanded Yakataga section indicates that strata at the base of this interval have not attained sufficient thermal maturity to generate potential hydrocarbons.

Organic matter extracted from well cuttings and cores from the deep-marine Poul Creek Formation in the OCS Y-0211 well consisted predominantly of thermally immature, recycled woody and inertinitic material. Although the TOC content of this interval ranges from 0.5 to 1.5 percent, the genetic potential (S_1+S_2) is poor, averaging about 500 ppm (fig. 102). This kerogen yielded a hydrogen index of less than 100 milligrams of hydrocarbon per gram of TOC. If more favorable organic material is present in the Poul Creek Formation in the deeper, northwest portion of the play, where Poul Creek strata are estimated to be in part thermally mature, rocks of this formation might have source potential.

The Eocene Kulthieth Formation appears to have moderately good source rock potential at the OCS Y-0211 well. The hydrocarbon potential of this section, summarized briefly in the discussion of the Yakataga fold and thrust belt play, is largely dependent on the genetic potential of the incorporated organic matter. Samples from this section are rich in type III kerogen and lesser quantities of type II kerogen, but commonly display pyrolytic genetic potentials of less than 2,000 ppm, the value considered necessary for substantial oil generation. However, several well cutting samples and core chips from the 10,000 to 12,500-foot interval (late middle to early late Eocene) in the OCS Y-0211 well exhibited a more favorable combination of organic richness and genetic potential (fig. 102). TOC values for this interval ranged up to 2.0 percent, and the genetic potential of several samples exceeded 3,000 ppm. Sediments from this prospective section (10,000 to 12,500 feet) are marginally thermally immature at the OCS Y-0211 well, where the top of the oil window occurs at about 12,500 feet. Northwest of the well, in the structurally deeper portion of the play, this prospective interval is projected to be within the oil window.

The section below 14,000 feet in the OCS Y-0211 well includes strata of the lower Kulthieth Formation and the Oily Lake siltstone equivalent. Although cuttings analyzed from this section yielded an insufficient pyrolysis response to qualify as potential source rocks, Lopatin modeling suggests that the organic matter in this early to middle Eocene section has reached an optimal level of maturity for potential hydrocarbon generation (fig. 105).

As in the Yakataga fold and thrust belt play, potential reservoir rocks in the Yakutat shelf play occur in both the Yakataga and Kulthieth Formations. Coarse-grained sediments are estimated to make up from 80 percent of the Yakataga Formation on the inner Yakutat shelf near Dry Bay, to less than 10 percent on the southern, outer margin of the play (fig. 72). This distribution is consistent with a sediment source in the coastal mountains to the northeast, and suggests that the Yakataga Formation may lack sufficient sandstones to be a reservoir objective in the southern play area. In the OCS Y-0211 well on the outer central Yakutat shelf, Yakataga sandstones are thin and compose only 8 percent of the 4,200-foot-thick section. Reservoir characteristics of Yakataga sandstones in this well were difficult to estimate from well logs due to the washed-out condition of the borehole, but are presumed to have properties comparable to the Yakataga sandstones of the Yakataga fold and thrust belt play.

Kulthieth sandstones make up as much as 50 percent of the formation along the inner shelf near Yakutat Bay, but may grade laterally into the shale facies of the Tokun-Stillwater-Haydon Peak Formations along the outer, southwestern margin of the shelf (fig. 89). The Kulthieth Formation is largely absent east of the Dangerous River zone, which is interpreted to represent the northern and eastern shelf margin of the Paleogene basin. Kulthieth sandstones in the OCS Y-0211 well constitute about one-third of the formation and are interpreted to be submarine fan and/or outer shelf/slope-break deposits that prograded northwest along the paleobasin axis. The paleodispersal direction of these sediments at the OCS Y-0211 well and the lateral distribution of correlative coarse-grained sediments in adjacent onshore wells suggest that Kulthieth sandstones may occur far offshore along the western flank of the Dangerous River zone.

Kulthieth sandstone porosities derived from well logs and conventional cores from the OCS Y-0211 well have favorable reservoir characteristics and range from about 12 to 26 percent. However, the permeability is low, commonly less than 10 millidarcies. The permeability of Kulthieth sandstones has been significantly reduced by the compaction of ductile mica grains, and by the alteration of feldspars to pore-bridging authigenic clays (Reservoir Rocks chapter). At burial depths below approximately 12,000 feet, Kulthieth sandstones do not exhibit effective permeability. In the OCS Y-0211 well, Kulthieth sandstones with marginal reservoir potential occur in a 1,100-foot-thick interval near the top of the section. Some sandstones in this section have thicknesses of 50 to 150 feet and display porosities of greater than 20 percent and potential permeabilities of 10 to 20 millidarcies. Conventional core no. 2 from this section (8,691 to 8,748 feet) displayed visible hydrocarbon staining. Subsequent quantitative analyses of this core indicated residual oil saturations of 0 to 27.3 percent (Core Laboratories, 1983).

Trapping mechanisms on the Yakutat shelf are subtle compared to the extensive and complex thrust and fold features that characterize the continental margin to the west. Potential structural and stratigraphic traps are controlled primarily by regional and local basement subsidence, paleotopography, lateral facies changes, and, to a lesser degree, faulting. Potential traps in the Yakutat shelf play are recognized in association with three principal features: (1) the Dangerous River zone, (2) the Fairweather Ground rift zone, and (3) the West Yakutat subbasin (fig. 28).

The Dangerous River zone and superimposed Paleogene basement high are updip barriers to the migration of hydrocarbons from possible Kulthieth source rock in the West Yakutat subbasin. Updip pinch-outs, down-to-the-basin fault seals, and structural drape over basement highs are potential trapping mechanisms along this trend. Traps east of the Dangerous River zone, including the east flank of the Paleogene basement high, are not particularly prospective because of the absence of mature Paleogene source rock. The northern, onshore extension of the Dangerous River zone was tested unsuccessfully in wells on the east and west sides of Yakutat Bay, where a predominantly continental section was penetrated (Plafker, 1987). However, the petroleum potential of the Dangerous River zone probably increases offshore, where the Paleogene section is thicker and more marine.

The Fairweather Ground rift zone contains up to 6,000 feet of predominantly Eocene strata deposited within a fault-bounded elongate, Paleogene subbasin (fig. 30). Potential traps in the rift zone include down-to-the-basin fault traps, updip pinch-outs against acoustic basement, strata above intra-basinal horsts, and possibly coarse-grained clastic sediments deposited adjacent to positive basement structures. Although sediments within the rift zone are not likely to be thermally mature, hydrocarbons may have migrated into the subbasin from deeply buried Paleogene source beds downdip to the northwest. Potential Paleogene source beds underlying the northwest portion of the Yakutat shelf are estimated to have entered the oil window by the middle to late Miocene, subsequent to the formation of potential trapping structures in the Fairweather Ground rift zone. The presence of numerous faults that bisect the rift section may be unfavorable for the entrapment of hydrocarbons, as they may provide avenues for escape as well as migration.

Strata in the West Yakutat subbasin, west of the Dangerous River zone, are largely undeformed. However, the association of potential source and reservoir beds, seals, and the favorable timing for the maturation of hydrocarbons are conducive to the formation of stratigraphic trapping mechanisms. The lower Yakataga Formation may contain the most promising targets in this subbasin. In this section, coarse-grained sediments with good reservoir qualities are interbedded with fine-grained clastics. Hydrocarbons may be trapped in updip pinch-outs of porous facies, or in subtle structural closures. The timing of hydrocarbon generation appears favorable, as potential Paleogene source beds are estimated to have entered the oil window during the middle to late Miocene near the basin depocenter, and at progressively later times on the basin flanks. Based on the thermal maturation history of the OCS Y-0211 well, potential Eocene source rocks are presently at peak levels for hydrocarbon generation at depths of approximately 12,500 to 15,500 feet.

Sandstones of the Kulthieth Formation are a secondary stratigraphic target in the West Yakutat subbasin. The trapping mechanisms in this section are similar to those of the younger Yakataga Formation. The reservoir potential of Kulthieth sandstones may be greatest on the northern flank of the subbasin between Icy and Yakutat Bays, where coarse-grained clastics are estimated to compose up to 50 percent of the section. Although the reservoir quality of the Kulthieth sandstones is marginal, these rocks are interbedded with potential source rocks. Because of this, a significant potential exists for enhanced secondary porosity and permeability to have developed from acidic fluids associated with hydrocarbon generation and migration. This possibility is supported by the Phillips Sullivan No. 1 well, located onshore just east of Icy Bay, which tested at 15 barrels of oil per day from the Kulthieth Formation (Phillips, 1954). The Kulthieth Formation is not considered a favorable target on the southwest flank of the subbasin, where the sandstone is believed to be replaced by a shaly facies.

Subducting Terrane Play

The subducting terrane play, described by Plafker (1987) and Bruns (1988), involves the tectonic interaction between the western margin of the Yakutat terrane and the Prince William terrane to the west (fig. 114). The Yakutat terrane is moving northwest in conjunction with the Pacific plate, and sedimentary strata are being subducted beneath, and in part offscraped against, rocks of the Prince William terrane at the Kayak zone. A regional décollement separates strata of the subducting Yakutat terrane from rocks of the overlying Prince William terrane (Griscom and Sauer, 1990; Brocher and others, 1991) (fig. 116). Neogene and Quaternary strata of the Yakutat terrane west of the Pamplona zone are detached at the décollement from underlying strata and are presently being deformed and accreted to the Prince William terrane. The intracrustal décollement appears to extend from the Pamplona zone west beneath the Kayak zone, and is inferred to underlie Prince William Sound. The Kayak zone may represent a subsidiary thrust or thrusts originating from the principal décollement (Griscom and Sauer, 1990; Brocher and others, 1991).

If this tectonic model is correct, Paleogene strata of the Yakutat terrane are present at depth beneath the Kayak zone and to the west below deformed metasediments of the Orca Group (fig. 116). The underthrust section is inferred to include Eocene sediments that exhibit hydrocarbon source potential in plays to the east. Hydrocarbons generated from subducted Eocene rock may be trapped beneath nonpermeable rocks of the Orca Group and/or migrating upsection along the principal or subsidiary thrust faults. The general association between hydrocarbon seeps and fault zones at the northern, onshore extension of the Kayak zone suggests that these faults are acting as conduits for the migration of hydrocarbons. A petroleum seep originating from rocks of the Orca Group west of the Ragged Mountain fault provides evidence for a minimum of 4 miles of underthrusting of Eocene and older strata along the Kayak-Ragged Mountain zone (Tysdal and others, 1976).

The initiation of subduction of Paleogene source rock along the northwestern margin of the Yakutat terrane is constrained by the timing of the collision and underthrusting of this part of the terrane with southern Alaska. Collision of the northwestern edge of the Yakutat terrane had commenced by late Miocene, as confirmed by the uplift of the Chugach Mountains and Fairweather Range, the initiation of alpine glaciation, and subsequent glacial-fluvial sedimentation on the continental shelf (Geologic History chapter). Potential Paleogene source rock at the leading edge of the Yakutat terrane may have reached thermal maturity by latest Miocene or early Pliocene time. Assuming a geothermal gradient of about 1.37 °F per 100 feet, Paleogene source rocks would have to be buried to 13,000 to 16,500 feet to have attained sufficient thermal maturity to generate hydrocarbons (Bruns, 1988). Migration is assumed to have commenced soon after thermal maturity.

Drilling constraints limit the offshore area of economic potential of the subducting terrane play to the Kayak zone and adjacent area, where reservoir strata and structural traps occur at attainable depths. Traps in this area consist of intensely folded and faulted strata, analogous to structures exposed on Kayak Island (Plafker, 1974), and Paleogene strata overlain by overthrust impermeable rocks of the Orca Group. Overthrust traps may be present west of and adjacent to Kayak and Wingham Islands. Hydrocarbon seeps near Wingham Island and in the northern, onshore extension of the Kayak zone (Plafker, 1987) indicate that mature source rock is present at depth. The seeped oil is migrating updip, possibly along thrust surfaces. No reservoir rocks are known in the Kayak zone, but fracture porosity in Paleogene or older strata may represent potential reservoirs. The Katalla field, in the onshore extension of the Kayak zone, produced hydrocarbons from fracture porosity in strata of the Poul Creek Formation (Martin, 1921; Blasko, 1976; Bruns, 1988).

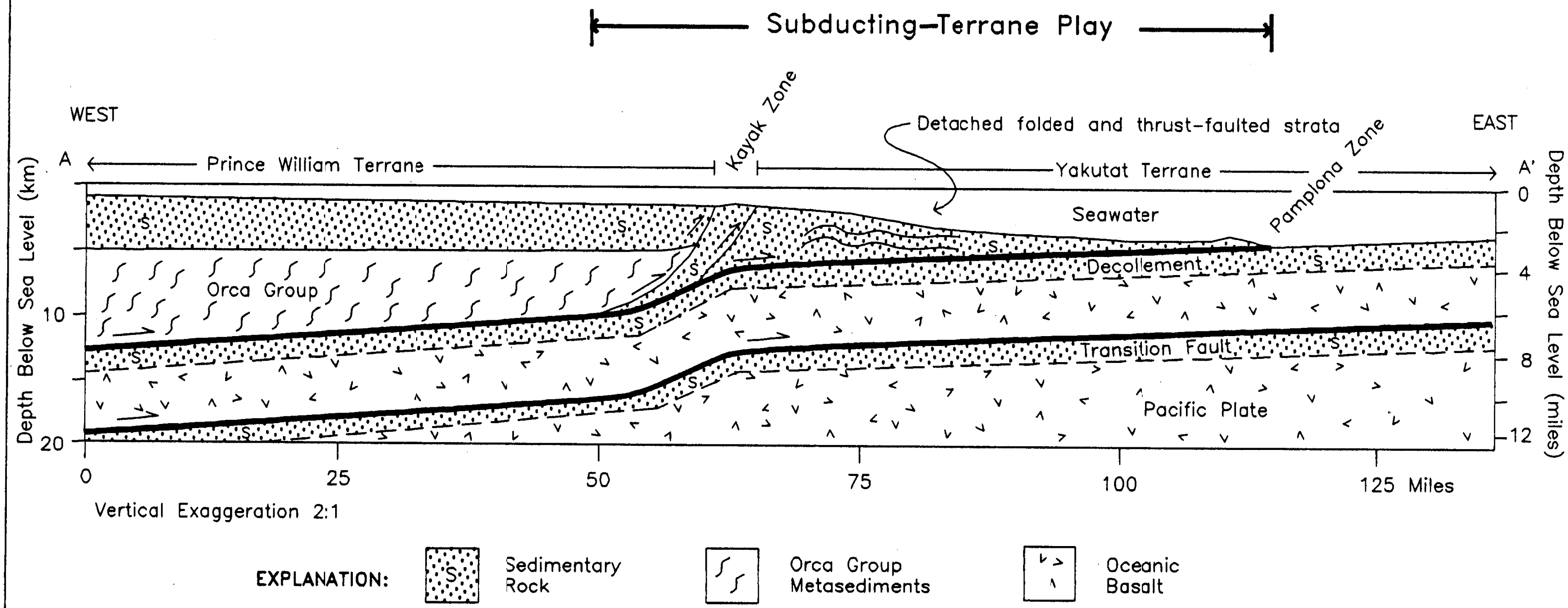


Figure 116. Generalized cross section of the subducting terrane play (modified from Griscom and Sauer, 1990). See figure 114 for the location of profile A-A'. The lower Paleogene crust of the Yakutat terrane is presently being thrust beneath rocks of the Prince William terrane to the west. The upper surface of this thrust is identified by a regional decollement. The Pacific plate, which lies seaward of the Yakutat and Prince William terranes, is converging obliquely with and subducting beneath the present North American plate margin. Hydrocarbon potential of the offshore part of the subducting terrane play is limited primarily to the Kayak zone and to deformed late Cenozoic strata to the east and southeast of this zone.

Southeast Alaska Subbasin Play

The Southeast Alaska subbasin play is located in a structurally isolated basin west of Prince of Wales Island that contains up to 20,000 feet of bedded probable Cenozoic strata (fig. 115). Sediments in this subbasin have not been sampled, so assertions about the nature and petroleum potential of the basin are largely speculative. The probable age of the basin-fill (Paleogene to Quaternary) is in part inferred from a regional study of interval velocities derived from seismic-reflection data (Seismic Stratigraphy chapter). Rocks underlying basin-fill strata are assigned to the Wrangellia and Alexander tectonostratigraphic terranes (Monger and Berg, 1987). Rocks composing the Wrangellia and Alexander terranes in southeast Alaska are typically deformed and/or altered, of varying lithology, and range in age from late Precambrian to Jurassic. These rocks have no known hydrocarbon potential and mark the lower limit of the play.

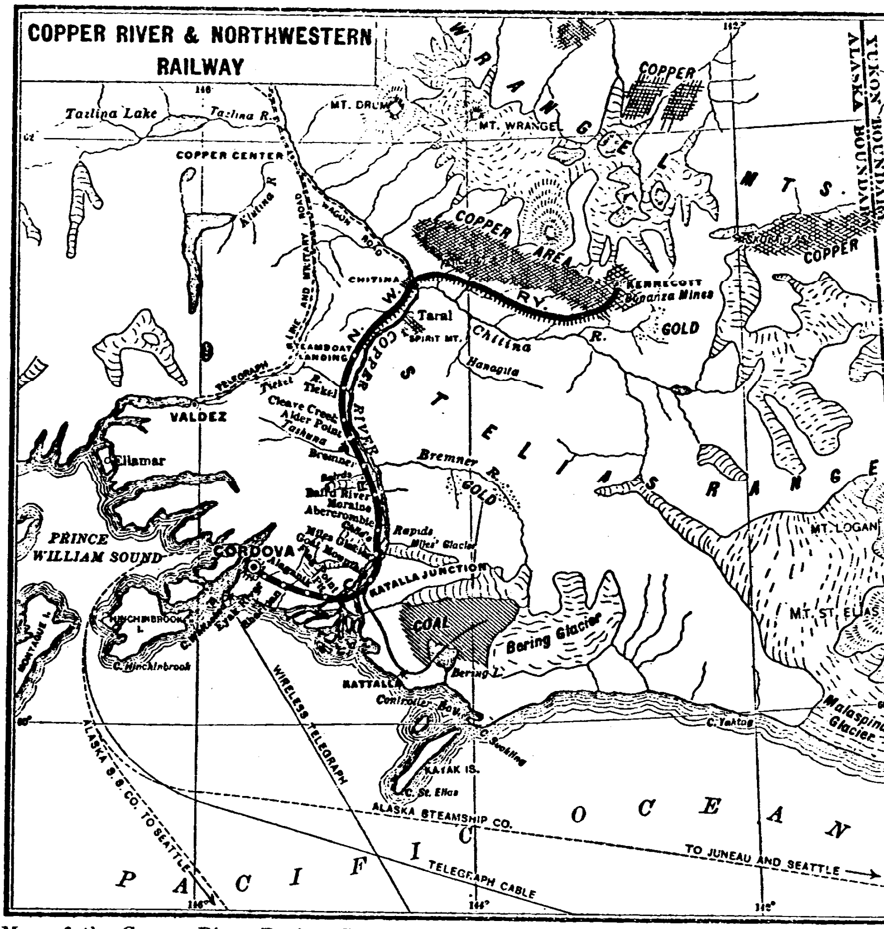
The source rock potential of basin-fill strata in the Southeast Alaska subbasin is unknown. However, rare exposures of Cenozoic nonmarine and/or deltaic rocks onshore to the east have negligible hydrocarbon potential (Bruns, 1988). Neogene and younger strata in the Southeast Alaska subbasin are roughly correlative with the upper Yakataga Formation on the Yakutat terrane to the north and are assumed to have similar glaciomarine origins and inadequate organic content for petroleum generation. If potential source rock is present in the subbasin, its distribution is likely limited to the deeper, Paleogene(?) section. Unfortunately, coeval rocks have not been identified onshore nor have Paleogene strata been encountered in wells to the south in the Queen Charlotte basin (Yorath, 1987).

Potential reservoir rocks are likely to be present in Neogene and younger Yakataga Formation equivalent strata in the Southeast Alaska subbasin. These glaciomarine strata are assumed to have reservoir properties similar to coeval rocks on the Yakutat shelf to the north. However, the inferred Neogene and younger section is relatively thin in the subbasin and appears to be absent over the basin's eastern flank (plate 4, line SE-2, post-UNC 4 strata). The reservoir potential of probable Paleogene rocks is unknown.

Assuming a simple model of constant deposition and a geothermal gradient of 1.43 ^{o}F per 100 feet, which is the average gradient observed in wells in the adjacent Queen Charlotte basin (Yorath and Hyndman, 1983), strata in the central Southeast Alaska subbasin would be thermally mature below approximately 13,500 feet. Faults of apparent wrench origin transect the basin fill and could provide a migration route for hydrocarbons to migrate updip to overlying reservoir rock. Possible traps in the Southeast Alaska subbasin play include fault traps and uplifted fault-bound blocks. The timing of potential hydrocarbon generation and expulsion in relation to trap formation is uncertain, but may be unfavorable because of the relatively young age of the structures.

The Southeast Alaska subbasin is not a particularly attractive hydrocarbon play because it possesses limited source area and relatively few trapping structures of significant volume. The quality, quantity, and degree of maturity of potential source rocks are unknown. However, additional geological information is needed before this play is assessed as having negligible resource potential.

The Chitina Copper Region



Map of the Copper River Region, Showing Route of the Copper River and Northwestern Ry. and Location of the Chitina Copper Belt and Other Mineral Areas.

THROUGH RAIL CONNECTIONS BETWEEN THE PORT OF CORDOVA, ALASKA, AND THE NEW TOWN OF CHITINA, GATEWAY TO THE GREAT CHITINA COPPER REGION, IS NOW COMPLETED.

The Alaska Steamship Company

furnishes the Fastest, Most Comfortable and Most Direct Connections with This Remarkable Scenic Route into one of Alaska's Newest and Richest Regions.

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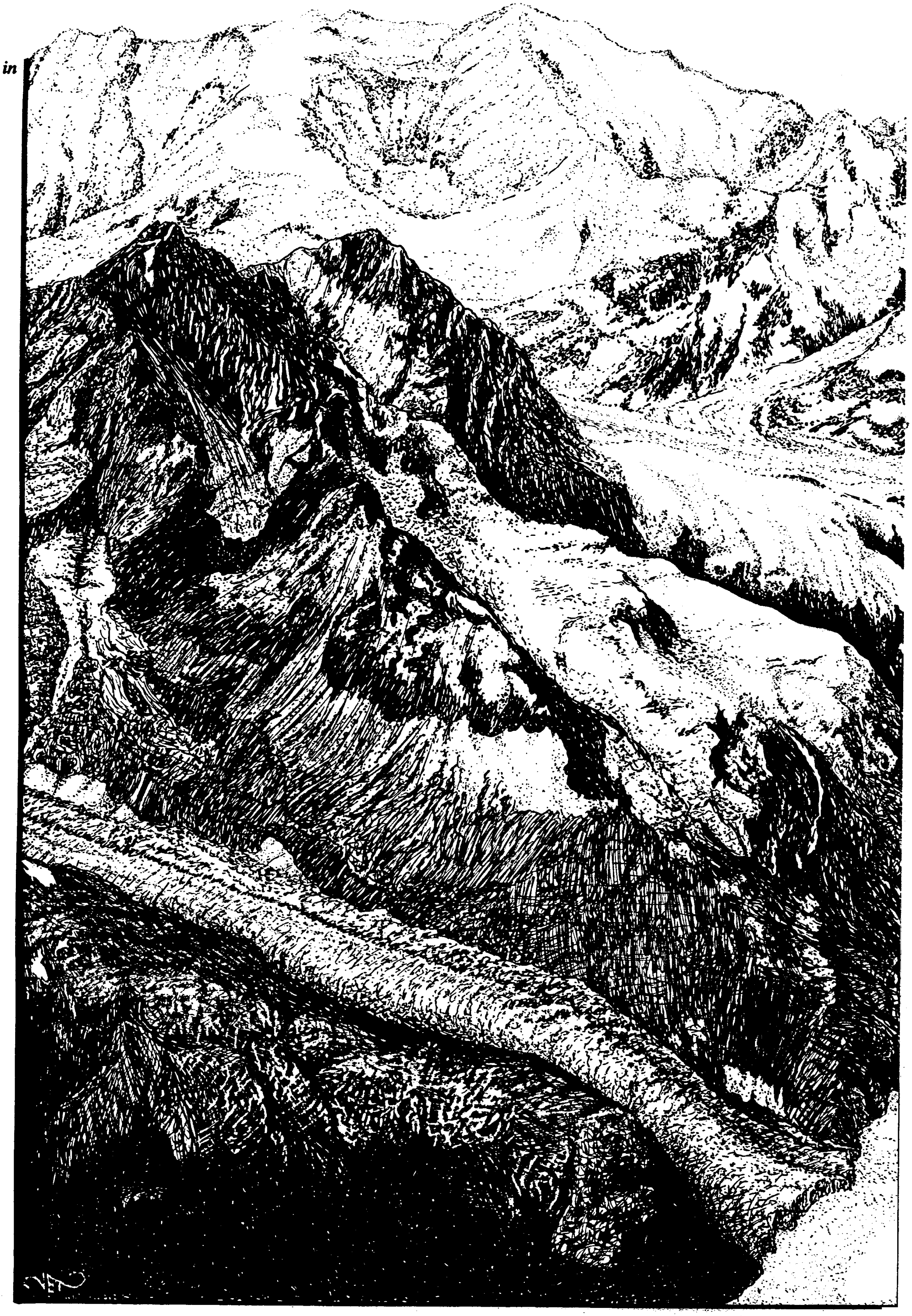
SEATTLE, WASH.

From "Alaska-Yukon Magazine" (1908). The glaciers depicted on page 244-245 are located just off map to the right of the Malaspina Glacier.

Part III:

Shallow Geology, Geohazards, and Environmental Conditions

Tidewater glaciers in St. Elias Range, Gulf of Alaska



THE KATALLA HERALD

KATALLA, THE COMING METROPOLIS OF ALASKA, WHERE THE RAILS MEET THE SAILS

VOL. I. No. 6. KATALLA, ALASKA, SATURDAY, SEPTEMBER 14, 1907. PRICE TEN CENTS

Will Bore Tunnels on Copper River Railroad Line This Winter

Construction work on the Copper River & Northwestern Company's lines is proceeding apace. A temporary track is being laid, on the line to the coal fields, as far as the head of the slough from which a spur will be extended to a dock to be built on the slough for the reception of railroad material and supplies. Erickson & Borland have the contract for the completion of the road to the coal fields, and this firm of experienced railroad contractors will rush the line to completion at as early a date as possible. They will probably work the greater part of the winter.

The site for the railroad bridge at the crossing on Copper river just below Abercrombie canyon has been changed to a point about 300 feet below the place first selected. From this point the bridge will cross the river in a horizontal line. The right of way to the new crossing is now being cut through the underbrush and timber.

The winter camps at Abercrombie canyon are well under way. On the line of the road above the canyon there will be three tunnels to construct, about 500, 600 and 800 feet respectively and this work it is understood, will be prosecuted throughout the winter.

Work at the other camps is being pushed as rapidly as possible. At camp 3 a Bagley scraper is being used in grading and a steam shovel is excavating at camp 2. Work has been retarded for a few days by a lack of coal, but machinery using coal as a motive power is again busy.

Six locomotives are busy and thus it will be seen that construction work is being pushed for all it is worth.

A donkey engine is at work on the breakwater pulling the huge boulders which line the shore above Palm point, to the breakwater where they are used to fill in the piling.

Several important changes have been made in the engineering staff. Chief Engineer Krey has resigned, and accompanied by Mrs. Krey left on the Santa Clara for Seattle. Mr. Krey, it is said, has been offered a responsible position in the Argentine Republic. H. R. Gabriel, formerly resident engineer, has been promoted to division engineer, and E. L. Kelzer becomes mechanical engineer. Mr. Gabriel, the new division engineer, is a young man of commanding ability in his profession. He is a graduate of the Massachusetts Polytechnical Institute, one of the foremost schools of the country.

Water for fire protection purposes has been piped from the reservoir to the Katalla Company's warehouse. A complete water system has been planned, with 10-inch pipes leading the water to the railroad yards and the company's buildings.

DROWNED IN BOILING SURF

Thomas Sands and Thomas Hastie, respectively master and engineer of the gasoline launch Pathfinder, belonging to the Katalla Company, met death in the surf Sunday afternoon about 3:30 o'clock, while hundreds of people lined the City dock and shore unable to render the slightest assistance.

The Pathfinder, which is a small vessel, without a deck, was towing a barge laden with crude petroleum down Katalla slough, and as the bar was reached either the tow line became entangled in the propeller or the engine stopped, thus bringing the little launch side on to the breakers, which were piling over the bar, capsizing her. The launch sank immediately.

The launch Imp, Capt. Nels Anderson and Engineer J. F. Perkins, shortly after the Pathfinder was capsized, went out to render aid, if possible, to the men. Chas. Johnson, who was also on the Imp, says he saw Hastie in the surf and threw a line which reached him, but Hastie apparently was powerless to help himself and a big wave suddenly swept him from view. Johnson says that Hastie called to him, but he could not understand what he said.

Engineer Perkins was nearly asphyxiated by gasoline, the waves having swept over the Imp, stopping the machinery.

The tug Elvira, Capt. Connors and Engineer C. H. Barnwell, and Dr. M. E. Smith followed the Imp almost immediately to the scene of the tragedy, but they saw nothing of the victims.

Edwin Lawrence Casey, a noted waterfront sailor, essayed to swim out to the scene of the disaster, but was dissuaded.

The body of Capt. Sands was found Tuesday afternoon on the beach, nearly opposite the place where the accident occurred, by Andrew Sorokovikof, Mrs. Peterson and the Misses Duval while returning from Strawberry Point. Judge Britton was notified and the body was brought to town.

Jess L. Morrison, of the Palace Bar, found the body about the same time. Morrison says that he also saw the body of Hastie, but before a rope could be brought to him to secure it a wave struck it and it floated seaward out of sight, and it has not, as yet, been recovered.

Only a few trinkets, a watch which had stopped at 4:05, and some letters, were found in Capt. Sands' pockets.

Sands was a member of Harbor 15, Master and Pilots' Association of San Francisco. He is said to have left a wife and two children in Seattle. He was about 35 years of age and had been here for about two months. The body was buried Wednesday afternoon by the Katalla Company in the graveyard at Palm Point.

Hastie was from Coupeville, Whidby island, Wash., where his parents reside. He was about 24 years of age and was unmarried.

Capt. Ben Durkee, master of transportation for the Katalla Company, says that the men had positive instruction not to tow the barge out of the slough, but the day being fine and the water apparently not dangerous they probably concluded to tow the barge to its destination.

A written demand was made upon Judge Britton, by a member of gasoline engineers, to hold an inquest, but the judge held that under the statutes of Alaska he was not authorized to hold an inquest, and therefore he declined to do so, also claiming that if an investigation was necessary it should be referred to the inspectors of hulls and boilers for Alaska.

Numerous reports have been circulated as to the number of men on board the Pathfinder at the time of the disaster. There are several, among them R. G. Day of The Herald office, who aver that they saw two men on the launch, outside the canvas cover. C. H. Barnwell, who knows the waterfront well says, however, there were only Sands and Hastie on the boat.

Orin W. Rank, who knew Hastie, the engineer, who had invited him to go out on the craft, declined at the last moment and, therefore, to-day he is in the land of the living.

WOMAN TAKES PISTOL ROUTE

Mrs. Blanche B. Gjirtson suicided Tuesday afternoon, in room 4 of the Hotel Northern, by shooting herself through the heart with a 32 Smith & Wesson revolver. The only person present was her sister, Mrs. Bera Cook. The sisters and Miss Lillian C. King arrived from Seattle on the Saratoga, and took rooms at the Northern. Mrs. Gjirtson had been drinking heavily, and so had her sister, it is said, and there is an element of mystery surrounding the tragedy, but it is highly probable that the act was either one of impulse or of premeditated self-destruction.

Judge Britton held an inquest Wednesday, the following jury being empaneled: Tony Rucker, C. J. Dykes, A. McRae, W. E. Root, Thos. Campbell and O. E. Lambert, the jury returning a verdict to the effect that the deceased came to her death "by a bullet wound inflicted by parties unknown to the jury."

The witnesses examined were Dr. Payzant, Bera Cook, Lillian C. King and Ralph Peck. Dr. Payzant described the wound [illegible] ranged downward from the [illegible] part of the sternum, passing [illegible] the heart and lodging betw[illegible] the third and fourth ribs, death being instantaneous.

Mrs. Cook, the sister, testified that she was in the room at the time, that her sister was facing the bed, but she averred that she did not even hear the shot that ended her sister's life. The revolver was found on the bed in the room, while the deceased fell close to the side of the bed. Mrs. Cook also stated that she had never heard her sister talk of committing suicide.

Miss King testified that she was in an adjoining room but that she did not hear the shot.

Ralph Peck was in a room above that occupied by the deceased and her sister. He stated that he heard a muffled report as of a shot from a gun, and rushed downstairs and found Mrs. Gjirtson dead on the floor.

There was a mark on the woman's clothing looking like a powder burn, and the jury experimented with a white cloth, discharging a revolver at it at distances of six and twelve inches and three feet, powder stains being left on the cloth, similar to that found on the wrapper which the deceased wore at the time of her death.

Miss King states that Mrs. Gjirtson threatened to commit suicide three times on her way up on the Saratoga.

Mrs. Gjirtson was 32 years of age, and was married a few years ago at Council City, Alaska, to William Gjirtson, well known in the Nome country as "Bill the Packer." He has been a victim of rheumatism for the past couple of years, and Mrs. Gjirtson's friends say that she came here to earn money to get her invalid husband to Seattle from Nome. It is also stated that her parents live in Seattle, and that a sister was one of the numerous wives of the notorious "Swiftwater Bill" Gates.

The remains were buried Wednesday afternoon in the old burying ground, near Palm Point.

TALKS OF THE OIL FORMATION

"The oil formation in and about Katalla is the same as that in the southern Kansas and Oklahoma oil fields," said George W. Kuppler, of Seattle, the other day. Mr. Kuppler spent a number of years in southern Kansas and Oklahoma, and he therefore knows whereof he speaks.

"Katalla is bound to become a great oil producing section," he said, "and within a year or two I expect to see the oil belt in and around Katalla covered with oil rigs as thick as they can stand. The formation is all right and boring deep enough for the oil is all that is needed. Where there is oil there is gas, and where there is gas there is coal, and I understand you have unlimited quantities of the latter. And I am sure you have the former, too."

Mr. Kuppler is an attorney by profession and he thinks seriously of locating here on his return from Valdez, to which place he went on the Saratoga. "Should I do so," he said, "I will probably erect a one-story brick building in Katalla."

NO NEWS OF BURNSIDE

No news has been received in Katalla concerning the movements of the cableship Burnside, except a report that reached town this week from Martin point, to the effect that the cableship was seen from that place a few days ago, apparently making a survey of the ocean, several miles seaward.

It is stated on good authority that the Burnside is not due here with the cable until some time next week, and the same authority does not credit the report that there has been a hitch in laying the cable to Katalla.

Delivered By Carrier.

Hereafter The Herald will be delivered to city subscribers by carriers. Any subscriber not receiving his paper regularly will please notify The Herald office.

The New Bank Building.

The steel safe for the First Bank of Katalla arrived on the Saratoga. Work on the interior of the bank building is being pushed rapidly and it will soon be completed. The building will be sealed throughout with beaded Washington fir lumber. The bank furniture and fixtures are on the Yucatan, and the cashier is expected on an early steamer. The bank will open for business about October 1.

Was It Wellman?

Last Tuesday night an aerial phenomenon appeared in the western sky. It was first noticed about 9 o'clock, and it had the appearance of a big balloon. Its position changed frequently until it disappeared, an hour later, toward the northwest. A large number of people watched the aerial visitor. The Indians said it was a star, while a few hazarded the guess that it was Walter Wellman's air ship, about which nothing has been heard in this section, it not being even known if Wellman started from Spitzbergen on his voyage in search of the North Pole.

Coal on the Market

Twenty-five tons of Bering lake coal was brought down from T. P. McDonald & Co's mine the other day. The Alaska Petroleum & Co. are sales agents for this coal. The quality is improving all the time as depth in the deposit is attained and it is expected that within a short time an excellent quality of coal will be on the market.

EXPECTS TO GET GUSHER

The new oil well of the Alaska Petroleum & Coal company is now down 1600 feet in an oil shale, and general manager Clark Davis says he expects to have a gusher in another week. The indications are exceedingly favorable. Between 1200 and 1300 feet a stratum of oil sand was encountered. It was so hard, in fact, that very slow progress was made in getting through it. Then oil shale was struck at 1300 feet and the drilling now is much easier and the well is being sunk at a rapid rate.

The Pacific Coal and Oil Co's well is producing about 40 barrels a day. The product is being used by the Katalla company as fuel for steam shovels and other purposes. This well was closed for three years, and it is said that the output could be materially increased by "shooting" it so that the accumulation of paraffine wax could be got rid of.

STEAMER ALTONA FOR CORDOVA RUN

Light Draft Steamer Arrives From Portland

[illegible] stern wheel steamer Altona, recently purchased in Portland by Capt. [illegible] for the Katalla company [illegible] undergoing repairs. [illegible] by Capt. [illegible] in tow of the [illegible] She is a vessel of 100 [illegible] draws 18 [illegible] She formerly plied on [illegible] river, and was purchased by the Katalla company for the [illegible] For the remainder [illegible] season, however, she will take the place of the Tebehlet between Cordova and camp 7 on Copper river. The Tebehlet is laid up for repairs [illegible] will act as pilot for [illegible] and the crew of the Tebehlet [illegible] be transferred to the Altona.

COMPLAINTS POURING IN

Because of Treatment Accorded Business Men By Steamship Companies.

Complaints are pouring in to The Herald concerning the treatment received by the business men of Katalla at the hands of the steamship companies.

"These companies," said a business man yesterday, "are doing more business here than with any port in Alaska, and yet you cannot buy a ticket here, as neither of them has a ticket or freight agent at this place. When freight arrives Capt. Strafford, the lighterage man, is compelled to pay the freight on every pound that arrives here, before it is landed. In this way the transportation companies are relieved from the payment of damages should the goods be received in bad condition, which is usually the case.

"A local business man recently received five sacks of sugar; two were broken and the sugar absolutely spoiled, and the others were all damaged. They looked as though they had been put in the ship's coal bunkers. A claim for damages for only two of the sacks was made, amounting to $16, but the company informed him that the freight had been delivered and receipted for, and no damage claim would be allowed. And this is merely a sample of what Katalla business men are up against every day."

Douglas' Bright Idea.

The Herald is in receipt of the following from John Hanson, secretary of the S. A. H. I. B., which, being interpreted means Southeastern Alaska Homeseekers Information Bureau, whose home office is Douglas, Alaska:

"Congratulations on your birth, and all kinds of good wishes for your long life and prosperity, from yours truly, The S. A. H. I. B., just born, in old [illegible] your old Douglas. Look [illegible] and if you have any [illegible] Alaska, help us with your [illegible]."

Berry Lost His Checks

Manuel Berry, an employe of the Alaska Pacific Co. came to town Thursday with pay checks in his pockets amounting to $123.30 besides some loose cash. Then he proceeded to get soused, and late in the afternoon he was found on the beach, sound asleep, by deputy marshal Tom Lane. Lane "frisked" him, and took the checks out of his pocket. When Manuel awoke he missed his checks and reported his loss to the company stating that he had not taken a drink. Timekeeper Rowland came to town and in the course of his investigations met Lane and the checks were immediately forthcoming.

THE TRESTLE COMPLETED

The Alaska Pacific's Terminal Grounds Connected With Whale Island.

The trestle connecting the terminal grounds of the Alaska Pacific Railway & Terminal Company with Whale Island was completed to-day, and the double railroad track will be laid at once.

Rock work on the cut through the island is being pushed in a rapid manner, and work on the immense dock will follow its completion. This dock will enable vessels to discharge cargo in almost any kind of weather.

Putting in Winter Supplies.

Thos. G. White, who is in charge of river transportation for the Katalla Company, left yesterday on the Ralph with ten men and three tons of supplies for Kayak. Mr. White has established camps all along the lower river, and is now able to handle three tons of freight daily between Katalla and [illegible] and by the time the river closes he expects to have most of the supplies needed for the winter at their several destinations. His boatmen, he says, are the best in Alaska.

Broke His Ankle

Fred Glasshrener, of the Poy-Bruhn company is in Dr. Payzant's hospital suffering from a dislocated ankle. Last Tuesday morning he was on the deck of the tug Elvira, assisting in hoisting the anchor when the rope became entangled with his foot, throwing him into the slough near the city dock, badly twisting his ankle. He secured prompt surgical attention and is now resting quite easily.

A Circulating Library.

John Krey, late chief engineer for the Katalla Company, has donated 200 volumes, including scientific and classical works and books of fiction, for the use of the employes of the company, and a circulating library will be established for the benefit of the men.

The Aurora Borealis

A brilliant display of "Northern lights" or the aurora borealis, was observed Wednesday night. The coruscating waves shot from a point apparently directly over the "man of Katalla," on Mt. Davis like the ribs of a monster parachute, all the colors of the rainbow being in evidence.

Dance Tonight

A dance will be given this evening in Pioneer hall, in Peterson & Lind's new building, the proceeds of which will be donated to the fund now being raised for fire protection for the town. The new hall is a commodious one and the dance should be well patronized.

FIRE PROTECTION NEEDED

Meeting to Consider the Matter Will Be Held Wednesday Evening.

The need of fire protection for the town in view of its rapid growth is daily becoming more apparent, and the time has come for united action on the part of all citizens who have property interests here. Among the instant needs are fire hose and a hose cart, and a chemical engine would be a wise investment.

For the purpose of securing concentrated effort a meeting of business men, property owners and all others interested in this matter has been called for Wednesday evening, Sept. 18, at Pioneer Hall, and it is hoped that there will be a large attendance.

Pleasant Surprise Party.

A surprise party was given Dr. and Mrs. Payzant last Saturday night at their residence. Cards were played, followed by music and refreshments, a most delightful evening being spent. Present were: Dr. and Mrs. Payzant, Mr. and Mrs. H. A. McClure, Mr. and Mrs. F. A. Castle, Mrs. Crowell, Mrs. Kendrick, Misses Nettleton and Richmond; F. R. Brenneman, Clark Davis, A. White, R. E. Nettleton, C. D. Davis, C. E. Edwards and W. J. Dennison.

Yucatan in Port.

Steamer Yucatan, Capt. F. S. Moore, reached port last night about 6:30 o'clock with a large passenger list and 700 tons of freight for Katalla. Included in the steamer's passengers were 170 employes for the Katalla Company. The [illegible] left Seattle Sept. 8, and had [illegible] weather during the trip.

The next steamer of the Northwestern line from the south will be the Santa Clara which, however, it is said, will go on the inside passage route, and the Northwestern will take her place on the outside route.

WIRELESS FOR THIS TOWN

Correspondence of The Herald

Seattle, Sept. 2. It is expected that the Seattle Alaska Wireless Telegraph company, which was organized here recently, will begin the work of constructing its stations at once. The initial point selected is at Gray's harbor; another of the main stations will be at Dutch harbor, and the third will be at Nome. Stations will be also erected at Juneau, Sitka, Katalla and Valdez and possibly other points along the coast.

The chief electrician of the company is Lee Milligan, formerly of the United States signal corps, who assisted in installing the wireless stations at Nome and St. Michael, and he also installed the government's wireless systems in the Philippines.

Mr. Milligan recently returned from Nome, where he secured forty acres of ground for the erection of the plant at that place. He will probably visit Katalla in the immediate future.

Gray's harbor has been selected as the starting point for the wireless system because it will afford a practically unobstructed sweep over the Pacific to Dutch harbor.

Brady Wants a Contest

Kid Brady, of Chicago, who arrived on the Saratoga is open for all boxing engagements at catch weights. At The Herald office the other day Brady stated that he preferred to box C. T. Welsh if a match can be made.

Brady's last battle was with Tom Riley, at Superior, Wis. for the championship of the Northwest, Brady being defeated in the fifteenth. Riley forfeited to Brady, however, after the latter's arrival in Seattle. Brady has been a great drawing card, he says, in his various bouts and especially in his famous battle with George Eldredge at Ashland, Wis.

After seeing Alaska Brady will return to his home at Cattletsburg, Ky.

12. Shallow Geology, Geohazards, and Environmental Conditions

Climate

The weather of the Gulf of Alaska Planning Area is influenced by coastal mountain ranges and the relatively warm Alaska Current. Because of the contrast in temperature and relative humidity between the air associated with the Alaska Current and that of the adjacent continent, the Gulf of Alaska typically has cloudy skies, moderately heavy precipitation, moderate winter temperatures, and cool summer temperatures. The weather across the planning area is also influenced by the seasonal northward and southward migration of the polar front to the north, and migration of storms along the Aleutian storm track to the southwest. High mountains along the western, northern, and eastern margins of the Gulf form barriers to the passage of these storms, typically causing them to stagnate and dissipate. Storm passage is also impeded by a high-pressure ridge that is present in the eastern North Pacific (east Pacific high) during much of the year. Because of the passage and dissipation of these storm systems, the Gulf of Alaska is one of the most meteorologically dynamic places on earth (Hood and Zimmerman, 1986).

The planning area is characterized by relatively cool summers and warm winters compared to interior continental regions at comparable high latitudes. This climate is caused by the Alaska Current, a relatively warm extension of the Kuroshio Current, which originates in the western equatorial Pacific (fig. 117). In winter, the Alaska Current warms the air and provides moisture for cloud formation. In summer, this current also provides moisture for cloud formation and precipitation, but the water mass then tends to be cooler than the air temperature over the adjacent landmass, which results in generally cooler temperatures over the planning area. The mean monthly air temperatures across the planning area for the months of January and July range between 28 and 39 °F, and 52 and 55 °F, respectively (Brower and others, 1988). The extreme maximum and minimum air temperatures across the planning area for the month of January range between 43 and 50 °F, and -4 and 21 °F, respectively; for the month of August the maximum and minimum temperatures range between 64 and 68 °F, and 46 and 50 °F, respectively (Brower and others, 1988). Table 14 shows the mean annual maximum and minimum temperatures and the highest and lowest recorded temperatures at four stations across the planning area (Cape Hinchinbrook, Cape St. Elias, Yakutat, and Port Alexander).

Because of the interaction between climatic and physiographic factors (the presence of the polar front, high bordering mountain ranges, and the frequent passage of storm systems), the Gulf of Alaska receives a great deal of precipitation (table 15). The horizontal and vertical mixing of cool and relatively dry continental air from the north with relatively warm and moist maritime air from the south associated with the polar front results

Table 14. Mean annual maximum and minimum temperatures and highest and lowest recorded temperatures in degrees Fahrenheit (Brower and others, 1988) at four stations across the planning area.

Station	Mean Annual Maximum Temp.	Mean Annual Minimum Temp.	Highest Temp.	Lowest Temp.
Cape Hinchinbrook	45	38	81	-15
Cape St. Elias	46	38	78	0
Yakutat	45	32	86	-24
Port Alexander	49	39	81	4

Table 15. Average total annual precipitation, greatest recorded monthly precipitation, and greatest recorded daily precipitation in inches (Brower and others, 1988) at four stations across the planning area.

Station	Average Total Annual Precipi.	Greatest Monthly Precipi.	Greatest Daily Precipi.
Cape Hinchinbrook	93	32	9.5
Cape St. Elias	101	27	5.4
Yakutat	134	44	7.8
Port Alexander	166	32	7.6

in cloud formation and precipitation. Data from recording stations across the Gulf show that precipitation in the form of rain, snow, or sleet occurs less than 15 percent of the time in August to more than 40 percent of the time in October (Brower and others, 1988).

Wind speed and direction are variable across the planning area. Data published jointly by the Minerals Management Service and the National Oceanographic and Atmospheric Administration (Brower and others, 1988) show that the mean scalar wind speed across the planning area ranges from 9.0 knots (nautical miles per hour) in July to 19.4 knots in December. Storm winds commonly reach 80 knots (Wilson and Overland, 1986), although unusually intense storms over water may have gusts to 100 knots (Thom, 1968). Winds in the Gulf of Alaska have a slight tendency to blow in a preferred direction depending on the season and location. Figure 118 shows the scalar wind speed and direction of surface winds across the planning area during the months of January and July. In winter, the principal factor in determining surface wind speed and direction is the movement of low-pressure systems through the Gulf (Wilson and Overland, 1986). In summer, the principal factor is the presence of a seasonal high-pressure system or of weak, transient, low-pressure systems (Wilson and Overland, 1986). Throughout the year, the nearshore wind field is variable owing to the presence of mountains that form barriers and channel onshore winds.

The weather in the Gulf of Alaska is influenced by the east Pacific and Siberian high-pressure systems, and the Aleutian low-pressure system (fig. 119). The Aleutian low is present 25 percent of the time, making it the dominant influence throughout the year (Overland and Heister, 1980). The Aleutian low-pressure system is generated by the passage of intense storms (Wilson and Overland, 1986). The weather in the Gulf of Alaska is characterized by the passage of these storms, which typically have low sea-level barometric pressure and associated cold fronts. Most of these storms form in the western Pacific near the coast of Asia where warm ocean currents flow adjacent to relatively cold land masses. These storms increase in intensity as they move across the north Pacific gathering heat and moisture from the ocean surface. From October through April, an average of one storm every 4 to 5 days crosses the Gulf, generally from west to east (Hartmann, 1974). These storms often have 80-knot winds that generate waves up to 65 feet high, and typically drop up to 300 inches of precipitation annually on the coastal mountains.

During the summer, the air over the Gulf is cooler than over the adjacent land mass and a large high-pressure system, the east Pacific high, forms over the ocean. Part of this high-pressure system is intermittently present year-round off the coast of California and Baja California, its presence due in part to the upwelling of cold, abyssal water. During the summer, the east Pacific high expands northward and reaches maximum intensity from June through August (fig. 119).

From October through March, the weather in the Gulf of Alaska is influenced by the Siberian high-pressure system. This high, which attains a maximum pressure in January, forms owing to the presence of very cold winter air over eastern Asia and northern Alaska. In winter, this high-pressure ridge deflects the Aleutian-low storm track system to the south.

Cloud cover and fog are common in the Gulf of Alaska. Fog occurs in the Gulf during every month, but is most prevalent during the summer and early winter (Grubbs and McCollum, 1968; Guttman, 1975). Cloud cover is greatest during July. The average number of "clear" days (those with less than one-eighth cloud cover) along the Gulf coast is four to seven per month (Grubbs and McCollum, 1968). During the summer, moist air is trapped near the sea surface by a low-level temperature inversion associated with the seasonal high-pressure system (Wilson and Overland, 1986), which results in persistent fog and low stratus clouds. Cloud cover in the winter is related to the passage of storms and the flow of cold, relatively dry continental air from the Alaska continent across the relatively warm waters of the Gulf (Wilson and Overland, 1986).

Superstructure icing is a serious hazard to both drilling structures and vessels operating in the Gulf. Under unfavorable conditions, fog, rain, or sea spray will freeze to the superstructure of a vessel. Wilson and Overland (1986) categorized the Gulf of Alaska as having a moderate to extreme potential for icing. A statistical study by Borisenkov and Panov (1972) showed that of 3,000 cases of sea icing, 86 percent were caused by ocean spray. Sea icing occurs most commonly at the mouths of major rivers and near major glaciers and ice fields (Brower and others, 1988). The development of icing is a function of several variables, the most critical being when the air temperature is colder than the freezing point of seawater (28.9 °F at a salinity of 35 parts per thousand)(Wilson and Overland, 1986). Other variables include sea temperature, wind speed, wave direction relative to the vessel, and the configuration of the vessel or structure.

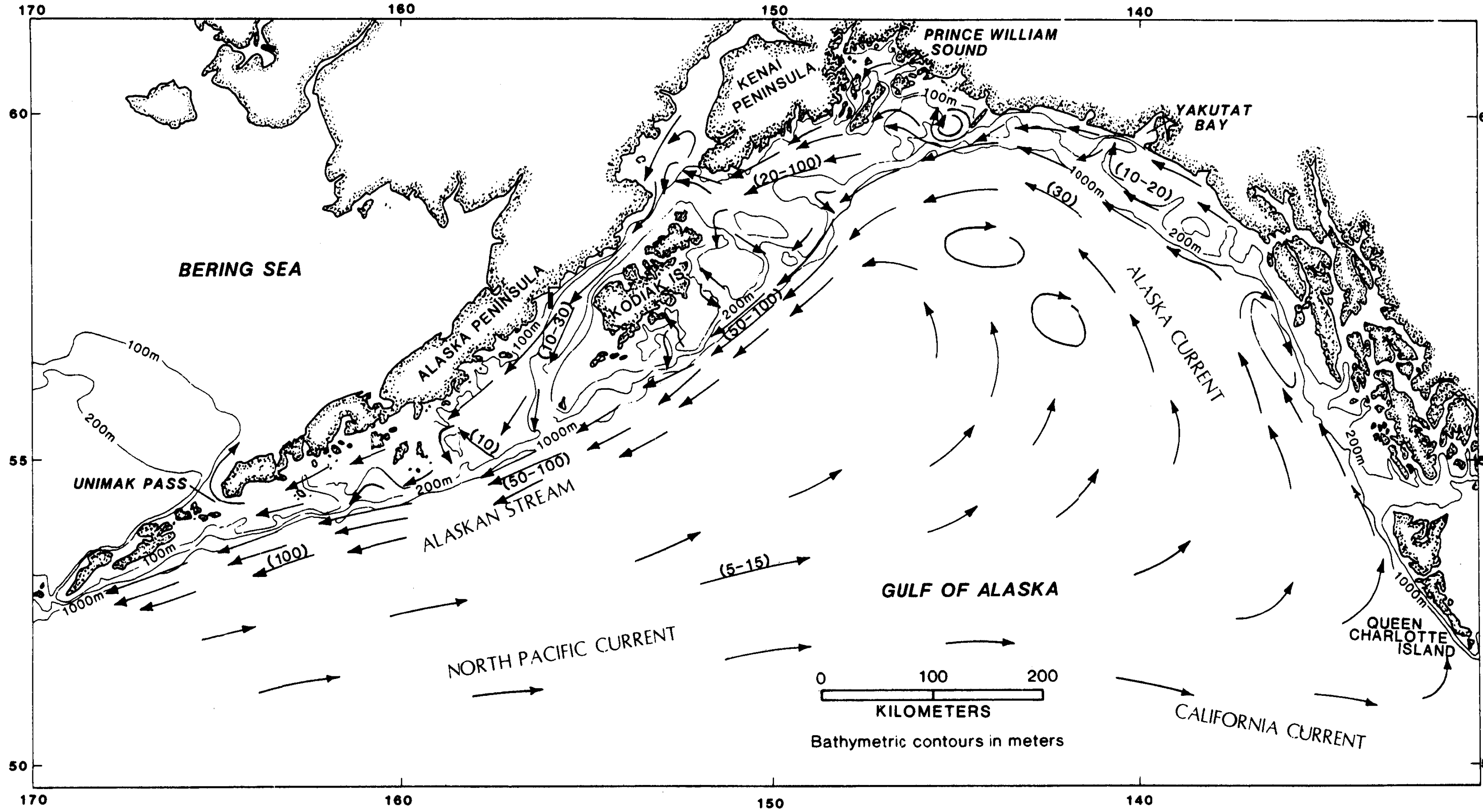


Figure 117. Schematic representation of current circulation in the Gulf of Alaska (after Muench and Schumacher, 1980). Numbers indicate the range of mean speed in centimeters per second and arrows represent current direction.

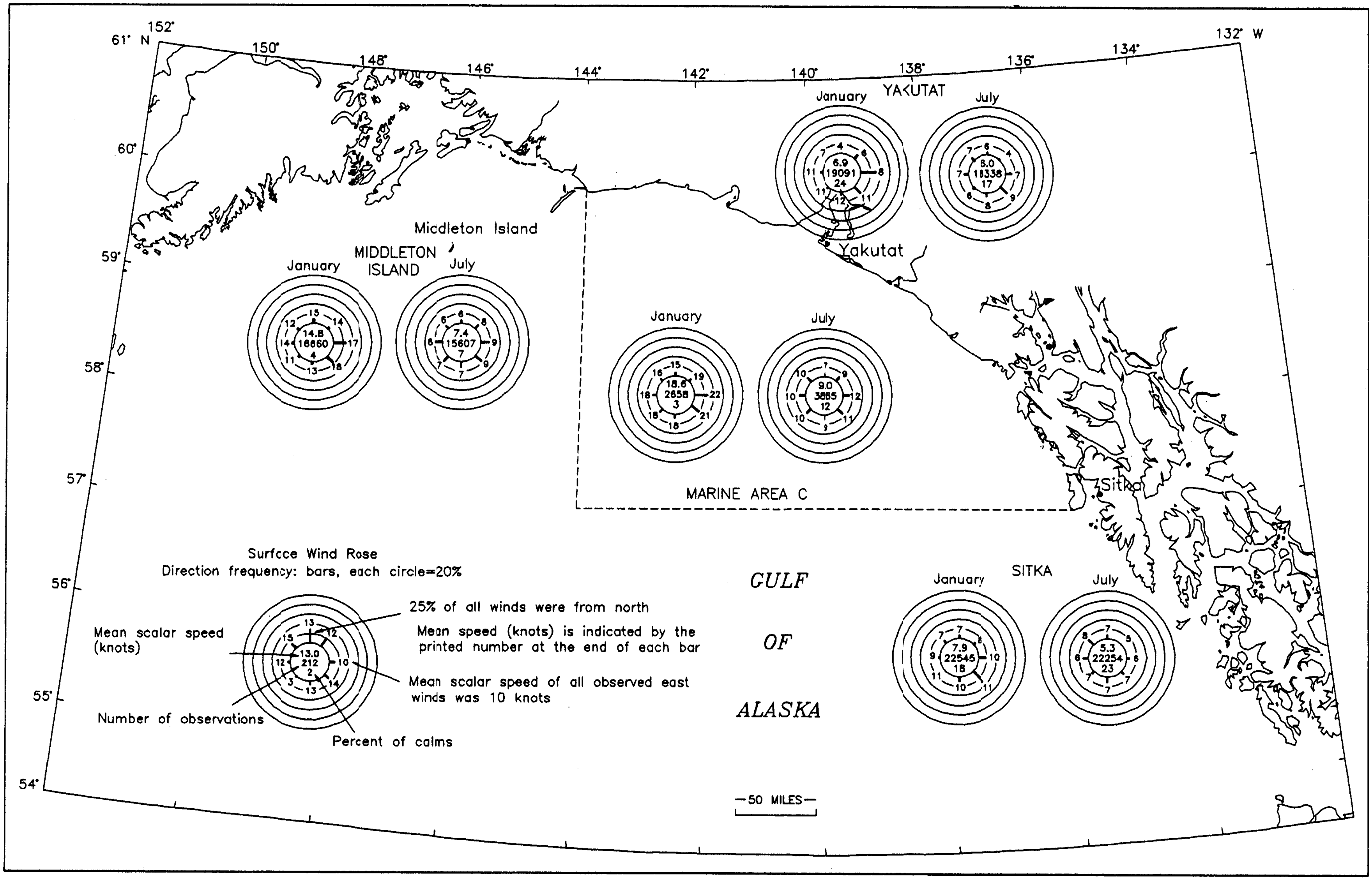


Figure 118. Scalar wind speed and direction of surface winds in the Gulf of Alaska for the months of January and July (modified from Brower and others, 1988).

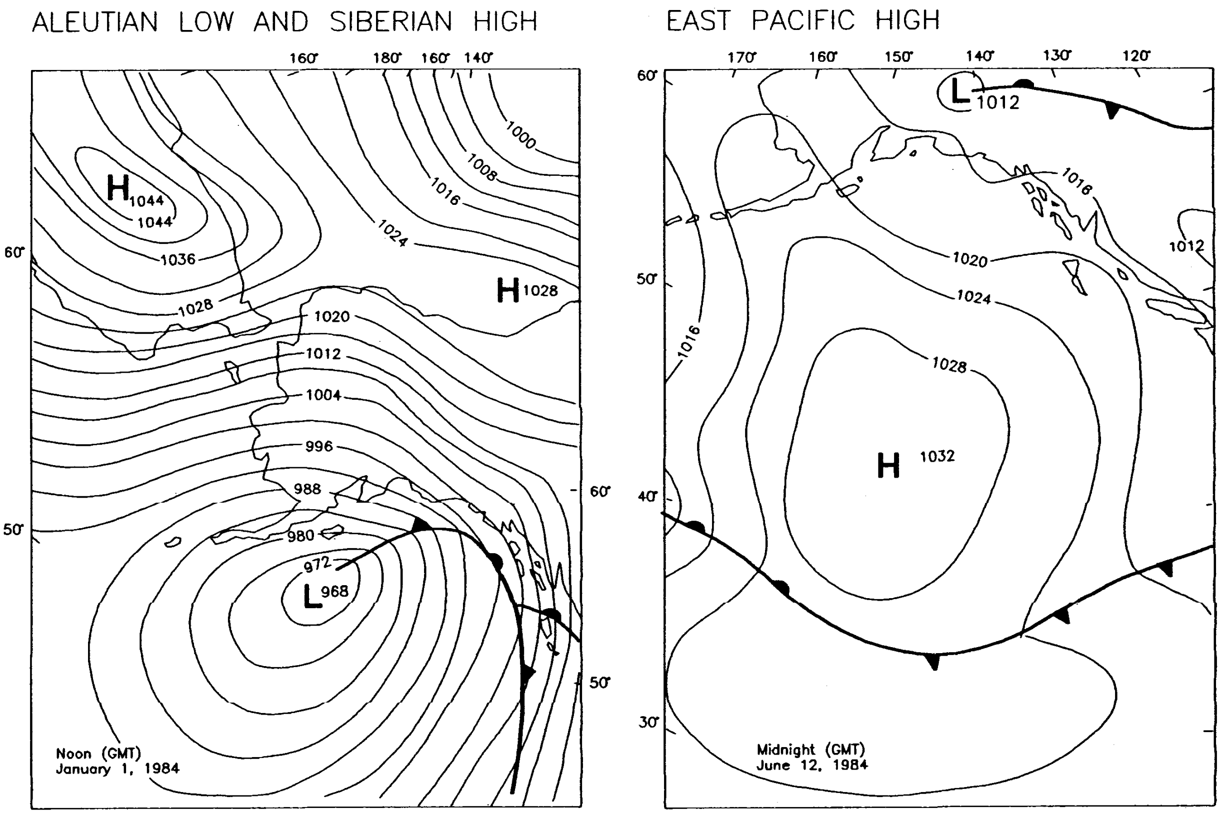


Figure 119. Examples of the Aleutian low-, Siberian high-, and east Pacific high-pressure systems. The contours represent sea-level pressure in millibars (from Wilson and Overland, 1986).

Ocean Currents

Strong currents can affect seafloor sediments around offshore drilling structures and pipelines. Bottom currents can exert horizontal or vertical forces against structural surfaces and create eddy patterns that can lead to severe erosion (Gerwick, 1986). The movement of dynamic sediment bed forms could leave bottom-founded structures or pipelines unsupported.

Surface currents in the Gulf of Alaska are part of a nongeostrophic wind-driven cyclonic gyre. These currents include the North Pacific Current (the eastward extension of the Kuroshio Current), the Alaska Current, and the Alaska Stream. Together they make up the Alaska Gyre (fig. 117). The Kuroshio Current originates in the western equatorial Pacific and flows northward as a western boundary current along the eastern coasts of the Philippine Islands, Taiwan, and Japan (Pickard, 1963). As the North Pacific Current approaches the west coast of North America, it separates into the southward-flowing California Current and the northward-flowing Alaska Current. The flow of the Alaska Current along the coast of British Columbia and Alaska is approximately 10 to 15 million cubic meters per second (Brower and others, 1988). Because it originates near the equator, the Kuroshio Current and its extension, the North Pacific Current, bring substantial heat to the Gulf of Alaska (fig. 117).

The flow of the Alaska Current and the Alaska Stream generally follows bathymetric contours and is normally centered along the shelf break. Where major submarine canyons incise the shelf (for example the Yakutat and Alsek sea valleys and the Amatuli Trough), the current follows the isobaths and flows into the canyons. Along the eastern and northern margins of the Gulf, the flow of the Alaska Current is broad and relatively slow, but where it turns southwestward to follow the Alaska Peninsula, it narrows and intensifies and becomes the Alaska Stream (Reed and others, 1980). Maximum winter velocities of the Alaska Current often exceed

60 centimeters per second and occasionally reach 80 to 100 centimeters per second. Direct current measurements on the shelf often exceed 120 centimeters per second (Brower and others, 1988).

Surface Geology and Geohazards

Geohazards data were collected by the petroleum industry and the USGS to study the safety of siting oil and gas exploration and production platforms and pipelines. Seafloor hazards on the shelf include ground shaking from earthquakes, surface faults, gas-charged sediments, submarine slides, and sediment gravity flows. Potential geohazards between the Dixon Entrance and the Kennedy Entrance (fig. 120) were identified from high-resolution seismic-reflection data. Four near-surface sedimentary units with different geotechnical properties were identified using grab samples, box cores, gravity cores, and piston cores. Geotechnical analyses were performed on these sediment samples to determine their susceptibility to failure by earthquake or storm wave loading. Detailed studies by Chase and others (1970), Woodward-Clyde Consultants (1976), Molnia and Sangrey (1979), Atwood and others (1981), Carlson and others (1985), Hood and Zimmerman (1986), and Schwab and others (1987) were used in this analysis.

The collision of the Pacific plate and the North American plate produced the Chugach, St. Elias, Wrangell, and Coast Mountain ranges onshore and the structurally complex sedimentary basins found offshore. The influence of the warm Alaska Current and the progressive uplift of these coastal mountain ranges brought about coastal marine glaciation. Glacial and glaciofluvial processes eroded large quantities of rock and transported the sediment to the continental shelf. These rapidly deposited sediments are typically underconsolidated and exhibit high pore pressure. Offshore, earthquakes, crustal deformation, and intense winter storm activity have destabilized parts of the Holocene glacial marine and normal marine sections, producing submarine slides.

Bathymetry and Geomorphology

The Gulf of Alaska extends for over 800 miles from Dixon Entrance in southeast Alaska to the Kennedy Entrance in the west (fig. 120). The width of the shelf, as defined by the 200-meter bathymetric contour, ranges from approximately 20 miles in southeast Alaska to over 100 miles west of Kayak Island. The average slope gradient between Cross Sound and Montague Island is about 0.15 degrees from the shoreline to the shelf break (Atwood and others, 1981). The main physiographic features on the shelf are seavalleys and structurally controlled topographic highs (fig. 121).

The morphology of the shelf reflects recent tectonic and glacial processes. Over 34,000 square miles of glaciers are present onshore. Major ice masses include the Harding and Seward ice fields, and the Bering, Guyot, Malaspina, Hubbard, Turner, Fairweather, Grand Plateau, and La Perouse glaciers (fig. 121). These ice masses presently flow out from the Kenai, Chugach, Wrangell, St. Elias, and Coast Mountain ranges, generally following the routes of glacial flow during the last major glacial advance in the late Pleistocene.

During the last low stand of sea level (late Pleistocene), these glaciers extended onto the shelf and carved large seavalleys (Carlson and others, 1978; Molnia and Sangrey, 1979). These seavalleys are, from east to west, the Yakobi Seavalley, Alsek Seavalley, Yakutat Seavalley, Bering Trough, Kayak Trough, Egg Island Trough, Hinchinbrook Seavalley, and the Amatuli Trough (fig. 121). Evidence for the glacial origin of these features includes their U-shaped cross sections, till-like sediments along the valley walls, and low-profile terminal or recessional moraines at their distal ends at the shelf break (Carlson and others, 1982). Smaller, morphologically similar glacial channels are present offshore south of the coastal glaciers (Molnia and others, 1980) and are filled with late Pleistocene and Holocene sediment.

Structural uplift in the late Cenozoic formed topographic highs on the shelf that influenced the flow of glacial lobes (Carlson and others, 1982). Some of these highs are the Learmonth Bank, Fairweather Ground, Pamplona Ridge, Kayak Island, Middleton Island, and Tarr Bank (Atwood and others, 1981) (fig. 121). High-resolution seismic data and shallow coring indicate that many of these features are made up of Neogene or Paleogene rocks.

Surficial Sediment and Bedrock Outcrops

Four broadly defined glacial marine and normal marine sedimentary units, predominantly components of the Yakataga Formation (Miocene to Holocene), have been mapped on the shelf between Cross Sound and Montague Island (Carlson, 1976; Plafker and Addicott, 1976; Woodward-Clyde Consultants, 1976; Molnia and Carlson, 1978; Carlson and others, 1980). These broadly defined sedimentary units are: (1) Holocene,

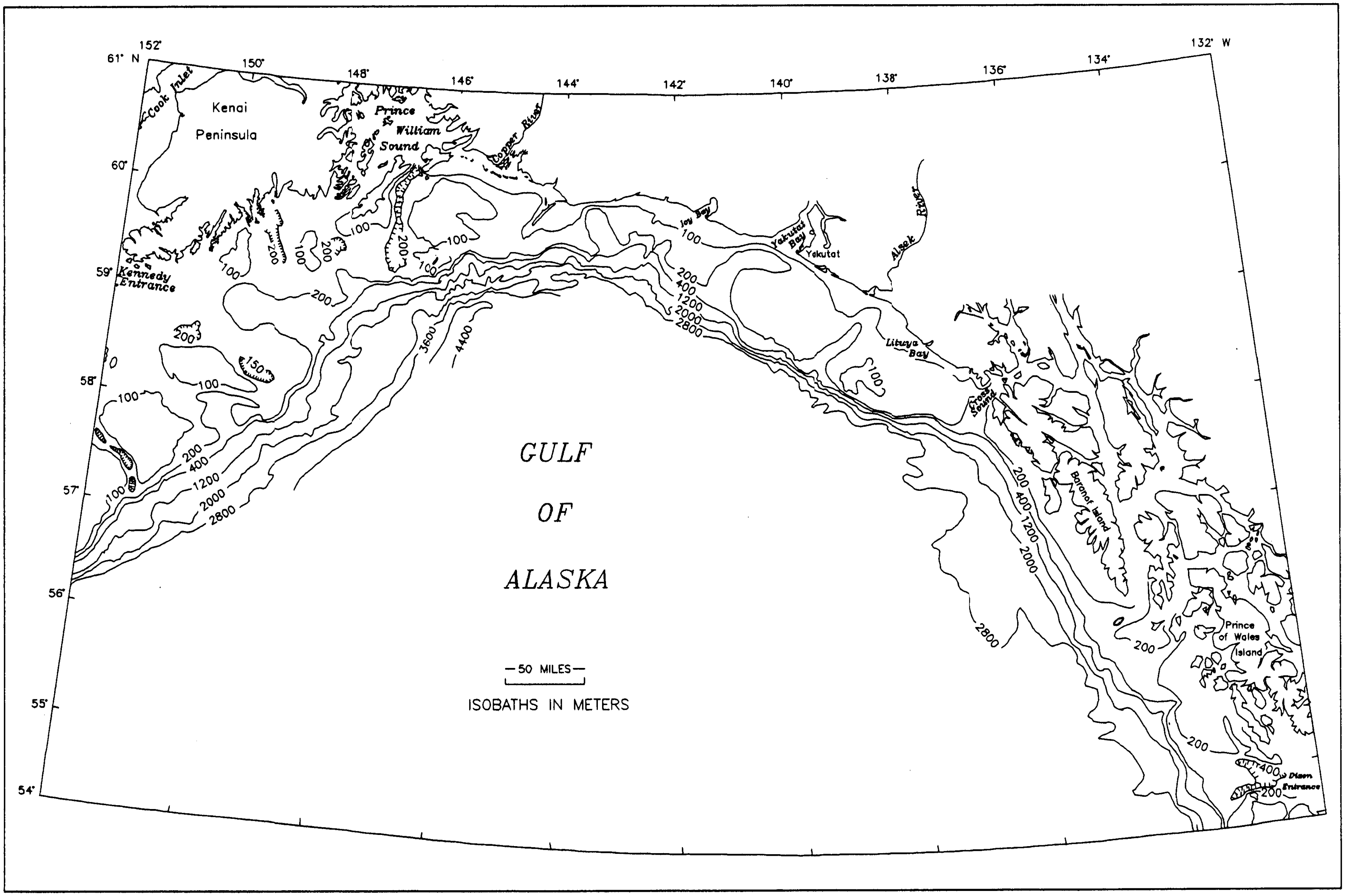


Figure 120. Generalized bathymetric map of the Gulf of Alaska continental shelf and slope. The isobaths are in meters (modified from Chase and others, 1970; Atwood and others, 1981; Seeman, 1982; Carlson and others, 1985; and Hood and Zimmerman, 1986).

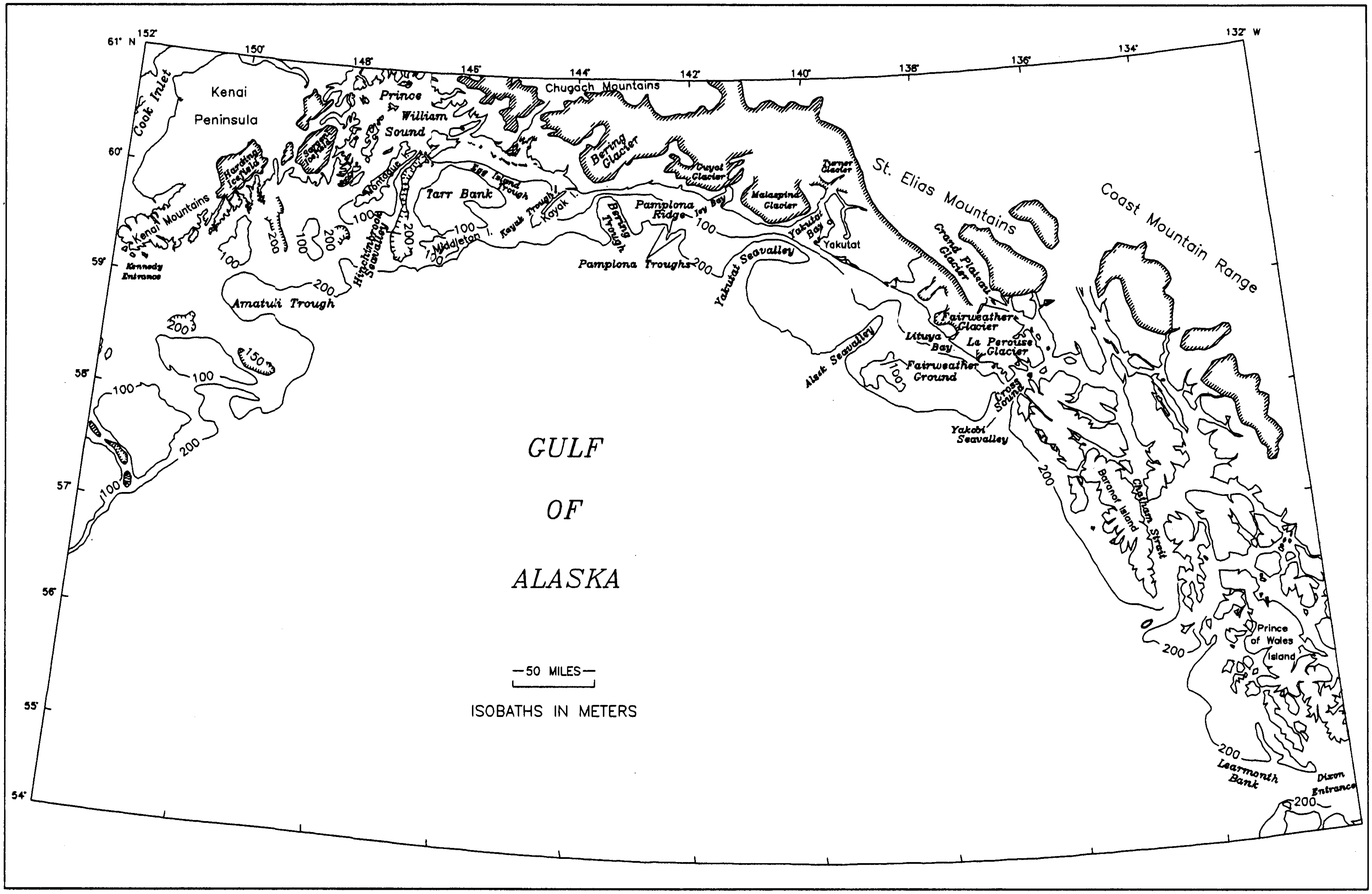


Figure 121. The major physiographic features of the Gulf of Alaska continental shelf (modified from Carlson and others, 1985).

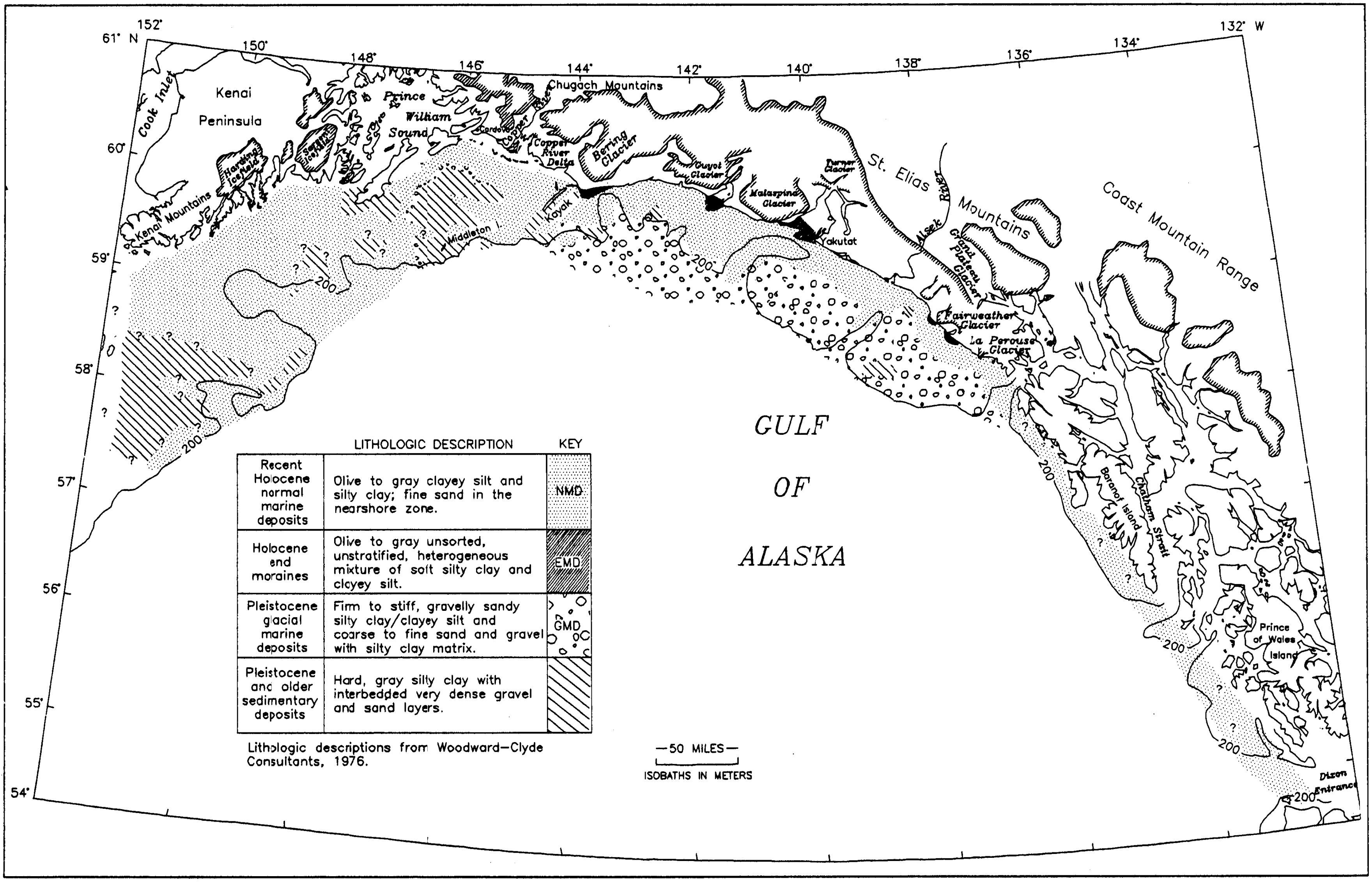


Figure 122. Areal extent of the four near-surface sedimentary units of the Gulf of Alaska continental shelf and slope (modified from Molnia ,1977; Molnia and Carlson, 1978; and Molnia and Sangrey, 1979).

normal marine deposits (NMD); (2) Holocene end-moraine deposits (EMD); (3) Quaternary glacial marine deposits (GMD); and (4) Tertiary through Pleistocene rocks (fig. 122). These near-surface units (fig. 123), were identified in the Sale 39 area (fig. 67) and are not present over the entire Gulf of Alaska Planning Area. The Tertiary through Pleistocene unit includes portions of the Yakataga Formation and older rocks found beneath the shelf.

The geotechnical properties of these near-surface sedimentary units must be considered in the design and subsequent installation of fixed offshore structures. Even on very gentle slopes, offshore structures should not be sited on thick accumulations of normal marine deposits because these sediments are susceptible to sediment slides and sediment gravity flows. Data from shallow cores in the Gulf of Alaska (Woodward-Clyde Consultants, 1976) indicate that normal marine deposits are poorly consolidated and contain a high percentage of water. Sediments that are saturated with water have a low bearing capacity and are susceptible to slope failure, even on slopes of less than 1 degree. Potential geohazards associated with glacial marine deposits include sediment slides and pockets of gas in permeable strata.

The volume of sediment being transported into the Gulf today is a primary reason for taking precautionary methods before siting offshore structures. Modern sedimentation began between 10,000 and 15,000 years ago. The Gulf of Alaska shelf, excluding the area southeast of Cross Sound, may have the highest sedimentation rate in the world (Hampton and others, 1986). Holocene normal marine sedimentation rates in the Gulf can be as high as 29 millimeters per year (Molnia, 1983b). The high sedimentation rate in the Gulf is the result of ongoing glaciation, high precipitation, and active tectonism. The Copper and Alsek Rivers and many glacial outwash streams carry large volumes of sediment onto the continental shelf, where it is distributed by the prevailing counter-clockwise currents of the Alaska Stream. These poorly sorted, Holocene normal marine sediments are characterized on seismic- reflection profiles by parallel, relatively horizontal reflectors, except where they have been disturbed by gas, sediment slumps, or slides (fig. 124).

A progradational wedge of normal marine fine sand to clayey silt extends from the littoral zone to the outer shelf edge, except on portions of uplifted blocks where storm waves and strong bottom currents prevent sediment accumulation. High-resolution seismic profile in figure 123 illustrates the absence of these fine-grained deposits on the Icy Bay structure. Cores taken on the flanks of the structure reveal a 0- to 63-foot-thick section of normal marine deposits (Woodward-Clyde Consultants, 1976). The consistency of these silty clays varies from very soft at the seafloor to firm at depth, with the upper surface clays being water saturated (Woodward-Clyde Consultants, 1976).

Holocene sedimentary deposits east of the Alsek Seavalley and southeast of Lituya Bay are thinner than those to the west (Molnia and Carlson, 1980). Between Cross Sound and the Dixon Entrance, the maximum sediment thickness is typically less than 100 feet. In the central Gulf, similar deposits are about 300 feet thick (Molnia, 1977). West of Montague Island, Holocene sediments are approximately 200 feet thick (Hampton, 1983).

Holocene end moraine deposits consist of poorly sorted, unstratified silt, sand, gravel, and clay. These end moraines are located at the mouths of Lituya Bay, Icy Bay (Molnia, 1977), Yakutat Bay (Molnia, 1979), and seaward of the Bering Glacier (Molnia and Carlson, 1980) (fig. 122). Late Pleistocene moraines have been identified on the shelf near the Yakobi, Alsek, and Yakutat Seavalleys, the Bering and Kayak Troughs, the Hinchinbrook Seavalley, and the Amatuli Trough (Carlson, 1989). This unit is characterized on seismic-reflection profiles by disordered reflections (Carlson, 1976).

Moraines mapped by Thrasher and Turner (1980) were also described in site-specific studies done by Nekton, Inc. (1982), in the Sale 55 area for the ARCO OCS Y-0211 No. 1 well. The local relief on these features is between 10 and 20 feet, the lateral extent about 1,000 feet. The morainal ridges are composed of consolidated glacial till, so their susceptibility to slope failure is moderately low despite their relatively steep slopes.

Glacial marine deposits underlying the Holocene normal marine sediments were deposited during the last glacial advance (fig. 123) (Molnia and Carlson, 1980). These deposits may include glacial till, moraines, and outwash sediments (Woodward-Clyde Consultants, 1976). On seismic lines, these glacial marine deposits appear as continuous to discontinuous, flat-lying to slightly irregular reflections except on top of the structural highs, such as the Icy Bay structure, where the reflections are discontinuous because the sediments have been reworked into ridges and mounds (fig. 123).

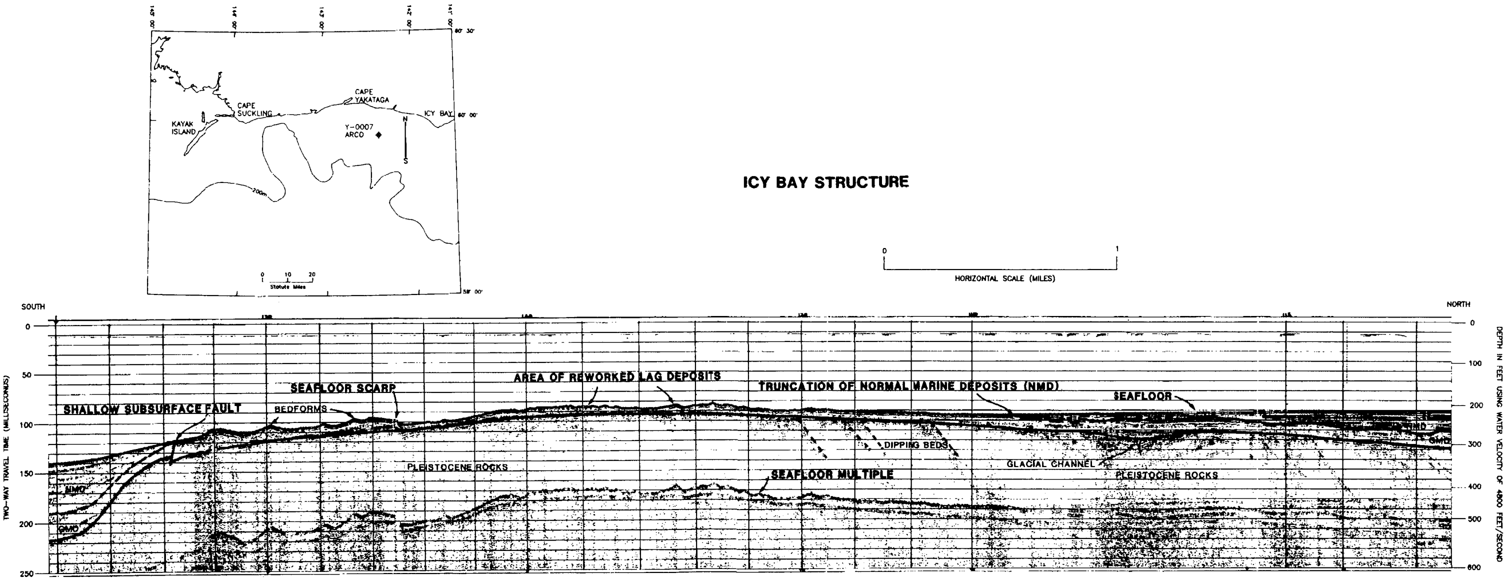


Figure 123. A high-resolution seismic-reflection profile across a portion of the Icy Bay structure southeast of Cape Yakataga showing sedimentary units in the upper Yakataga Formation, truncation of Holocene sediments, and an area of lag deposits. The upper sedimentary units are defined as Holocene normal marine deposits (NMD), Pleistocene glacial marine deposits (GMD), and older Pleistocene rocks. (Shot by BBN Geomarine Services, 1975.)

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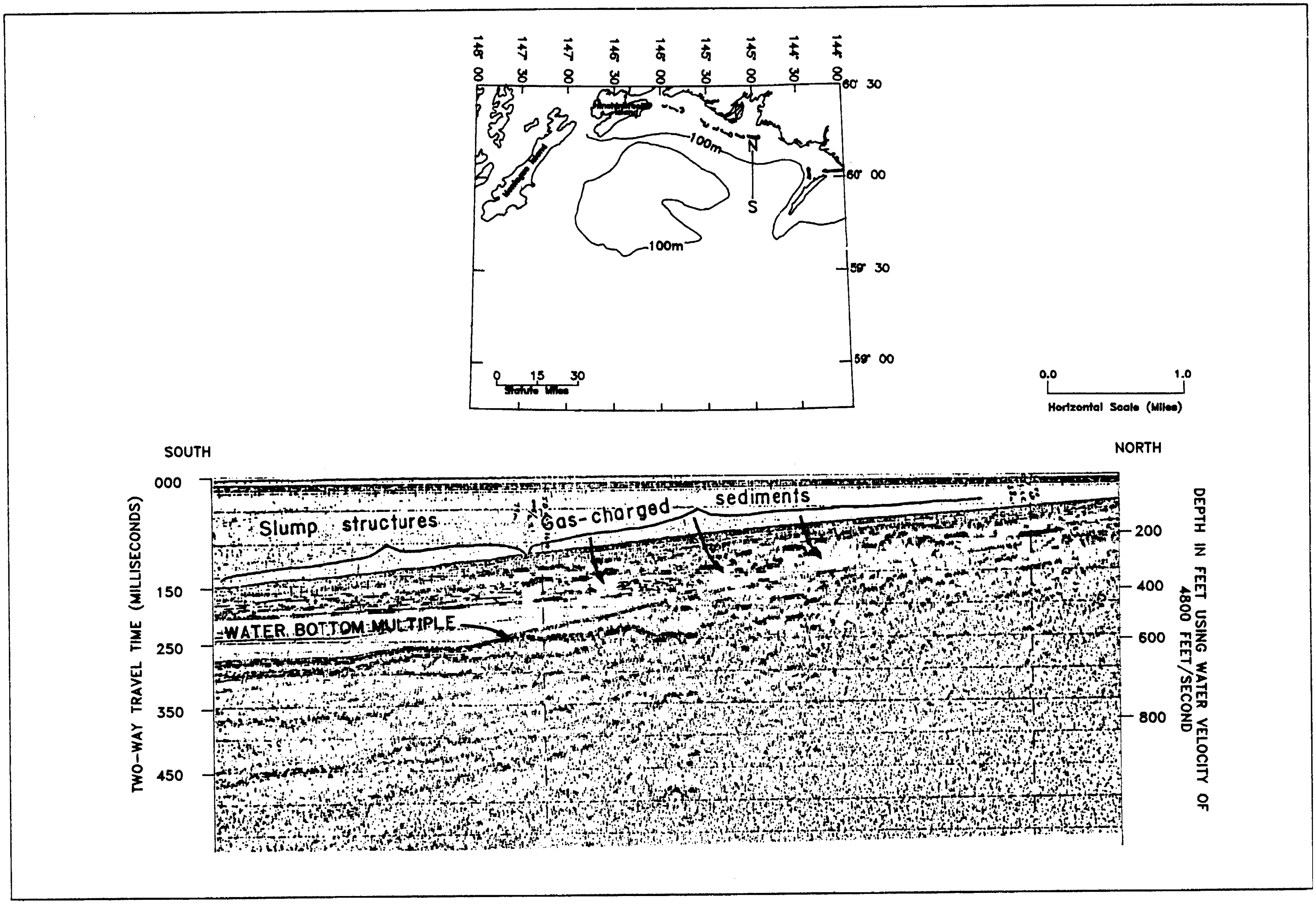

Figure 124. A minisparker profile that shows gas-charged sediments and slump features south of the Copper River delta (Carlson, 1976).

Post-depositional winnowing from severe storms produced lag deposits of sand and gravel north and west of Tarr Bank and between Kayak Island and Cross Sound (Molnia, 1983a) (fig. 122). Glacial marine deposits are typically firm and are not often involved in sediment slides except on steep slopes on the continental slope. Small pockets of low-pressure gas are found in gravels at the base of the unit (Woodward-Clyde Consultants, 1976).

The oldest described outcropping on the shelf is composed of semi- to well-indurated Pleistocene deposits of silty clay, gravel, and sand (Woodward-Clyde Consultants, 1976), and older sedimentary rocks that are Paleogene in age (Molnia and Carlson, 1978). These rocks are exposed in the Hinchinbrook Seavalley and on the bathymetric highs of the Fairweather Ground, Tarr Bank, and offshore of Montague Island, on the Middleton and Kayak Island platforms, and on Pamplona Ridge. On a high-resolution seismic-reflection profile across the Icy Bay structure, the Pleistocene and older rocks below the glacial marine deposits appear as irregular, discontinuous reflections. Some of these reflections appear to be steeply dipping (fig. 123). Sediments obtained from coring had a water content of less than 20 percent and a shear strength greater than 2.5 feet per square ton. The relatively high structural integrity of these sediments is in part due to glacial loading and depth of burial (Woodward-Clyde Consultants, 1976).

Sediment Slumps and Sediment Gravity Flows

Marine geotechnical studies on the Gulf of Alaska continental shelf identified numerous areas of slope instability on slopes between 0.5 and 1.3 degrees (Carlson, 1978; Carlson and others, 1978; Hampton and others, 1978; Molnia and Sangrey, 1979; Schwab and Lee, 1988). Major areas of slope instability are present south of the Copper River prodelta, Bering Glacier, Malaspina Glacier, Yakutat Bay, and Alsek prodelta, and on the continental slope south of the Pamplona zone (fig. 125). The high rates of shelf and slope sedimentation in these areas contribute to unstable near-surface conditions.

Carlson and Molnia (1978) showed that slope failures typically occur within thick sections of relatively unconsolidated Holocene normal marine sediments on the shelf. These recently deposited clayey silts have water contents between 35 and 45 percent (Lee and Schwab, 1983) making them highly susceptible to cyclic loading from storm-wave activity and ground failure due to seismic shaking. Failure occurs when the sediment mass is changed from compacted to expanded by the redistribution and incorporation of water, which reduces the sediment shear strength and increases its fluidity (Schwab and others, 1987).

Winter storms in the Gulf of Alaska can generate wave heights between 50 and 65 feet and disturb the seafloor to water depths as great as 600 feet (Carlson, 1978), weakening the internal resistance of underconsolidated sedimentary deposits. Wave-generated forces such as cyclic loading are responsible for large sediment slides, slumps, and sediment gravity flows on the shelf and slope. Sediment slides and slumps are found in nearshore areas, off the mouths of rivers, on the walls of seavalleys, and along the continental slope (fig. 125). Periodically, these large slump blocks flow seaward. Offshore structures such as drilling platforms and pipeline installations could be adversely affected if not properly sited.

The Copper River and the Malaspina glacial system have contributed half the sediment volume now present on the shelf (Molnia and others, 1980). The largest sediment slide zones in the Gulf of Alaska are associated with these sedimentary systems. High-resolution geophysical studies over the Malaspina slump and in adjacent areas south of Icy Bay by Carlson (1978) show large slump structures in water depths of 210 to 450 feet on slopes of less than 0.5 degrees. These slumps lie within the low-strength, poorly sorted, Holocene normal marine section (figs. 122 and 125). Slumping is uncommon between Cross Sound and the Dixon Entrance because there is less Holocene sediment being deposited on the shelf there. Southwest of Middleton Island only a few slumps are known, even though a thick section of Holocene sediment is present on the shelf (fig. 125).

Schwab and Lee (1988) defined two types of slope failure: nondisintegrative failure, characterized by limited internal deformation and downslope movement (as in the slumps south of Malaspina Glacier); and disintegrative failure, characterized by failure of the entire sediment mass (as in the sediment gravity flows associated with the Alsek prodelta). The mechanism most likely to cause slope failure is related to water depth: at depths of less than 100 feet, storm-wave-generated cyclic loading causes shear stress on recently deposited sediments and produces slope failure; at depths greater than 200 feet, earthquake loading is the most likely cause. Unstable sediments in water depths

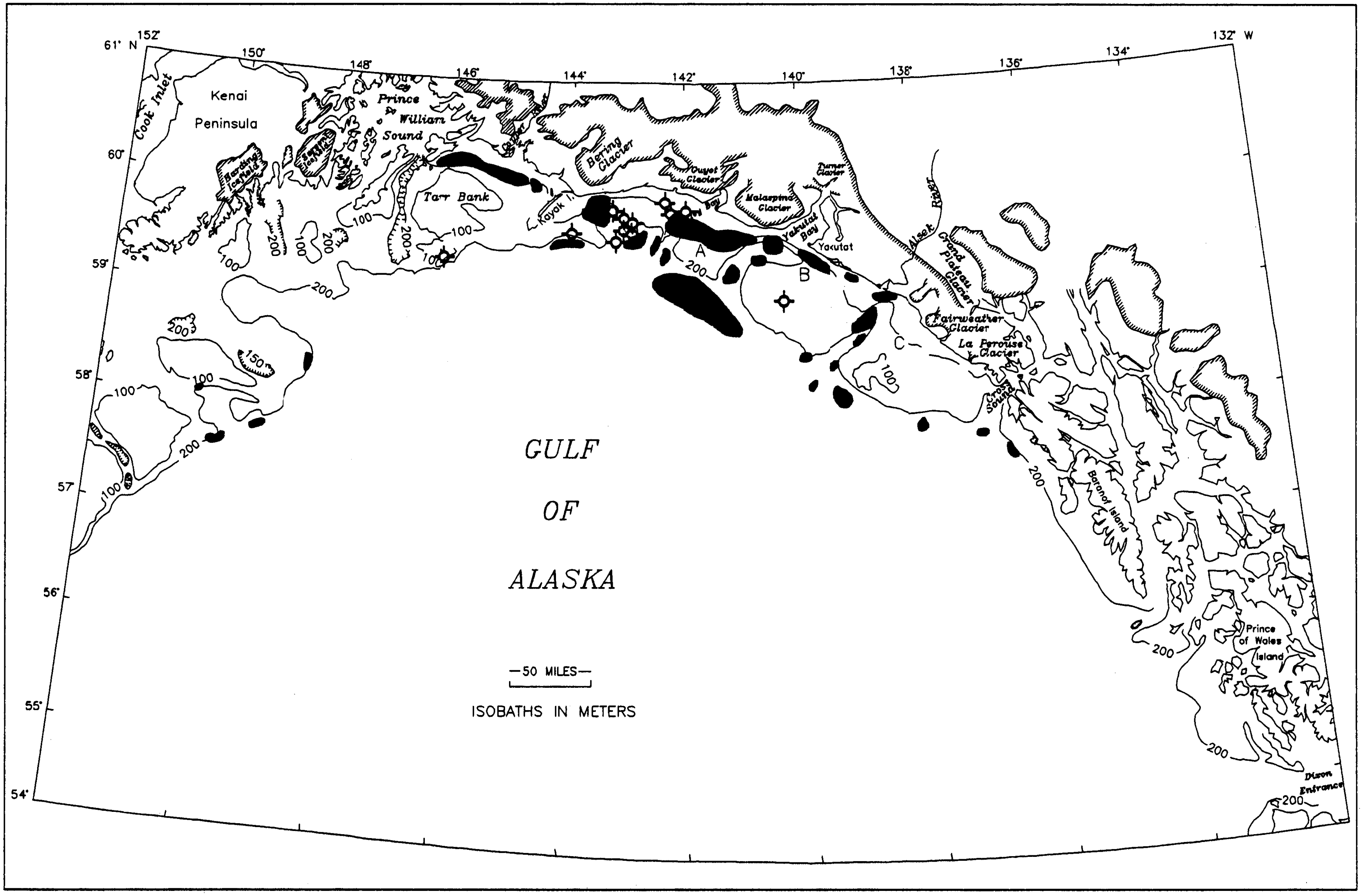

Figure 125. The location of all exploration wells and known sediment slides on the Gulf of Alaska continental shelf and slope, including the Icy Bay-Malaspina slump (A), the Yakutat slump (B), and sediment gravity flows of the Alsek prodelta (C) (modified from Hampton and others, 1978, and Schwab and Lee, 1988).

between 100 and 200 feet fail equally by either process (Schwab and Lee, 1988).

The Icy Bay-Malaspina and Yakutat slumps and the sediment gravity flows on the Alsek prodelta (discussed in detail by Schwab and Lee, 1988) would experience the same degree of ground-shaking intensity during an earthquake because both are situated on the Yakutat crustal block and both are composed of Holocene normal marine sediments. Seismic loading was the probable cause of the Icy Bay-Malaspina and Yakutat slumps because storm waves are less effective at water depths greater than 200 feet. The sediment gravity flow seaward of the Alsek prodelta was probably caused by storm waves acting on sediments at water depths between 100 and 200 feet (Schwab and Lee, 1988).

Numerous large slumps on the continental slope were identified from high-resolution seismic data just beyond the continental shelf edge south of the Sale 39 area. These slumps involved consolidated sediments on steep slopes. One of the slumps occurred on a slope greater than five degrees, south of the highly faulted Pamplona zone (fig. 126).

Areas on the shelf characterized by patchy Holocene sediment distribution are Tarr Bank, Middleton Island, and the shelf southeast of Kayak Island (Molnia, 1977). The scarcity of Holocene sediment there is the result of erosion by strong bottom currents and large storm waves (Molnia and others, 1980). In these areas, the sediment is more consolidated and less likely to fail during storm-wave loading.

Gas-Charged Sediments

Shallow, gas-charged sediments are a hazard to the siting of offshore drilling structures because of their low structural integrity, and a hazard to drilling operations because of the possibility of the loss of well control from a blowout. The high sedimentation rates in the Gulf of Alaska favor the preservation of organic matter and are a necessary prerequisite for the production of biogenic gas. Several field and laboratory studies by Hampton and Anderson (1974) and Schubel (1974) show that biogenic gas in sediments is related to significantly diminished signal response from high-resolution subbottom profiles.

Because gas-charged sediments have low shear strength and bearing capacity, careful siting of offshore facilities is necessary in areas that contain such sediments. As the concentration of gas increases, the stability of the sediment decreases, which may lead to failure. Such sediments are more likely to fail when cyclic loading from storms or ground shaking from seismic activity causes the sudden release of gas and water resulting in subaqueous mass movements of sediment.

The incident that has caused the greatest concern during oil and gas drilling operations on the outer continental shelf is the blowout. A blowout is the complete loss of well control by the unexpected penetration of an overpressured sand while drilling in underbalanced conditions. A blowout can cause the loss of life, property, and possible environmental damage. Although there has never been a blowout in any Alaska OCS well, the possibility of one always remains.

As part of a USGS study, areas of gas-charged sediments in the Gulf of Alaska were identified utilizing high-resolution and echo sounder profiles (fig. 127). Gas chromatographs from sediment cores were used to further delineate gas-charged areas. The gas collected from cores was mostly biogenic methane generated in the upper portion of the thick Holocene normal marine stratigraphic section (Molnia and others, 1979). In one section found south of the Copper River delta, gas-laden sediments were identified by the absence of acoustic returns (fig. 124).

Site-specific geophysical surveys for OCS Lease Sale 39 (Woodward-Clyde Consultants, 1976) and OCS Lease Sale 55 (Nekton, 1982) located no significant gas seeps, although core holes in the Sale 39 area revealed shallow pockets of low-pressure gas in a gravel unit at the base of the glacial marine deposits (fig. 123).

Earthquakes

Earthquake hazards to offshore facilities include substrate deformation, ground shaking, tsunamis, and sediment failures. Seismic shaking, faulting, and sediment slides pose the greatest threats to offshore facilities. Historical records of seismicity are used to estimate the location, size, and frequency of future earthquakes in a region. In the Gulf of Alaska, data are available for the past 100 to 200 years, which is a relatively short record.

The Queen Charlotte-Alaska-Aleutian seismic zone, one of the world's most seismically active areas (Nishenko and Jacob, 1990), extends from the Juan de Fuca spreading center off British Columbia through the Gulf of Alaska and along the Aleutian trench to the Kommandorski Islands in the northwest Pacific. In the

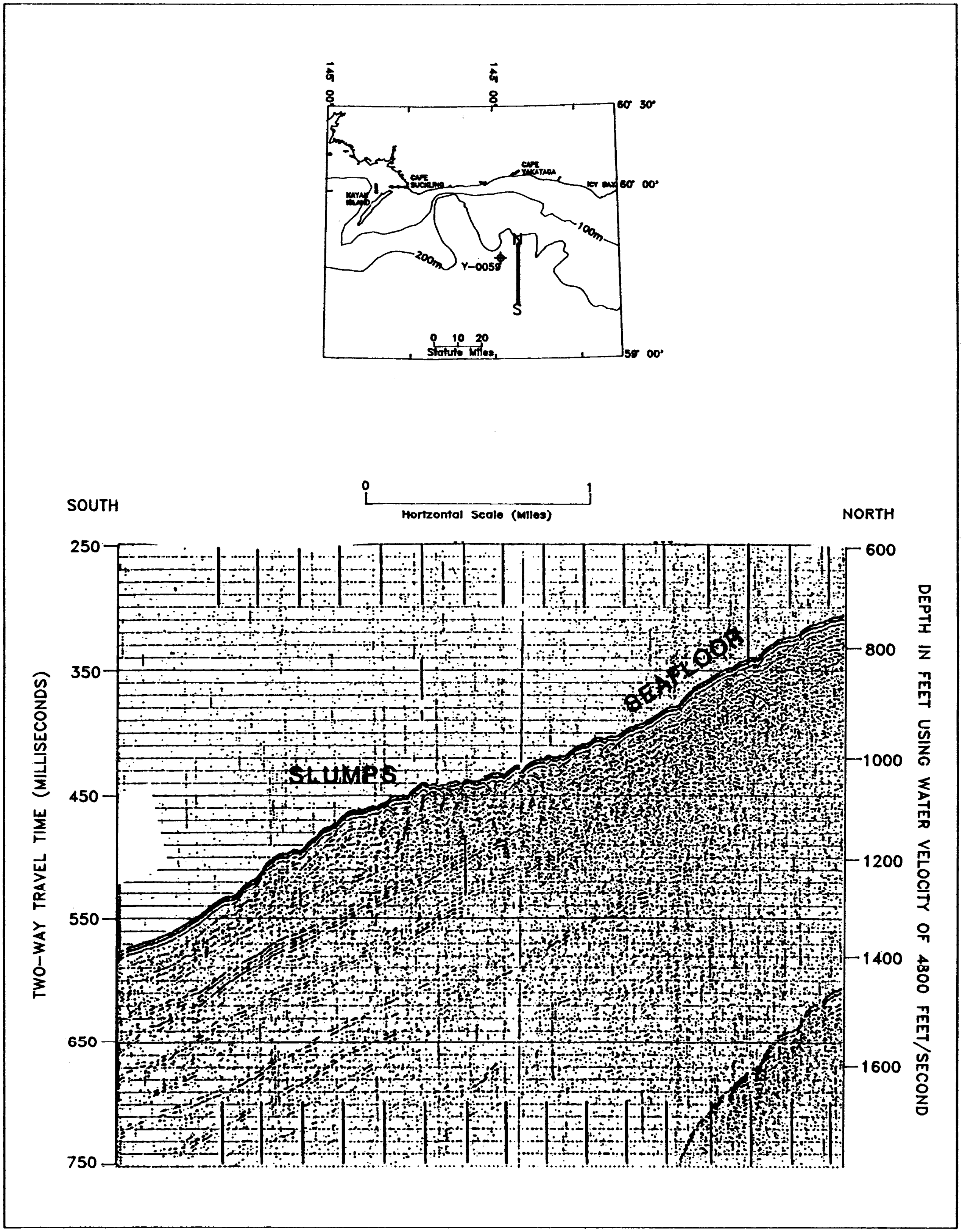

Figure 126. A minisparker profile that shows slumping on the continental slope south of the OCS Sale 39 area (BBN Geomarine Services, 1975).

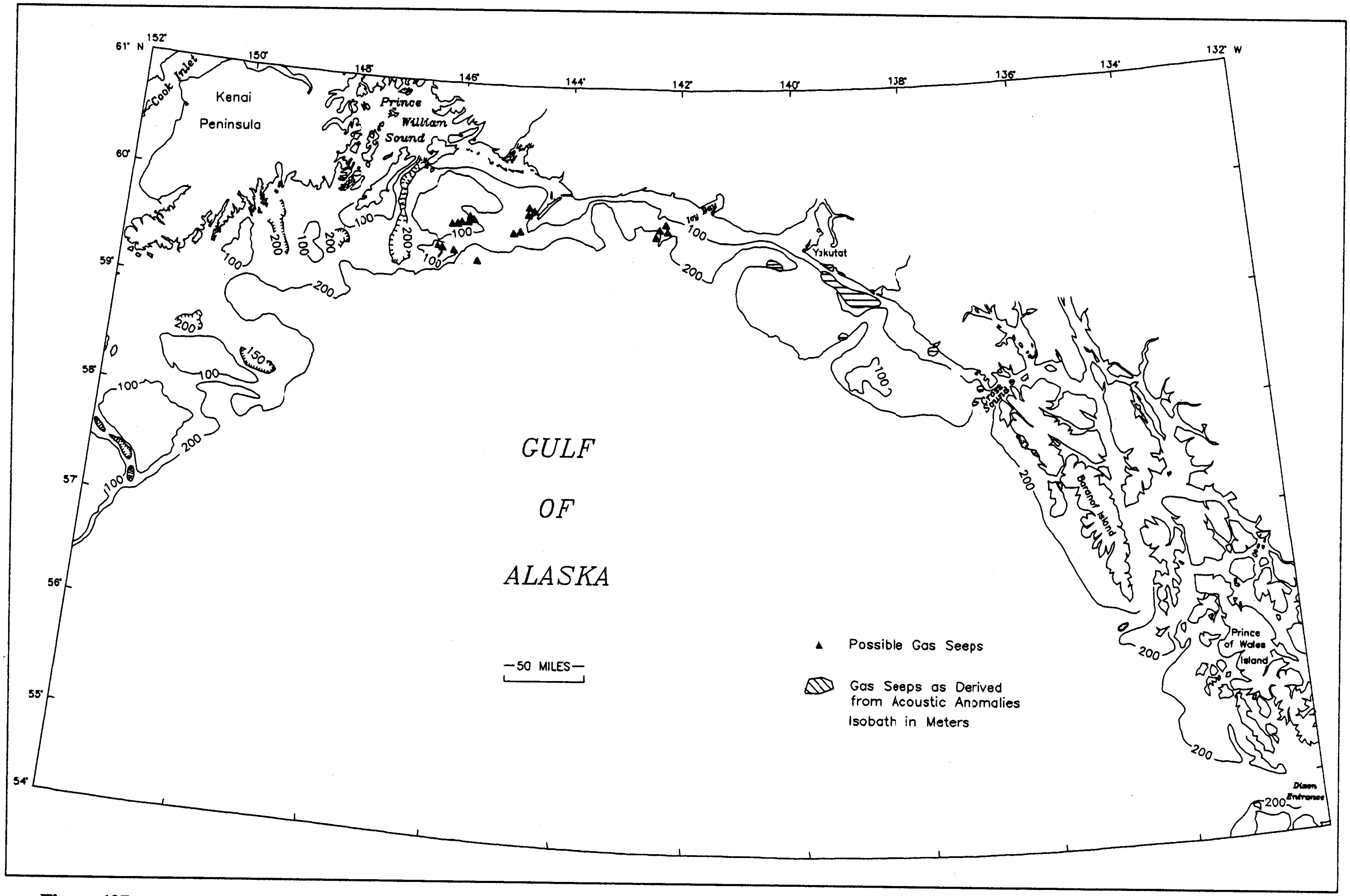

Figure 127. Areas of gas-charged sediments in the northeastern Gulf of Alaska (modified from Molnia, 1979, and Thrasher and Turner, USGS unpublished data).

Gulf of Alaska, most of the motion between the Pacific and North American plates is taken up by great thrust earthquakes along the Aleutian megathrust, thrusts within the Kayak and Pamplona zones, and by strike-slip motion along the Fairweather-Queen Charlotte fault system (Jacob, 1986). This motion controls the tectonics, seismicity, volcanism, and morphology of the Gulf of Alaska region (fig. 128).

Nishenko and Jacob (1990) subdivided the Queen Charlotte-Alaska-Aleutian seismic zone into 17 subzones, or segments, based on historical records, the damage and intensities of seismic events, and the positions of large and great earthquakes and their aftershocks (fig. 128). The segments in the Gulf of Alaska were delineated by the Prince William Sound earthquake (Mw 9.2) of March 24, 1964, the Fairweather fault earthquake (Mw 8.2) of July 10, 1958, and the Sitka earthquake (Ms 7.6) of July 30, 1972. Mw is the total kinetic energy radiated by an earthquake and Ms is based on the size of the long-period surface waves. Because these segments have ruptured in great events within the last 40 years, they have a low probability of rupture from a similar large earthquake within the next few decades (McCann and others, 1980; Nishenko and Jacob, 1990).

The occurrence of a large magnitude event does not rule out the likelihood of a lesser magnitude event. Page and Basham (1985) think that there is a high probability of lesser magnitude quakes occurring along the Fairweather fault in the foreseeable future. Lahr and others (1980) estimated the recurrence intervals for lesser magnitude events in southern Alaska on the basis of seismic moments and slip rates. Their data showed that earthquakes with a magnitude of 6.6 may occur every 12 years.

Tobin and Sykes (1968), Sykes (1971), and Kelleher and Savino (1975) defined "seismic gaps" as segments along active faults where large magnitude earthquakes have not occurred within the past three decades but have in historical times. These areas are of the most concern because of their potential for a sudden large release of accumulated elastic strain. The Yakataga seismic gap (between approximately 140° and 144° W. longitude) is thought to have a high probability for a great earthquake within the next 20 years because strain has accumulated there since the last two great earthquakes (McCann and others, 1980; Jacob, 1984). These great earthquakes were the Yakataga earthquake (Mw 8.1) of September 4, 1899, and the Yakutat Bay earthquake of September 10, 1899.

No great earthquakes have occurred within the Yakataga seismic gap since the 1899 earthquakes, although two sequences of earthquakes occurred there after the 1964 Great Alaskan event: a Ms 6.8 shock in 1970 beneath the Pamplona zone, and the St. Elias earthquake (Mw 7.5) on the eastern margin of the gap (Lahr and others, 1980; McCann and others, 1980; Savage and Lisowski, 1988). These earthquakes demonstrate the relatively high strain levels still present in the region. A more recent set of earthquakes occurred on the Pacific plate south of the Transition zone, seaward of the Yakataga seismic gap (November 17, 1987, Ms 6.9; November 30, 1987, Ms 7.6; and March 6, 1988, Ms 7.6) (fig. 128) (Lahr and others, 1988a). Strain data from the Yakataga seismic gap after these events suggest some relaxation of accumulated strain (Savage and Lisowski, 1988), although not enough to significantly alter the projections of a major shock within the next few decades (Jacob, 1984).

Surface and Near-Surface Faults

The style of faulting in the Gulf of Alaska changes along the plate boundary in response to relative plate motion. The Pacific plate moves 5 to 7 centimeters per year (cm/yr) northwest relative to the North American plate, with the rate of movement increasing to the west (fig. 128). Seismicity is concentrated along plate boundaries, where some of the largest magnitude seismic events ever recorded have occurred (Mw 9.2 in the Great Alaskan Earthquake of 1964) (Krauskopf and others, 1972).

Recent tectonism in the Gulf of Alaska is indicated by mountain ranges, raised beach terraces, and numerous active faults. Fault displacements have been utilized in conjunction with recorded seismic activity over the last 200 years to predict the approximate size, frequency, and location of future great earthquakes. The frequency of Quaternary movement along faults in the Gulf of Alaska suggests that an earthquake could occur during the life of an offshore production platform, although it is less likely during the shorter time period needed to drill an exploratory well. Surface faults may be generated by shallow-focus earthquakes and could be hazardous to pipelines and large offshore structures built within or across fault zones.

Virtually all earthquakes occur as ruptures on pre-existing faults (Page and Basham, 1985). Numerous active faults are found at or near the surface on most of the Gulf of Alaska shelf. These faults are located along the Fairweather-Queen Charlotte fault system,

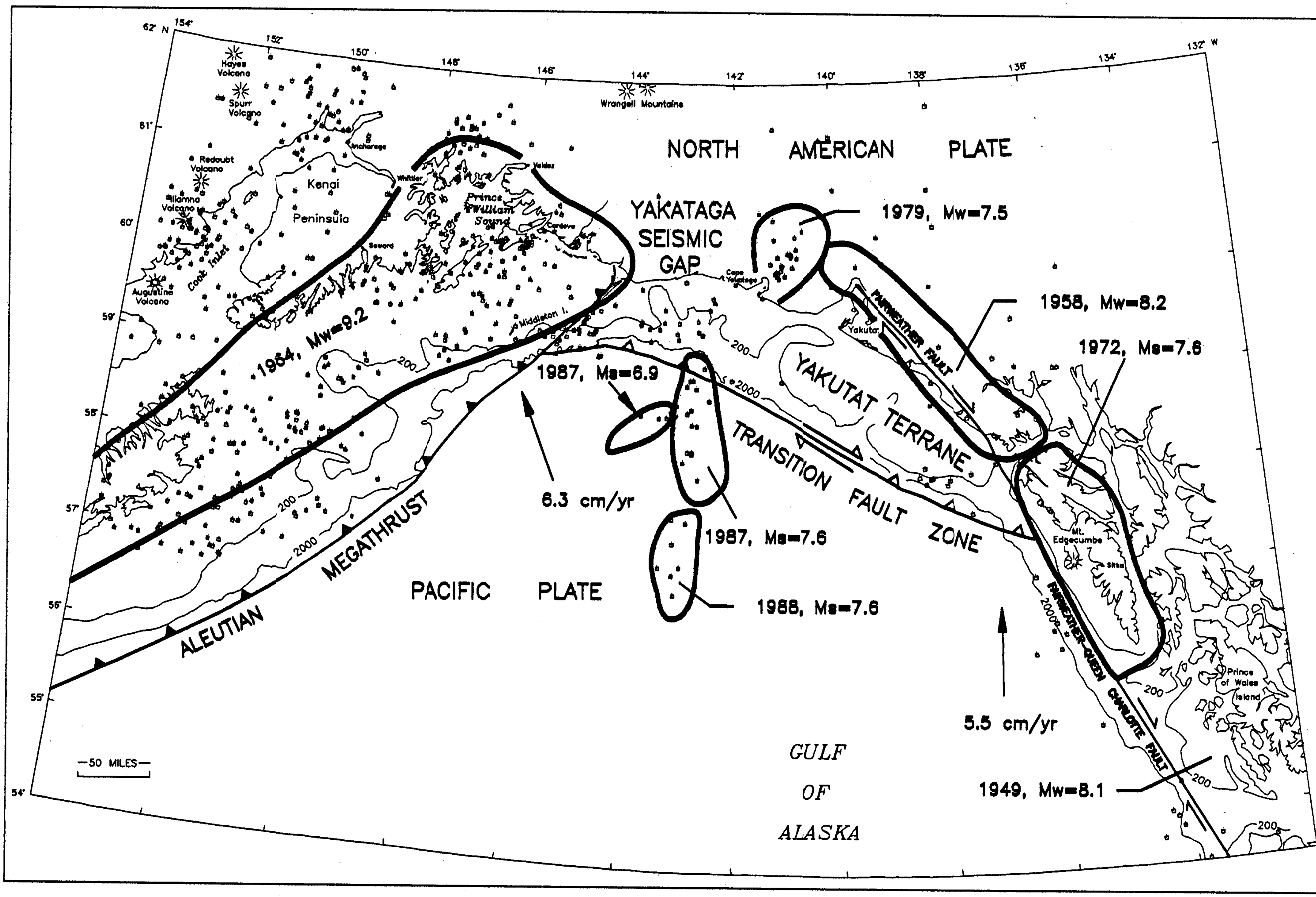

Figure 128. A portion of the Queen Charlotte-Alaska-Aleutian seismic zone showing the rupture zones as defined by major earthquakes and their aftershocks (Nishenko and Jacob, 1990). Pacific plate motion vectors relative to the North American plate are in centimeters per year (Minster and Jordan, 1978). Data points are earthquake epicenters since 1899 (National Earthquake Center, Boulder, Colorado, 1990).

Fairweather Ground, the shelf edge near the Alsek Seavalley, the Pamplona zone, the Yakataga segment, the Middleton Island shelf, and the shelf portion west of Middleton Island (fig. 129).

Nearly all plate motion since the early Paleogene in southeast Alaska has occurred along the Fairweather-Queen Charlotte fault system (Hudson and others, 1982). Many seismic-reflection profiles across the northwest-trending fault system reveal seafloor offsets. In some places between Cross Sound and Chatham Strait, the seafloor is offset by as much as 100 feet (fig. 130). Many surface displacements occurred following earthquakes along the Fairweather fault system in historic time. In 1949, a Mw 8.1 earthquake was recorded centered around the Queen Charlotte fault near Prince of Wales Island (Combellick and Long, 1983). During that event, significant differences in displacement along strike occurred, although the average slip was approximately 20 feet (Nishenko and Jacob, 1990). On July 10, 1958, the Fairweather fault was ruptured by a Ms 7.9 earthquake in the Lituya Bay area. Dextral strike-slip movement on this fault was approximately 20 feet, with a vertical displacement of 3 feet (Tocher, 1960; Plafker and others, 1978b).

Three sets of faults are located on the shelf adjacent to the Alsek Seavalley. A set of faults is located above the Fairweather Ground structure, a topographic high east of the Alsek Seavalley. Recent uplift on the structure produced northwest-trending fault scarps with a maximum relief of 150 feet. Faults are also present along the continental slope southeast of Fairweather Ground and at the shelf edge west of the Alsek Seavalley (Carlson and others, 1980)(fig. 129). Very few near-surface faults have been mapped between the Alsek Seavalley and the Pamplona zone (Yakataga seismic gap). This segment coincides with an area of low seismicity.

To the west, beginning in the Pamplona zone, numerous near-surface reverse faults trend north-northeast. North of the Pamplona zone, the Yakataga segment contains similar faults. These faults often extend into the Holocene section, and sometimes approach the surface (Carlson and others, 1980). This highly disrupted portion of the shelf has a history of numerous seismic events (Lahr and others, 1980).

In the vicinity of Middleton Island, a series of east-west-trending faults cut strata of the Yakataga Formation. The relative movement on these reverse faults appears to be north-side up (Carlson, 1976). Dip-slip fault displacement of approximately 9 feet was documented on Montague Island following the Great Alaskan Earthquake (Mw=9.2) of 1964 (Plafker, 1969). Northwestward underthrusting of the Pacific plate beneath the North American plate resulted in large vertical displacement on a reverse fault that broke the surface. Similar faults are found as uplifted marine terraces on Middleton Island. Radiocarbon dating of peat layers from five marine terraces on Middleton Island established an uplift rate of approximately 1 cm/yr for the past 4,500 years (Hudson and others, 1982). Southwest of Montague Island, normal faults that strike northeast-southwest parallel to the Aleutian trench are present.

Volcanic Hazards

Volcanic ash falls can affect large areas. Localized volcanic hazards are lava flows, mudflows, pyroclastic bombs, nuées ardentes, debris avalanches, seismic deformation, tsunamis, noxious fumes, and acid rain. Atmospheric effects associated with volcanism cause radio interference.

Earthquakes related to volcanic activity frequently occur prior to eruptions. Most such earthquakes are caused by the upward movement of magma. Volcanic earthquakes occur at shallow depths and the potential damage is local. Ground deformation typically occurs before and after eruptions, and may generate landslides and tsunamis.

Three areas that flank the Gulf of Alaska contain Quaternary volcanoes: the eastern Aleutian Arc along the west side of the Cook Inlet (Augustine Volcano, Mount Iliamna, Redoubt Volcano, Mount Spurr, and Hayes Volcano), the Wrangell Mountains (Mounts Drum, Sanford, Wrangell, Blackburn, and Regal), and Mount Edgecumbe, the easternmost volcanic center, on Kruzof Island near Sitka (fig. 128).

With the exception of the enigmatic location of Mount Edgecumbe, most of the volcanoes that ring the Gulf of Alaska are located on the North American plate, approximately 100 km above the subducted Pacific plate. The eastern Aleutian Arc volcanoes have been the most active in the past 100 years (Simkin and others, 1981), although these pose little risk to exploration in the Gulf of Alaska Planning Area because of their great distance. Recent eruptions that affected populated areas include Mount Spurr (1953), Augustine Volcano (1976, 1986), and Redoubt Volcano (1966–1968, 1989–1990). The 1990 eruption of Redoubt Volcano produced

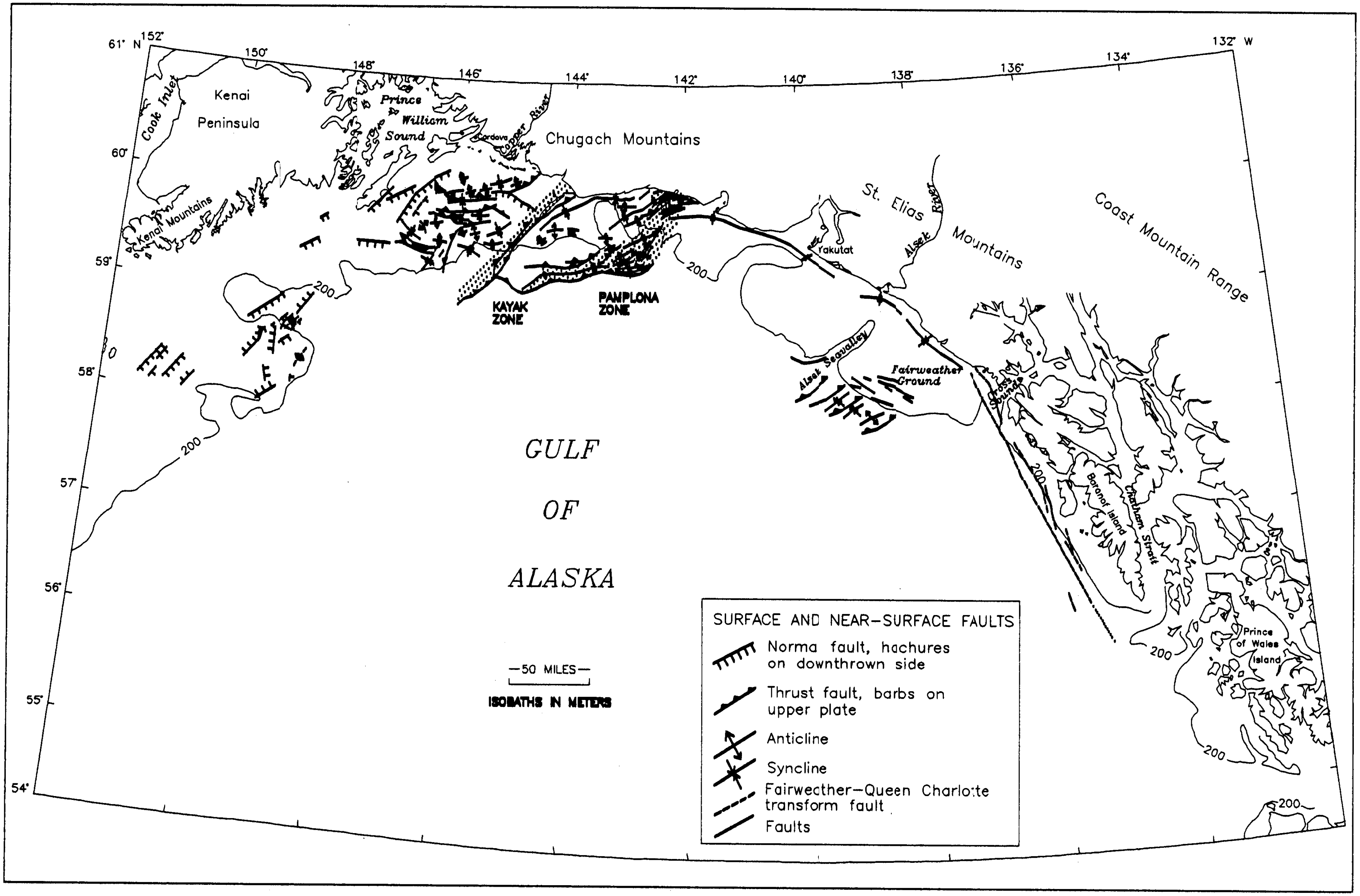

Figure 129. Faults and folds at or just beneath the seafloor (data from Carlson and others, 1985, and Hampton and others, cited in Hood and Zimmerman, 1986).

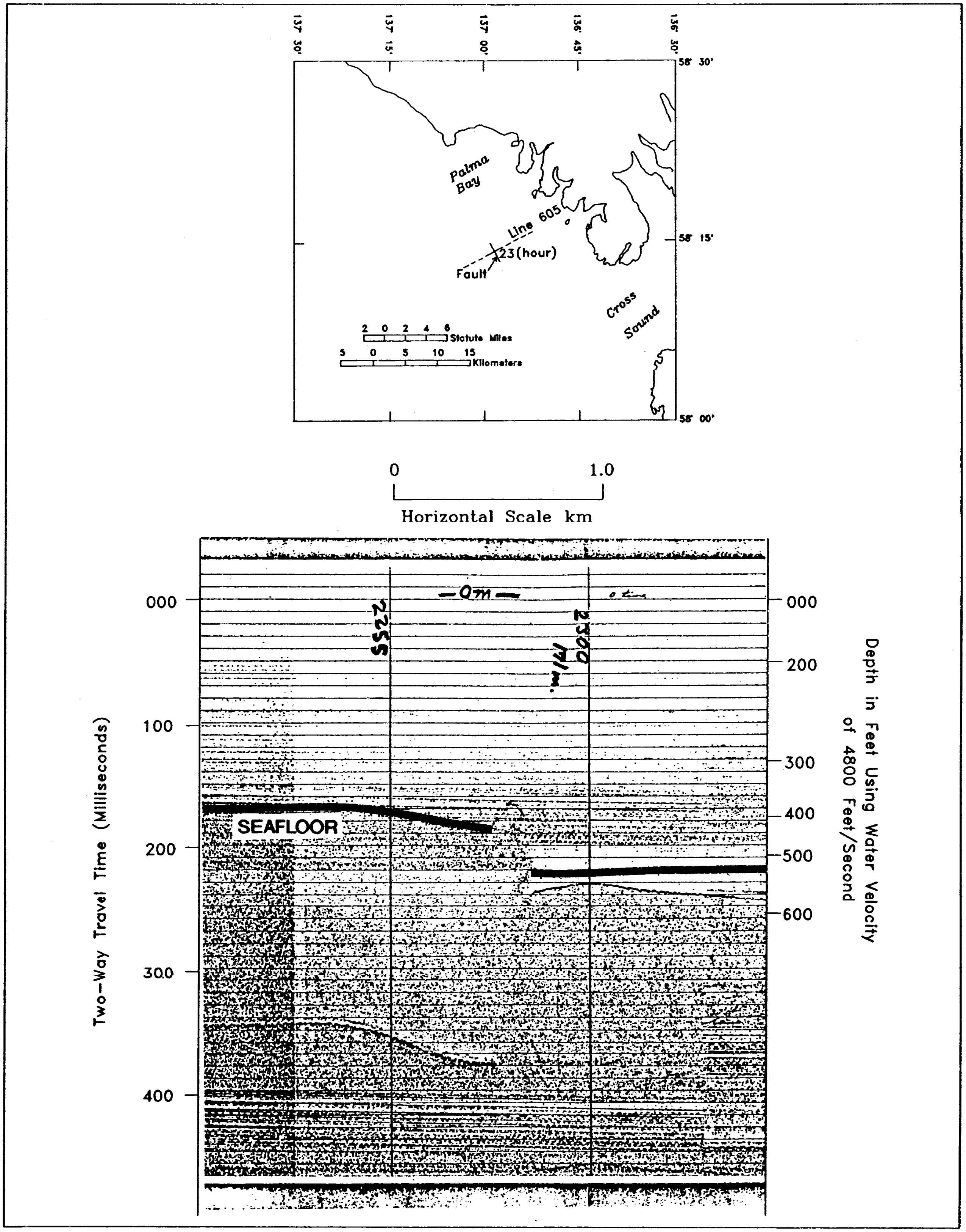

Figure 130. A uniboom seismic profile (USGS line number 605) showing vertical offset of approximately 100 feet across the Fairweather-Queen Charlotte fault scarp, south of Palma Bay (Carlson, 1976).

mudflows that threatened the Drift River oil terminal and temporarily curtailed oil production in Cook Inlet (Major and others, 1990). Volcanic ash from the 1989 eruptions of Redoubt Volcano disrupted airline traffic in and out of Anchorage, Alaska. The abrasive nature of the ash forced the shut-down of electronics equipment and was detrimental to the health and safety of the local population. Neither the volcanoes of the Wrangell Mountains or Mount Edgecumbe have erupted within the last 2,000 years although the possibility remains (Simkin and others, 1981).

Tsunamis and Seiches

Tsunamis are waves produced by the sudden displacement of a large volume of water by the rapid upward or downward movement of the ocean floor during a strong earthquake or during a volcanic eruption (Page and Basham, 1985). Tsunamis are not often hazardous to floating structures on the open sea, though they may be dangerous to structures grounded in underconsolidated sediments. Tsunamis can destabilize portions of the shelf by changing the thixotropic properties of sediment, a change which can result in subaqueous slumping and turbidity currents. Seiches are large waves generated in closed or semiconfined bays from subaqueous slumps and local subaerial landslides related to ground shaking during earthquakes. These locally generated waves are oftentimes a greater threat to shore-based facilities than tsunamis because they occur so suddenly with little warning.

Tsunamis are typically caused by dip-slip faulting and rarely, if ever, by strike-slip faulting (Bolt and others, 1977). Tsunamis were generated by low-angle thrusting beneath the continental shelf during the Great Alaskan Earthquake, but were barely noticeable following the 1949 Queen Charlotte earthquake, which had a strike-slip mechanism (Cox and Pararas-Carayannis, 1976).

The size and shape of the uplifted portion of the shelf controls the direction and magnitude of a tsunami. As the rupture length increases, the direction of the tsunami becomes more orthogonal to the source, and the waves are largest in the direction of movement (Berg and others, 1972). In the Great Alaskan Earthquake of 1964, the largest waves were transmitted perpendicular to the Aleutian megathrust (Steinbrugge, 1982). In the open ocean, tsunamis are of little concern because of their small wave heights. The distance between wave crests in the open ocean may be as much as 50 miles, with wave heights of less than 2 feet. As a tsunami approaches the shallower water of the coastline, however, the wave height increases manyfold because of the configuration of the coastline, shape of the ocean floor, and the tidal stage (Combellick and Long, 1983). Little damage will occur to the coastline if the waves are nonbreaking, low, and occur at low tide. Extensive damage will occur when high, breaking waves reach the shoreline at high tide.

In the 1964 Great Alaskan Earthquake, coastal communities were heavily damaged by tsunamis generated by vertical uplift of the outer continental shelf and by seiches generated by landslides in semiconfined bays and inlets (von Huene and Cox, 1972). Large landslide-generated waves in enclosed bays were more destructive than those that originated on the continental shelf (von Huene and Cox, 1972). Sheltered bodies of water bounded by high, steep slopes of unstable sediment or rock are most vulnerable to landslide-generated tsunamis (Combellick and Long, 1983). In the Great Alaskan Earthquake of 1964, landslide-generated waves caused great destruction and loss of life in the towns of Seward, Valdez, and Whittier (Spaeth and Berkman, 1967). Seismic shaking from the Lituya Bay earthquake (Mw 8.2) of 1958 caused an enormous landslide at the head of Lituya Bay that generated a seiche with a wave run-up of over 1,500 feet. This event caused the loss of life and deforested shoreline of Lituya Bay (Combellick and Long, 1983).


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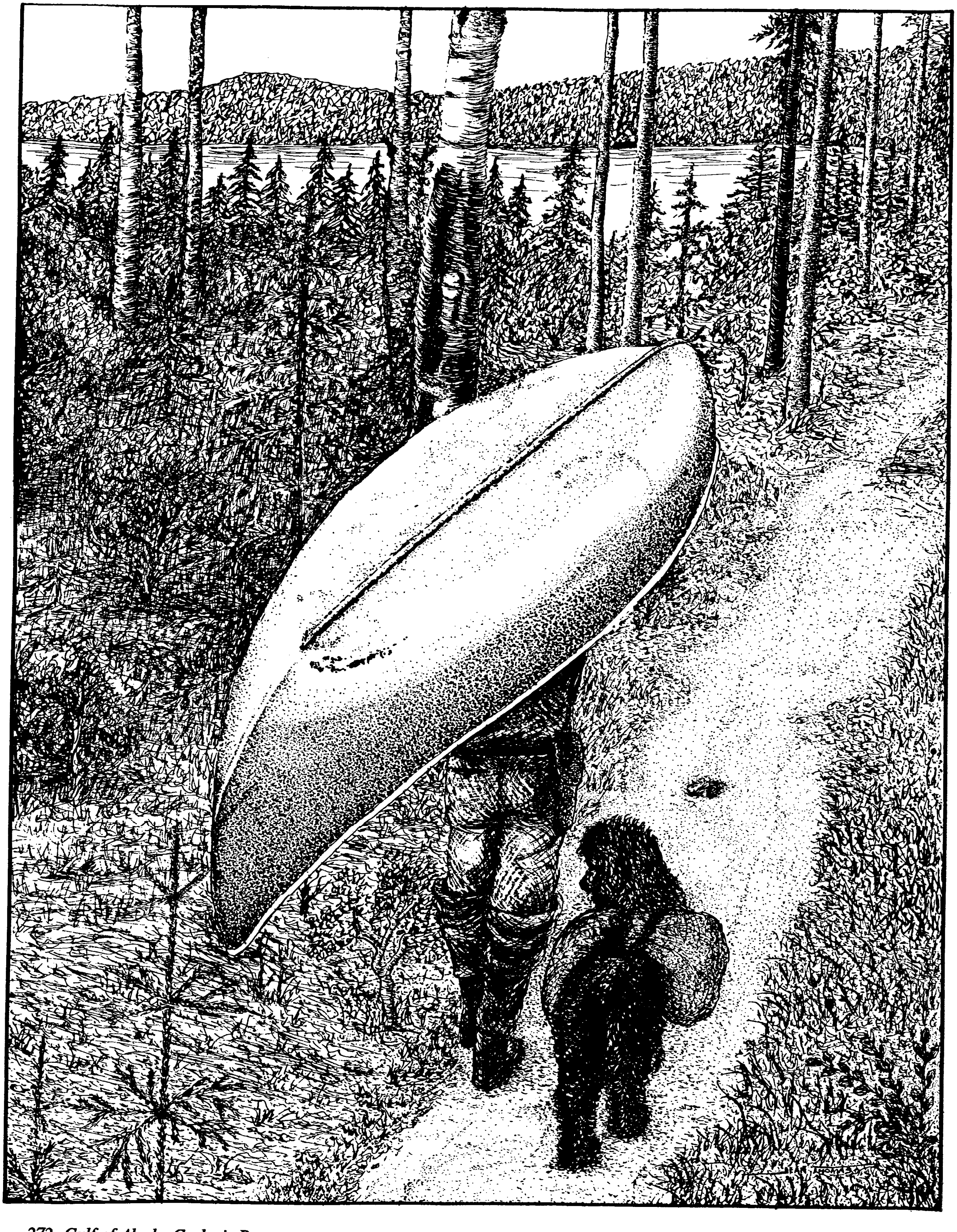

Summary

The Gulf of Alaska Tertiary Province is located in one of the most dynamic areas on earth. Active tectonism driven by plate collision and subduction results in great earthquakes, vulcanism, faulting, and rapid uplift. The maritime weather is some of the most severe known. Glaciation is active, with vast ice fields, numerous tidewater glaciers, and actively calving icebergs. It also boasts one of the highest sedimentation rates ever measured. Despite the difficulties associated with operating in this harsh frontier area, it has been the site of extensive logging, mining (gold, coal, and copper), fishing, and drilling efforts over the last century. Modern petroleum exploration began in 1896 on the north side of Controller Bay, and petroleum was produced from the Katalla field from 1901 to 1932. A total of 80 wells, onshore and offshore, were drilled in the Gulf of Alaska, the most recent in 1983. Geological investigations in the area are ongoing.

On the basis of onshore data, both public and proprietary, the most prospective source rocks for petroleum generation are the middle Miocene to late Eocene Poul Creek Formation and the late to early Eocene Kulthieth Formation and its equivalents (including the slightly older Oily Lake siltstone). The Miocene part of the Poul Creek Formation appears quite prospective, particularly onshore, where it is organically rich, characterized by Type I and II kerogen, and oil prone.

Offshore, the immature to marginally mature Poul Creek Formation has been disappointing, perhaps because the most prospective section has not been extensively sampled, although there are hints of its source rock potential, particularly in the OCS Y-0211 No. 1 and Y-0080 No. 1 wells. Poul Creek samples from well cuttings often contained a high proportion of inertinite (Type IV kerogen), which suggests a high input of recycled material and perhaps the oxidation of many of the in situ kerogens. Offshore, the Kulthieth Formation is also organically lean though more mature, and is characterized by Type III and IV kerogen. Both formations have been considered to be sources of the petroleum produced at the Katalla Oil Field. Very limited analytical data from offshore wells are inconclusive about this question, although industry, academic, and USGS workers generally consider the Poul Creek Formation to be the primary source both onshore and offshore. Chapter 10 advances an alternative hypothesis suggesting that the Kulthieth Formation is a more likely source.

Opposite. Collecting geological samples in the Kenai lowlands near Sterling, Alaska. This area has numerous Pleistocene bog deposits rich in pollen, spores, and fresh water diatoms. The field assistant, a standard poodle, carried more than half her weight in sediment samples.

The most prospective reservoir rocks offshore occur in the thick, widespread middle Miocene to Pleistocene Yakataga Formation, particularly the nonglacial marine sandstones in the lower part, which retain good porosity and permeability as deep as 11,000 feet. The late to early Eocene Kulthieth Formation has modest reservoir potential. The most prospective reservoir rocks in the Kulthieth Formation offshore occur near the top of the formation in the 1,100-foot sequence (with a net sandstone thickness of 760 feet) seen in the OCS Y-0211 No. 1 well. These well-sorted arkosic sandstones become tighter with depth due to diagenesis and probably have no reservoir potential below 12,000 feet.

Because of the extreme tectonism in this area, structural plays abound. The five major hydrocarbon plays presently recognized in the Gulf of Alaska (the Middleton fold and thrust belt play, the Yakataga fold and thrust belt play, the Yakutat shelf play, the subducting terrane play, and the Southeast Alaska subbasin play) are discussed in chapter 11. The presence of large structures offshore coupled with numerous oil and gas seeps onshore as well as historical production are auspicious signs despite recent disappointing exploration results. Industry interest in this area remains high. Sale 79, the State of Alaska's Cape Yakataga sale, is scheduled for May 1994. OCS Sale 158, the offshore Federal Yakutat sale, is scheduled for August 1995.

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THE KATALLA HERALD

KATALLA, THE COMING METROPOLIS OF ALASKA, WHERE THE RAILS MEET THE SAILS

VOL. 1. NO. 4. KATALLA, ALASKA, SATURDAY, AUGUST 31, 1907. PRICE TEN CENTS

An 800-Pound Nugget of Pure Copper Found In Kotsina

A BIG LEDGE OF COPPER ORE

A big ledge of copper ore and which apparently carries good values in gold as well, has been located on Copper river, about twelve miles from Katalla.

The discovery was made by B. T. Ulrich, Bob Morris and Frank Bradshaw a few days ago. They brought down samples of the ore taken from the ledge about two feet below the surface. Though very little work was done on the ledge it is estimated to be fifteen feet wide, from present indications. The ore is dull in color and copper glance can be plainly seen without the aid of a glass. It is almost a certainty, too, that it carries gold in good quantities.

No assay has as yet been made of the rock for the good and sufficient reason that Katalla is as yet without an assay office, and in passing, it may be remarked that there appears to be a good opening here for a man of that craft.

The ledge from which the ore was taken is on the side of a mountain and it can be easily worked, as it is but a short distance from the line of the Copper River & Northwestern railroad. Miners who examined the rock states that it would run 60 per cent. copper.

"Copper river is lined with float ore," said Mr. Ulrich, "and I verily believe that enough of it could be easily scraped up to keep a smelter busy for a long time. There's thousands of tons of it, and it looks as though it carries high values."

"There is any quantity of fine copper and gold quartz right in the immediate vicinity of Katalla," said Mr. Bradshaw. "The country adjacent has never been prospected, but when it is you can look out for many big discoveries of copper, gold and other ores. There is a great field right here for the prospector and miner."

RESCUE FOUR MEN FROM A BARGE

Capt. Dalby of the Katalla Company and Six Brave Men.

A heavy rain, accompanied by a northeast wind, set in Thursday evening and raged furiously all through the night. The glass in the windows of the Katalla Banking Association building, on Front street, was blown in by the force of the gale, and buildings exposed to its force were rocked like cradles. However, little damage was done.

Four men in the employ of the Katalla Company were left on a barge out in the roadstead last night, by some mistake, and they remained there until yesterday forenoon, when a [illegible] belonging to the Alaska Petroleum & Coal Company, was secured, and manned by Captain Dalby of the Katalla Company and a crew of six brave men. It went to the rescue of the marooned men, while many interested spectators watched its progress through the boiling surf. The boat reached the barge without mishap. [illegible]

BODY OF DEAD MAN FOUND ON BEACH

[illegible] Supposed to Have Jumped Overboard from Steamer Jeanie

The body of an unknown man was found Friday morning on [illegible] Point by John [illegible] Lovelle, who are employed by the Katalla Company. [illegible]

An inquest was held in the afternoon, the following jury being impaneled: E. [illegible], Henry Pinckney, William Compton, C. G. Herrmann, Tony Bushee and [illegible]. Colman and Lovelle [illegible] finding the body on the beach, and described its condition. Colman said that he thought he had seen the man at the Katalla Company's camp, and Lovelle thought he had met the man about a week ago and gave him four bits and bought him a drink. Neither of the men knew his name.

Coroner Britton and the jury then viewed the remains, and when court again convened Dr J. A. Payzant was called. Dr. Payzant testified that he had examined the body and found it that of a man between 40 and 50 years of age and well nourished. The body had been in the water from one to two weeks. It presented some abrasions and bruises, and the nose was fractured, all of which might have taken place after death, there having been nothing to show that the wounds were inflicted before death. The fracture of the nose might have been caused by the body beating against the rocks.

This closed the testimony, and the jury returned a verdict to the effect that the man's name was unknown to them and that he had met his death in a manner to the jury unknown.

It is surmised that the dead man may have committed suicide by jumping overboard from the steamer Jeanie during her recent stay in port.

SHOVEL USES LOCAL OIL

The big steam shovel, now in operation at Camp 2 of the Katalla Company, is using local crude oil as fuel, the shovel having been equipped for burning oil under the direction of Alfred White, the efficient superintendent of machinery for the company.

Drilling the rock on Martin Point is under way, and the trestles this side are being filled with the muck and dirt taken out by the steam shovel.

The shoo-fly track which is being built over Martin Point to Camp 7 has a 4 1-2 per cent. grade, but when completed will greatly facilitate the work of construction and handling supplies for points beyond.

WILSON TO BOX WILSON

Kid Wilson of Minneapolis, where he is known as the "Minneapolis Cyclone," and Curly Wilson of Seattle, will have a try-out this (Saturday) evening in Petersen & Lund's new hall, opposite P. J. Erussard Co.'s. The contest will be for ten rounds for a decision for points.

The contest is being pulled off under the auspices of the Katalla Athletic Club, which is under the management of C. L. Brockmiller and Jim Lewis. This is the first institution of the kind to be organized in Katalla, and its management propose to give a series of athletic events each week hereafter. Mr. Brockmiller is an old timer who has mushed from Dawson to Nome and from Nome to Katalla. Mr. Lewis is from Hot Springs, Ark. Both are well known in athletic circles.

The Wilsons will weigh in Saturday night at about 150 pounds, Curly being slightly the heavier. The latter recently won a purse of $400 in a boxing contest at Renton, Wash.

SEAL POACHERS FINED

Nine Japanese Mulcted in Sums Ranging From $200 to $500 Each.

The cases against the Japanese seal poachers were disposed of at the recent term of the district court at Valdez. The cases were segregated into two groups, according to Attorney R. J. Boryer, of the Katalla Company. The sealers were in two schooners. One had a boat out in which were three sealers, and this boat was captured within the three-mile limit. One green pelt and a dead seal were found in the craft. The three sealers were fined $500 each, and in the other case the captain of the crew was fined $500 and the six sealers $200 each. The cases against the others were dismissed.

Meet me at the Northern Cafe and have a square meal.

A remarkable trip through the heart of the Copper river country, lasting for nearly six months, has just been brought to a successful completion, and a vast fund of information concerning the immense copper deposits of that region has been acquired.

The men who made the long journey are Earl Hyde, J. M. Cavanaugh and Will Cavanaugh, the two former having reached Katalla Thursday by way of Copper river.

The party left Valdez March 1 last, with pack horses, going in by way of Thompson's Pass and the Tonsina, and making their main camp at the head of the Kotsina river.

They cruised the country pretty thoroughly, taking in Strelna, Kuskulana, Lakana and the Kennicott rivers as far as the Bonanza copper mines on the Kennicott.

Through the Kotsina country several companies are doing considerable work. Among these is the California-Alaska Mining & Development Company, which is doing extensive representation work on good-looking ground. The work is in charge of Lathrop and Gelineau, and is largely confined to doing assessment work, because of the large number of claims held by the company, and the distance of the claims from a base of supplies coupled with the shortness of the season.

This company has first-class copper showings, and an 800-pound copper nugget was taken out of a ledge. The nugget is nearly pure copper, but it shows some silver as well.

The Alaska-Kotsina Mining Company has cross-cut several true fissure veins on its properties and it has a good showing.

The Scotty Crawford outfit, in the same section, employed about 15 men during the summer and they have a number of good claims. A number of smaller concerns are also at work in that region.

The strongest company in that particular district is the Great Northern Development Co., a New York concern which is operating through the Chittina valley. Most of the work accomplished this summer was comprised in the establishment of camps, building bunk houses, getting out mining timbers etc.

Several camps have been placed on the Kotsina and tributaries, and the company is making preparations for driving tunnels and other extensive work on the Kotsina ore bodies. This company will also do extensive work on Iron mountain on the Chittina valley side, and directly opposite its Kotsina properties. It also has valuable holdings as far east as the Kennicott.

The Hubbard-Elliott company has a crew of engineers surveying a tramway for carrying ores to the Copper River railroad when it shall have reached that section. A force of men is also doing active development work at the mines.

On the Kuskulana Jas. McCarthy has done considerable work and he also has a great showing of bornite, or purple copper, on another creek, a second [illegible] enrichment on still another group. Mr. McCarthy has engineers in the field who are surveying for patents, and geologists from Philadelphia have also been examining the ground. There are several other small outfits on the Kuskulana, among them Mr. Garrison, who has been employing a small force and he has done considerable work. Deyo, the engineer, has also done considerable work on the Lakana, and Tom Lynch employed five men all summer and did good work and he has a fine showing.

On the Kennicott are several large outfits, including the Great Northern Development Co., the Valdez Exploration Co. (a branch of the Guggenheim exploration Co.) which has ground on Hidden creek, and which is employing a force doing development work on ground upon which the company has [illegible]. Work has been handicapped [illegible] inaccessibility of the country, goods having to be packed from the main camps on the Kotsina. The Great Northern company has employed 15 or 18 men all summer.

On the Bonanza group engineers are surveying tunnels, etc. for the extensive development of the mines.

The majority of the [illegible] occur in a contact between limestone and greenstone, and they lie in conformity with it. The contact can be followed as far as the hills can be seen. A secondary mineralization or enrichment follows.

James L. Galen who left Valdez at the same time as Mr. Hyde, with Will Cavanaugh, went over to the head of the Nabesna and White rivers, and S. R. Burch and Prof. Irwin went into the same country. The entire section is full of engineers, who are making as thorough examinations of the mineral zones as they can. Timber is scarce excepting in the river bottoms.

Manager Gray of the Great Northern Development company will employ 200 men all winter, if he can get them. He has put in a telephone line to connect with the government telegraph station at Tonsina. The distance is 40 miles, and the lines will be extended to Iron mountain and the rest of the company's camps this fall. There is plenty of sheep and game, and beef cattle were driven in during the summer.

Tom Larson, of Fairbanks has an outfit on the Tonsina, and considerable Alaska money is being invested in the Copper river country. A government survey party in charge of F. H. Moffatt have finished topographical and geological maps of the Kotsina and Kuskulana, and are now on the Lakana.

Snow is already falling on the mountains and winter is fast commencing.

On the trip out Messrs. Hyde and Cavanaugh came to the mouth of the Tonsina where they got a boat and came down the Copper river to Abercrombie Canyon, the trip down the river being a fine one.

Mr. Hyde is a well-known mining engineer and has been located in the Nome and Fairbanks districts for several years. Both he and Mr. Cavanaugh speak highly of the railroad route up the Copper river. A great deal of railroad work is under way on the lower river. At Abercrombie [illegible] they were most hospitably entertained by M. J. Sullivan, assistant superintendent of the Katalla Company.

KATALLA CO.'S BIG RESERVOIR

Work is progressing rapidly on the dam and reservoir for the Katalla Company, a short distance west of [illegible]. A substantial dam is being [illegible] and the reservoir will have [illegible] of 1,000,000 gallons. The water [illegible] from a never-failing mountain stream and it will be piped from the reservoir, through a 10-inch pipe, to the railroad yards. It will also be used for motive power for the company's big electric power plant.

For the Chemawa School.

A number of Katalla children left on the Portland for Chemawa, Or., where they will be placed in the school at that place. The children were: Dave White, son of Thos. G. White; Duncan Lawton, son of Pioneer Lawton; Bessie McGuire, daughter of Frank McGuire, and two children of Dan Durben. The school at Chemawa is an excellent one and is largely attended from all parts of the Pacific Coast.

Station Work at Camp 8.

J. T. Hamilton returned Wednesday from a point three miles above Camp 8 of the Katalla Company on Copper river. Station work is in progress near Camp 8, among the contractors being Messrs. Smith and Callaghan. E. F. Hooker is in charge of the commissary at the camp.

SEA DOGS AS KNOCKERS

The steamer Yucatan pulled out for the westward before she had finished [illegible] her cargo for this port, although it is claimed that she could have [illegible] the work in six hours had [illegible] captain restrained his impatience a little. The steamer returned Thursday afternoon and began discharging the balance of her cargo, but she was caught in the storm that sprung up during the night and was forced to run for the islands. The result was that the cargo is still on board.

"The steamers of the Northwestern Steamship company and the Alaska Coast company have a monopoly of the traffic of [illegible], but that is no reason why their captains should commence [illegible] this port and the people who live here, as soon as they round Cape St. Elias, or even long before. It is also to be suggested that when the good Lord fashioned this coast these gentlemen were not consulted."

Such were the preliminary remarks of a well known citizen, who has lived here for several years, and who knows whereof he speaks. Then he went on:

"I, for one, am getting tired of this unmerited abuse. Captain Moore of the Yucatan and Captain Omar J. Humphrey of the Portland are particularly obnoxious in this respect, and the others may be as bad for anything I know. These officers are paid their wages and I do not conceive it to be any part of their duties to fume and fuss, and decry this port constantly. But that is just what they do. Ask almost any passenger who happens to travel on these boats, and he will corroborate what I am saying.

"And yet these same steamship captains have been known to remain in Prince William sound for days at a time, afraid to poke their ships' noses out of it. But they seem to reserve their anathemas for Katalla. Instead of discharging their cargoes here when the weather is fine, they seem to be obsessed with the idea that if they discharge a few tons and hurry westward, that is all that should be expected of them. The net result is that merchants and others are put to great inconvenience and much loss. They cannot get their goods when they want them, and when they at last arrive much of the perishable freight, especially, is utterly ruined.

"A new system is needed. The people of this section are making it possible for these sea lords to come here, thereby getting employment in that way, and if it were not for the development of the region, these steamship companies would be seeking elsewhere for a less profitable field of operations.

"We do not ask much, but we do protest against the knocking and abuse of port and people by steamship officers who come to this part of Alaska."

ALASKA PACIFIC LOCATING LINE

The Alaska Pacific Railway & Terminal Company has several parties of surveyors in the field between Katalla and the Bering lake section. Resident Engineer F. W. Allen has charge of a party at Clear Creek, Engineer Hamilton is located between Clear Creek and the summit, and Engineer Smith is locating the line from the summit to and across Bering lake.

Engineer Lintner is at the head of a locating party of twenty men, five miles beyond Bering lake.

The different survey parties are making good progress and they are getting a good line, according to reports received this week.

The Alaska Pacific's work has been somewhat retarded of late by reason of a lack of timber. Superintendent Thomas Dwyer states that a large supply is expected from Puget Sound within a short time. The company is building a large stretch of trestles, and Mr. Dwyer states that the first mile alone will consume 2,000,000 feet of timber.

This company's line runs direct to the Bering coal fields and then swings around into the Copper river country.

The "Gentleman Jollier."

Fred A. Hartigan, the "gentleman jollier" of the Board of Trade, presents his friends and acquaintances a card, printed at The Herald office, carrying such legends as "Let's Get Acquainted." "Capital $15,000,000 (in my dreams)." "Ragtime Millionaire looking for someone to love." "Not Married and out for a good time." "Kind regards to friends and knockers."

SIXTY-FIVE MEN HAVE RETURNED

Sixty-five of the men who last week left Katalla for Valdez where they were promised steady employment and big wages to work on the electric tramway being built at that place, returned Thursday on the Yucatan and went to work for the Katalla Company. These men say that the Reynolds Company—the tramway promoters—can use but few men at present, and that the wages they offer are $2.50 per day, $1.00 being deducted for board.

VEIN OF COAL 30 FEET DEEP

A vein of coal 30 feet deep, and of unknown width, as yet, is said to have been struck on the property of the Anglo-American Coal & Oil Company in the Bering lake section. The coal, it is alleged, is of fine quality. Capt. Rathbone, manager of the company, who was in town this week, declined to confirm the report, but it has been verified from other sources. The Anglo-American Company is doing considerable work in the way of developing its coal and oil properties.

CORSER SAVED BY B. F. HILL

Cable Corser, resident engineer of the Katalla Company at Abercrombie Canyon, was saved from death by drowning in Copper river the other day by the presence of mind of B. F. Hill, his camp cook. Corser was in a boat and was going down Chinaman Charlie's slough. The slough is full of big boulders and the current is swift. The boat struck a rock and capsized, Corser being hurled against a rock, the impact rendering him insensible, but his hand still clutched an oar. He sank like a stone, then came to the surface and sank again. Men on the river bank stood dazed, but Hill, who happened along just then, took in the situation at a glance, jumped into the river, swam out thirty or forty feet, seized the oar in the insensible man's hand, and then swam back pulling Corser after him. He was pretty nearly gone, and it took a full half hour to revive him. The news of the accident was brought to town by Thos. G. White on Thursday.

Owl Cafe Sold.

Mrs. E. Brown has sold the well-known Owl Cafe to R. E. Ase and Fred Brentlinger, well and favorably known throughout the north. The Owl will be re-opened in a few days in the new Willoughby building on Front street, adjoining the Katalla Bar. Mrs. Brown, after a short visit to the States will return to this city.

A Landmark Gone.

Postmaster Williams' "easy chair"—the big stump that stood for ages past in front of the post-office—has made its final exit. It was pulled out yesterday under the direction of Charley Davis, with the postmaster, Cole Bush, Judge Potts, Dr. Payzant and Doc. Harwood [illegible] its dying hours.

Just arrived [illegible] boots and shoes, best quality at P. J. Erussard Co.

CUTTING THE RIGHT OF WAY

Six miles of the right-of-way of the Copper River & Northwestern road have been cut, 200 feet wide, below Abercrombie Canyon, according to Thos. G. White of the Katalla Company, who came down from the canyon Thursday. A good deal of grading has also been done, and a new camp has been put in above the canyon at the steamboat landing. Another new camp has been located on the east side of the river, below the canyon, and a wagon road is being cut from the crossing to Cottonwood Point. Supplies will then be hauled from Mile 17 to Mile 25, and hauled from thence by wagons.

Mr. White says that fish and game are plentiful and the salmon are excellent. He will return to the canyon with supplies, on the arrival of the Santa Clara, due to-day.

SUPPLIES FOR NABESNA

Where H. Bratnober Has a Copper Prospecting Party.

Thomas Lloyd Henry, a pioneer of Fairbanks, is in town from the Tenderfoot country, about 100 miles above Fairbanks. Mr. Henry arrived Thursday from Valdez to look over the coming metropolis of Alaska. He says that the Tenderfoot section is quiet and but little work is under way.

Steamer White Seal made a trip this summer to Tanana Crossing with supplies for Henry Bratnober's camp near the headwaters of the Nabesna, where Mr. Bratnober has had a prospecting party for the past two or three years, reports from which this year are unusually encouraging.

LOST LIFE ON RIVER

How John Davis Met His Death

BODY EATEN BY WOLVERINES THEN HE BEGINS TO KNOCK

The Horrible Story of Death in the Arctic Winter, As Told By Emil Shubeck, a Hunter and Trapper in the Copper River Country.

After spending thirteen months continuously in the Copper river basin, at Abercrombie canyon, Emil Shubeck, blond and burly, came into town this week none the worse for his long period of isolation.

Shubeck was formerly a guide for the survey parties of the Alaska Pacific Railway & Terminal company, later he became a hunter and trapper, and as such he has been employed for several months in the Copper river country.

In The Herald of August 10 was told a brief story of the finding of the bones of a man last February near a deserted cabin on Copper river. The dead man's name was given as Jones, but according to the statement made by Shubeck, who found what the wolverines had left of the body, the man was John Davis, an Australian of twenty years' residence, who went up to Childs Glacier in the employ of J. Stevens, of Valdez, who had located a homestead on the river. On Monday last Shubeck went to Judge Britton's office and formally notified him of his gruesome find.

According to Shubeck's story Davis came up to his (Shubeck's) camp near the rapids on Dec. 26 last year. The weather was cold and windy and Davis remained there eight days. Then he started down the river, despite Shubeck's advice to remain with him until the weather was better. This was the last seen of him alive.

On Feb. 26, last Shubeck left his cabin for Martin river. "At an abandoned railroad cabin he saw two guns standing beside the door, and a sack was tied to a pole, evidently as a signal, but he saw no sign of human footsteps or life. He called but got no answer. Shubeck then started back to his own cabin, and when about four miles from Childs' glacier, he saw a black spot on the ice of the river; he looked again and saw several smaller spots. "It looked me not good", said Emil in relating his pathetic story. So he went over to the place and found poor Davis' body. The legs, back and hands and arms and a part of the head had been eaten away by wolverines, while scattered about were Davis' fur cap, bits of clothing and a snowshoe. Carefully Shubeck gathered up the remnants of what once had been a man, and carried them tenderly to the river bank and buried them in the snow. And around them he set four traps to catch the wolverines, which he knew would come again, and satisfy their hunger and go away uncaught, unless traps were set for them, for the wolverine is a cautious animal and centuries of struggling for existance have taught him how he may often circumvent his foes. But these traps were not disturbed.

Shubeck then secured two bear traps and as these were new engines of destruction, to them, he succeeded in trapping five, the first of which, in his anger over the mutilation of his friend's dead body, he attempted to flay alive, but fortunately he did not completely succeed.

In March he again succeeded in gathering Davis' remains together and gave them decent burial on Stevens' ranch near Childs' glacier.

Davis' death, Shubeck says was due to the biting wind which he essayed to face but before whose stinging breath he fell on the ice-clad river, to rise no more.

[illegible] Twenty Rounds

[illegible] champion of the north- [illegible] G. W. Beckman, champion [illegible] "Terrible Dutchman" [illegible] rounds, for a [illegible] this [illegible] hall [illegible]. The contest [illegible] with [illegible] Queensberry rules [illegible]. The bout is being [illegible] under the auspices of the [illegible] Athletic club, C. L. Brockmiller promoter. The men each weigh about [illegible] pounds. Both have good records [illegible] the boxing [illegible] and while [illegible] said to be a scientific boxer, the [illegible] has the reputation of being [illegible] take any amount of punishment and still look pleasant. Brady was formerly a volunteer in the Cuban war and in [illegible] was stationed at Porto Rico.

ALASKA KNOCKERS

Scored by Major John E. Ballaine

Seattle-Seward Promoters Knock the Copper River & Northwestern Railway and Shake Guggenheim Bogey in Alaska Club, Seattle.

Seattle, Sept. 10. Major John E. Ballaine, promoter of the Alaska Central railroad and owner of the Seward townsite, threw a bomb in the midst of the Alaska club last night by denouncing what he said was a tendency of all Alaska to "knock" everybody and everything that the knocker was not directly interested in.

While his statement created a mild sort of excitement, nobody appeared to get real angry about it. In fact Major Ballaine was backed up in his statements by Henry D. Reynolds of the Reynolds Alaska Development company; Judge D. A. McKenzie and others.

According to Major Ballaine, Alaska is one splendid, unconcerted knock. Everybody helps to knock—in Alaska. He told of how the Alaska Central has for years been the victim of the anvil chorus, how Senator Nelson of Minnesota, said the railroad was a fake stock jobbing scheme because somebody in Valdez told him so. He said that every part of Alaska pounded every other part with its little hammer and that Seattle didn't stand by timidly and just listen. Seattle got in and knocked, too and materially assisted in swelling the chorus. Then Major Ballaine put in a little knock himself and said that the Guggenheim road in the Copper river country would give that country a tremendous setback for the reason that Guggenheim interests are identified with the American Smelter company and won't try to develop any property except their own.

A few of the oldtime Alaskans present apparently didn't know whether to get sore or not, but when Henry D. Reynolds got up and said that Ballaine had hit the mark kerplunk and that there was altogether too much of the anvil chorus, it seemed to be the unanimous opinion that everything was all right. The opinion was clinched when Judge McKenzie also concurred.

NO LACK OF PROVISIONS

Plenty of Foodstuffs For the Winter Landed at Yakataga

"There is plenty of food at Yakataga to last the people now there during the coming winter" said W. A. Eberly a well known mining man of that place who is now in town. On her last trip the Saratoga landed forty tons of provisions, and that quantity will be sufficient for all demands.

"Considerable gold is being mined on Yakataga beach, and I look some day for extensive mining developments in that section, and especially in the mountains back of Yakataga, from which source must have come the gold found in the beach."

Ladies' and Gents' Furnishing Goods—C. J. Dykes, Post Office B'ldg.

TUG BEN HUR ASHORE

Believed That Vessel Can Be Successfully Floated in a Short Time

An attempt made on Tuesday to float the tug Ben Hur, belonging to T. P. McDonald & Co., which went ashore about three weeks ago, ten miles this side of Yakataga, resulted in failure. Owing to a storm that arose the tug Corsair, which went down to pull off the Ben Hur, was forced to return to Katalla early Wednesday morning. The Corsair, however, returned to the beach in the afternoon, and it is believed that if the weather holds good she will experience little difficulty in getting the Ben Hur afloat.

The Ben Hur, which is fifty feet in length and equipped with a 40-horse-power gasoline engine, left Seattle under her own steam, and met little trouble until Yakataga was reached, when Capt. Johnson, mistaking the coast line, ran her too close, and she went ashore. The tug is [illegible]. She will be used to tow coal barges from the McDonald mine at Bering lake, if successfully floated.

BUILDING MATERIALS

Glass, sashes, doors, wall paper and paint at Kendrick's, Front street.

WAITING FOR THE SUPPLIES

FOR VALDEZ ELECTRIC TRAMWAY

People Are Beginning to Doubt Whether Reynolds' Railway Project Will Be of Much Use in Developing the Interior Country.

(Special Correspondence)

Valdez, Sept. 17—Pending the return of H. D. Reynolds the promoter of the Alaska Home railway, from Seattle, the excitement over his numerous capitalized enterprises in Valdez, has quieted down. Some work work is under way on the electric road, but it will not be in full swing until material and supplies are received, and these are expect- within a few days.

Now people are wondering what real benefit a narrow, light rail, electric railroad is going to be to the town. It is to be built only to the summit, distance of about thirty miles, and it is conceded that a railway of this kind can never be expected to reach the mines of the interior, or be an important factor in any way in their development or in the development of the immense Copper river valley.

The people of Valdez have unbounded faith in the future of their town; and it has a future as a supply point for a big contiguous territory along the coast but there are men who concede that with the building of railroads from Katalla to the Bering coal fields and the Copper river country, the business of great sections must, in the very nature of things, be from Katalla. They realize that this is a condition and not a a theory which confronts Valdez as a possible gateway to the Copper river country. And they realize only too well that a small electric railroad in a country such as it must penetrate in order to get anywhere, cannot be much of a developing factor.

SIMPLEX

New Emporium Building

The new emporium being built by P. J. Brussard, the well known merchant, is fast approaching completion, and will be finished and ready for occupancy the latter part of next week. The new building will be a decided addition to the business houses of Katalla.

Keep dry—C. J. Dykes has a full line of Slickers. Post Office B'ldg.

THE DIGGINGS OF YAKATAGA

SOME BIG NUGGETS ARE FOUND

Judge Thompson and Associates Lease Their Holdings, and the Judge and His Son Will Commence Practice of Law at Katalla.

The Yakataga beach diggings are producing considerable gold, according to a statement made by Judge Julius Thompson, who with Mrs. Thompson and Mrs. Arthur G. Thompson, arrived from Yakataga Sunday morning. With his son, Arthur G. Thompson, Judge Thompson has been engaged in placer mining at Yakataga for the past four years, where they have large holdings, now under lease to other parties.

Nuggets worth as much as $48 have been found in the beach sands, and just now the source of the gold deposits is attracting more attention than usual. And it is believed that rich deposits of placer and quartz gold will some day be found in the mountains and foothills beyond the coastal plains which skirt the beach in the Yakataga country.

Judge Thompson, who is an authority on mining as well as in law, believes that vast oil deposits will be developed in that section as well as in and around Katalla. He is an [illegible]astic believer in this part of [illegible], and for that reason he and his [illegible], with their families have decided [illegible] locate in Katalla and resume the practice of their profession.

Judge Thompson [illegible]ly from Colorado, where he [illegible] as one of the leaders of the [illegible] the Centennial State, and in [illegible] political history he also took [illegible] commanding part.

In 1900 he went to Nome and with his son soon had an extensive legal practice, engaging in mining at the same time, securing a number of claims on the since well-known Nome tundra but which then was not thought to contain the riches which it subsequently revealed. In 1903 he became interested in Yakataga.

The firm of Thompson & Thompson have opened an office on D street, adjoining the Herald office, and it goes without saying that they will command a full share of the legal business of this section.

Visit Katalla Drug Store; hear the music; over 200 selected records.

Appendix A

Appendix A is a listing of the foraminifera species identified from the offshore Gulf of Alaska wells analyzed in this report. The foraminifera of each biostratigraphic interval are listed. All of the planktonic foraminifera are listed for each interval, whereas benthic foraminifera are generally listed only in the interval of their highest occurrence. Repeated occurrences of significant and/or distinctive benthic species may be mentioned. The Biostratigraphy chapter discusses details of the distribution of species within biostratigraphic intervals for each well.

The Pliocene and Pleistocene foraminiferal assemblage was similar in all of the wells studied. The listings of foraminifera from the Plio-Pleistocene section of the OCS Y-0080 No. 1 well and from the Pliocene section of the OCS Y-0211 No. 1 well are the most complete and are recorded separately here to facilitate comparison with assemblages from the Plio-Pleistocene sections of the other wells discussed in the text.

Pleistocene

Late Pleistocene

OCS Y-0080 No. 1 well: Seafloor-4,560 feet
(no samples seafloor to 2,090 feet)

Benthic Foraminifera

Bolivina interjuncta
Bolivina spissa
Buccella frigida
Buccella sp. cf. *B. inusitata*
Buccella tenerrima
Bulimina sp. cf. *B. subacuminata*
Bulimina tenuata
Cassidulina californica
Cassidulina cushmani
Cassidulina delicata
Cassidulina islandica
Cassidulina limbata
Cassidulina lomitensis
Cassidulina minuta
Cassidulina norcrossi
Cassidulina reflexa
Cassidulina teretis
Cibicides fletcheri
Cibicides lobatulus
Cibicides sp. cf. *C. mckannai*
Cyclammina cancellata
Cyclammina sp. cf. *C. pacifica*
Dentalina baggi
Dentalina californica
Dentalina frobisherensis
Eggerella sp.
Elphidium bartletti
Elphidium clavatum
Elphidium frigidum
Elphidium sp. aff. *E. incertum*
Elphidiun incertum
Elphidiella arctica
Elphidiella groenlandica
Elphidiella oregonense
Elphidiella sibirica
Epistominella pacifica
Eponides subtener
Globobulimina pacifica
Gyroidina sp. cf. *G. soldanii*
Haplophragmoides spp.
Hyperammina sp.
Karreriella sp.
Lagena sulcata
Lenticulina sp. cf. *L. cultratus*
Martinottiella communis
Nonionella auricula
Nonionella labradorica
Protelphidium orbiculare
Quinqueloculina sp. cf. *Q. akneriana*
Quinqueloculina seminula
Trifarina fluens
Triloculina trihedra
Uvigerina sp. cf. *U. auberiana*
Uvigerina cushmani
Uvigerina juncea
Uvigerina peregrina
Valvulineria glabra

Planktonic Foraminifera

Globigerina bulloides
Globigerina quinqueloba
Globigerinoides conglobatus
Neogloboquadrina dutertrei
Neogloboquadrina pachyderma (sinistral)

Early Pleistocene

OCS Y-0080 No. 1 well: 4,560-6,210 feet

Benthic Foraminifera

Bulimina sp. cf. *B. exilis*
Bulimina mexicana
Cassidulina sp. cf. *C. laevigata carinata*
Cassidulina subglobosa
Cibicides sp. aff. *C. conoideus*
Elphidium sp. cf. *E. discoidale*
Gyroidina sp. cf. *G. condoni*
Melonis barleeanum
Melonis sp. cf. *M. zaandamae*
Nonion sp. cf. *N. incrassatus*
Nonionella basispinata
Nonionella fimbriata
Oolina sp. cf. *O. apliopleura*
Oolina melo
Planulina sp. cf. *P. alaskense*
Pseudoglandulina laevigata
Pullenia bulloides
Pullenia salisburyi
Trifarina hughesi

Planktonic Foraminifera

Globigerina bulloides
Globigerina quinqueloba
Globigerinoides conglobatus
Globorotalia humerosa humerosa
Globorotalia sp. cf. *G. pseudopima-Neogloboquadrina dutertrei*
Neogloboquadrina dutertrei
Neogloboquadrina pachyderma (10-20% dextral)

Pliocene

Late Pliocene

OCS Y-0080 No. 1 well: 6,210-8,400 feet

Benthic Foraminifera

Cassidulina sp. cf. *C. quadrata*
Cribrononion sp.
Cribrostomoides sp.
Cribroelphidium crassum
Elphidiella sp. cf. *E. arctica*
Elphidiella simplex
Epistominella sp. cf. *E. pulchella*
Epistominella smithi
Fissurina pelucida
Nonionella sp. cf. *N. stellata*
Pullenia malkinae
Quinqueloculina sp. cf. *Q. arctica*
Uvigerina sp. aff. *U. hootsi*

Planktonic Foraminifera

Globorotalia sp. cf. *G. pseudopima*
Neogloboquadrina sp. cf. *N. asanoi*
Neogloboquadrina pachyderma (sinistral)

OCS Y-0211 No. 1 well: 1,580-2,120 feet (no samples seafloor to 1,580 feet)

Benthic Foraminifera

Buccella frigida
Buccella inusitata
Buccella tenerrima
Cassidulina californica
Cassidulina cushmani
Cassidulina islandica
Cassidulina limbata
Cassidulina norcrossi
Cassidulina reflexa
Cassidulina subglobosa
Cassidulina teretis
Cassidulina transluscens
Cibicides fletcheri
Cibicides lobatulus
Cibicides mckannai
Dentalina baggi
Dentalina decepta
Dentalina frobisherensis
Elphidium bartletti
Elphidium clavatum
Elphidium frigidum
Elphidium hughesi
Elphidium incertum
Elphidiella sp. cf. *E. arctica*
Elphidiella oregonense
Epistominella sp. cf. *E. narai*
Fissurina lucida
Glandulina sp.
Karreriella baccata
Lagena sulcata
Lenticulina sp.
Lenticulina sp. cf. *L. occidentalis*
Marginulina sp. cf. *M. glabra*
Nonionella labradorica
Oolina costata
Oolina globosa
Polymorphina charlottenensis
Pyrgo lucernula
Pyrgo murrhina

Pyrgo rotalaria
Quinqueloculina akneriana
Quinqueloculina seminulum
Rotalia columbiensis
Trifarina angulosa
Trifarina fluens
Triloculina tricarinata
Triloculina trihedra
Uvigerina cushmani
Uvigerina juncea
Uvigerina peregrina

Planktonic Foraminifera
Globigerina bulloides
Globigerina quinqueloba
Neogloboquadrina dutertrei
Neogloboquadrina pachyderma (100% sinistral)

Early Pliocene

OCS Y-0080 No. 1 well: 8,400-8,470 feet

Planktonic Foraminifera
Neogloboquadrina pachyderma (dextral)

OCS Y-0211 No. 1 well: 2,120-4,805 feet

Benthic Foraminifera
Cassidulina sp. cf. *C. laevigata*
Cribroelphidium sp. cf. *C. paromaense*
Elphidiella groenlandica
Epistominella pacifica
Epistominella pulchella
Fissurina marginata
Glandulina laevigata
Haplophragmoides sp.
Lagena sp. cf. *L. striata*
Protelphidium orbiculare
Pullenia malkinae
Pullenia salisburyi
Quinqueloculina lamarckiana
Quinqueloculina sp. cf. *Q. oblonga*
Quinqueloculina sp. cf. *Q. subrotunda*
Trifarina sp. cf. *T. hughesi*
Trochammina sp. cf. *T. globigerinoides*
Uvigerina sp. cf. *U. hootsi*
Uvigerina sp. cf. *U.* subperegrina

Planktonic Foraminifera
Globigerinoides? sp. cf. *G. trilobus*
Globorotalia sp. cf. *G. acostaensis*
Neogloboquadrina pachyderma (25-100% dextral)
Neogloboquadrina pachyderma var. "*incompta*"

Pleistocene

Other Wells

Similar to the Plio-Pleistocene assemblage of the OCS Y-0080 No. 1 well and the Pliocene assemblage of the OCS Y-0211 No. 1 well, plus:

Late Pleistocene

Benthic Foraminifera
Astrononion gallowayi
Bolivina sp. cf. *B. beyrichi*
Buliminella elegantissima
Cassidulina nakamurai
Epistominella exigua
Frondicularia sp. cf. *F. gigas*
Lenticulina sp. cf. *L. strongi*
Polymorphina charlottensis
Rotalia columbiensis
Rotalia subcorpulenta
Rotalia umbonata teneris
Saidovella sp. cf. *S. okhotica*
Silicosigmoilina groenlandica
Trichohyalis ornatissima (small form)
Virgulina complanata

Planktonic Foraminifera
Globigerina bulloides
Globigerina quinqueloba
Globigerina woodi var.*
Globigerinita sp. cf. *G. naparimaensis*
Globigerinita sp. cf. *G. uvula*
Neogloboquadrina dutertrei
Neogloboquadrina pachyderma (sinistral)

Early Pleistocene

Benthic Foraminifera
Bolivina interjuncta
Bolivina sp. aff. *B. numerosa*
Bolivina spissa

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* reworked

Bolivina subadvena
Bolivinita sp.
Buccella subperuviana
Bulimina exilis
Cibicides (*Planularia*) *wuellerstorfi*
Cyclammina cancellata
Dentalina sp. cf. *D. decepta*
Elphidiella groenlandica
Eponides sp. cf. *E. tener*
Lenticulina sp. cf. *L. occidentalis*
Nonion sp. cf. *N. goudkoffi*
Nonionella sp. cf. *N. auricula*
Nonionella basispinatum
Rosalina ornatissima
Rotalia columbiensis
Silicosigmoilina groenlandica
Trichohyalis bartletti
Trichohyalis ornatissima
Trifarina sp. cf. *T. baggi*
Triloculina tricarinata
Uvigerina cushmani
Uvigerina hispidocostata
Uvigerina yabei
Valvulineria auracana

Planktonic Foraminifera

Globigerina bulloides
Globigerina sp. cf. *G. parabulloides*
Globigerina quadrilatera
Globigerinita glutinata
Globigerinita humilis
Globigerinita uvula
Globigerinoides sp. cf. *G. conglobatus*
Globigerinoides trilobus
Globorotalia sp.
Globorotalia sp. cf. *G. puncticulata**
Neogloboquadrina pachyderma (increased percent dextral)

Pliocene

Other Wells

Similar to the Plio-Pleistocene assemblage of the OCS Y-0080 No. 1 well and the Pliocene assemblage of the OCS Y-0211 No. 1 well, plus:

Late Pliocene

Benthic Foraminifera

Astacolus sp.
Buccella sp. aff. *B. mansfieldi*
Bulimina sp. cf. *B. subacuminata*
Cassidulina sp. cf. *C. limbata*
Cassidulina minuta
Cassidulina nakamurai
Cassidulina sp. cf. *C. translucens*
Cibicides conoideus
Cibicides sp. aff. *C. perlucidus*
Cibicides sp. cf. *C. refulgens*
Elphidiella arctica
Elphidiella sp. aff. *E. simplex*
Elphidium sp. cf. *E. bartletti*
Elphidium discoidale
Elphidium sp. cf. *E. discoidale*
Elphidium frigidum
Epistominella pulchella
Glandulina laevigata
Globobulimina auriculata
Guttulina sp.
Haplophragmoides deformes
Haplophragmoides sp. cf. *H. trullisata*
Melonis sp. cf. *M. pacifica*
Nonionella auricula
Nonionella basispinatum
Nonionella digitata
Nonionella sp. cf. *N. miocenica*
Planularia sp.
Plectina sp.
Protelphidium orbiculare
Protelphidium sp. aff. *P. orbiculare*
Pyrgo vespertilio
Quinqueloculina agglutinata
Quinqueloculina sp.
Quinqueloculina sp. cf. *Q. stalkeri*
Rotalia columbiensis
Sigmomorphina sp.
Sigmomorphina sp. cf. *S. fenestrata*
Uvigerina hootsi
Uvigerina yabei

Planktonic Foraminifera

Globigerina bulloides
Globigerinita uvula
Globigerinoides trilobus

* reworked

Globorotalia sp. cf. *G. acostaensis*
Globorotalia sp. cf. *G. crassaformis*
Globorotalia sp. cf. *G. inflata*
Globorotalia sp. cf. *G. pseudopima*
Globorotalia sp. cf. *G. puncticulata*
Neogloboquadrina pachyderma (sinistral)

Early Pliocene

Benthic Foraminifera
Anomalina sp. cf. *A. californiensis*
Bulimina subacuminata
Cribrostomoides veleronis
Cyclammina pusilla
Dentalina ittai
Dentalina pauperata
Elphidium sp. cf. *E. poeyanum*
Haplophragmoides trullissata
Lenticulina sp. cf. *L. simplex*
Martinottiella communis
Nonion sp. aff. *N. goudkoffi*
Nonionella miocenica stella
Oolina lineata
Oolina squamata
Oolina striatopunctata
Polymorphina charlottensis
Pullenia sp. cf. *P. salisburyi*
Sphaeroidina sp. cf. *S. variabilis*
Uvigerina auberiana
Uvigerina excellens
Uvigerina hootsi
Uvigerina peregrina

Planktonic Foraminifera
Globigerina bulloides
Globigerina quinqueloba
Globigerina sp. cf. *G. venezuelana*
Globigerinita glutinata
Globigerinita sp. cf. *G. naparimaensis*
Globigerinita uvula
Globigerinoides sp. cf. *G. conglobatus*
Globorotalia spp.
Globorotalia sp. cf. *G. crassaformis ronda*
Globorotalia sp. cf. *G. inflata*
Globorotalia pseudopima
Neogloboquadrina dutertrei
Neogloboquadrina pachyderma (increased percent dextral)

* reworked

Miocene

<u>All Wells</u>

Late Miocene

Benthic Foraminifera
Alveolophragmium sp.
Alveolophragmium rotundidorsata
Alveovalvulina sp.
Alveovalvulinella sp.
Anomalina sp. cf. *A. californiensis*
Anomalina glabrata
Anomalina sp. cf. *A. glabrata*
Anomalina sp. cf. *A. salinasensis*
Arenoturrispirillina? sp.
Asterigerina crassiformis
Bathysiphon spp.
Bathysiphon arenacea
Budashaevella sp.
Bulimina sp. cf. *B. alligata*
Bulimina sp. cf. *B. inflata*
Bulimina subacuminata
Bulimina sp. cf. *B. subcalva*
Cassidulina sp. cf. *C. crassa*
Cassidulina sp. cf. *C. laticamerata*
Cassidulina pulchella
Cassidulina subglobosa
Chilostomella sp. cf. *C. cylindroides*
Cibicides sp.
Cibicides sp. cf. *C. conoideus*
Cibicides sp. cf. *C. elmaensis*
Cibicides sp. cf. *C. perlucidus*
*C. spiropunctatis**
Conicospirillina sp.
Cornuspira byramensis
Cribroelphidium sp. cf. *C. crassum*
Cribrostomoides spp.
Cyclammina spp.
Cyclammina cancellata
Cyclammina incisa
Cyclammina pacifica
Dorothia sp.
Elphidium sp. aff. *E. californicum*
Elphidium sp. cf. *E. minutum*
Epistominella pacifica
Epistominella parva
Epistominella sp. cf. *E. peruviana*

Epistominella pulchella
Eponides sp. cf. *E. healdi*
Eponides sp. aff. *E. subtener*
Gaudryina sp.
Gyroidina sp. cf. *G. condoni*
Gyroidina soldanii
Gyroidina soldanii altiformis
Haplophragmoides trullisata
Haplophragmoides spp.
Lagena strumosa
Lenticulina inornata
Lenticulina sp. cf. *L. strongi*
Liebusella sp.
Marginulina sp. cf. *M. adunca**
Marginulina sp. cf. *M. subbullata*
Martinottiella sp.
Melonis barleeanum
Melonis communis
Melonis sp. cf. *M. pacificum*
Melonis pompilioides
Nodogenerina sp. aff. *N. sanctaecrucis*
Nodosaria sp. cf. *N. longiscata*
Nonionella sp. cf. *N. costiferum*
Oolina globosa
Oolina melo
Oridorsalis umbonatus
*Plectofrondicularia packardi**
Pullenia malkinae
Pullenia miocenica
Quinqueloculina sp. cf. *Q. goodspeedi**
Quinqueloculina sp. cf. *Q. weaveri*
Reophax sp.
Rhabdammina sp.
Rotalia sp. cf. *R. garveyensis*
Spirosigmoilinella sp. cf. *S. compressa*
Trochammina sp.
Trochammina globigeriniformis
Uvigerina auberiana
Uvigerina sp. cf. *U. cushmani*
Uvigerina sp. cf. *U. gallowayi*
Uvigerina sp. cf. *U. hannai*
Uvigerina sp. cf. *U. hootsi*
Uvigerina sp. cf. *U. obesa*
Uvigerina peregrina hispidocostata
Valvulineria sp. cf. *V. auracana*
Virgulina sp.

Planktonic Foraminifera

Globigerina bulloides
Globigerina sp. cf. *G. juanai*
Globigerina sp. cf. *G. pseudopima*
Globigerina venezuelana
Globigerinita sp. cf. *G. naparimaensis*
Globigerinoides sp. aff. *G. conglobatus*
Globorotalia acostaensis
Globorotalia sp. cf. *G. conoidea*
Globorotalia sp. cf. *G. continuosa**
Globorotalia sp. cf. *G. crassaformis ronda*
Globorotalia sp. cf. *G. humerosa*
Globorotalia sp. cf. *G. opima*?
Globorotalia pseudopima
Globorotalia sp. cf. *G. sphericomiozea*
Neogloboquadrina pachyderma (sinistral)
Orbulina universa

Middle to late Miocene

Benthic Foraminifera

Cassidulina laevigata carinata
Cornuspira byramensis
Fissurina marginata
Liebusella sp.
Pullenia bulloides
Pullenia salisburyi
Quinqueloculina sp. cf. *Q. lamarckiana*
Spiroplectammina sp. aff. *S. directa*
Uvigerina sp. cf. *U. cushmani*

Planktonic Foraminifera

Globigerina bulloides
Globigerina sp. cf. *G. venezuelana*
Globigerinita uvula
Globigerinoides sp. aff. *G. bolli*
Globigerinoides sp. cf. *G. trilobus*
Globorotalia sp. aff. *G. conica*
Globorotalia sp. cf. *G. conoidea*
Globorotalia sp. aff. *G. continuosa*
Globorotalia sp. cf. *G. scitula*
Orbulina universa

Middle Miocene

Benthic Foraminifera

Anomalina sp. cf. *A. californiensis*
Anomalina glabrata
Anomalina sp. cf. *A. salinasensis*

* reworked

Bulimina sp. cf. *B. alsatica*
Bulimina ovata
Bulimina subcalva
Cassidulina sp. cf. *C. crassaformis*
Cassidulina sp. cf. *C. laevigata*
Cibicides perlucidus
Dentalina sp. cf. *D. pauperata*
Dorothia sp. cf. *D. bulletta*
Eponides sp. cf. *E. subtener*
Globobulimina pacifica
Hoeglundina elegans
Karreriella sp. cf. *K. baccata*
Lagena laevis
Liebusella sp.
Nonion goudkoffi
Plectina sp.
Pseudoglandulina inflata
Sigmoilina sp.
Sphaeroidina variabilis
Spirosigmoilinella sp. cf. *S. compressa*
Triloculina tricarinata
Uvigerina sp. cf. *U. cushmani*
Uvigerina sp. cf. *U. hispida*
Uvigerina sp. cf. *U. modeloensis*
Uvigerina senticosa
Uvigerina senticosa adiposa

Planktonic Foraminifera

Globigerina bulloides
Globigerina sp. cf. *G. nepenthes*
Globigerina quadrilobatus triloba
Globigerina sp. cf. *G. venezuelana*
Globigerina sp. cf. *G. woodi*
Globigerinita sp. aff. *G. uvula*
Globigerinoides sp. cf. *G. bolli*
Globigerinoides sp. cf. *G. trilobus*
Globoquadrina dehiscens
Globorotalia sp. cf. *G. conica*
Globorotalia conoidea
Globorotalia sp. aff. *G. conoidea*
Globorotalia sp. cf. *G. continuosa*
Globorotalia sp. cf. *G. lata*
Globorotalia sp. cf. *G. mayeri*
Globorotalia sp. cf. *G. obesa*
Orbulina suturalis
Orbulina universa

Early to Middle Miocene

Benthic Foraminifera

Anomalina glabrata
Bulimina inflata alligata
Cassidulina sp. cf. *C. crassa*
Cassidulina crassipunctata
Cyclammina sp. cf. *C. pacifica*
Glandulina laevigata
Martinottiella communis
Melonis zaandamae
Oridorsalis umbonatus
Psammosphaera sp.
Siphogenerina sp. cf. *S. branneri*
Sphaeroidina bulloides
Uvigerina sp. cf. *U. peregrina*

Planktonic Foraminifera

Globorotalia pseudokugleri

Possible Early Miocene

Benthic Foraminifera

Bulimina sp.
Cassidulina laevigata carinata
Cassidulina margareta
Cassidulina pulchella
Epistominella parva
Nodosaria? sp.
Siphogenerina sp. aff. *S. kleinpelli*
Sphaeroidina sp.
Textularia? sp.
Uvigerina montesanensis

Oligocene

Benthic Foraminifera

Allomorphina macrostoma
Anomalina californiensis
Anomalina sp. cf. *A. loweryi*
Bathysiphon sp. cf. *B. eocenica*
Bathysiphon sp. cf. *B. sanctaecrucis*
Bathysiphon eocenica
Biloculina sp. aff. *B. cowlitzensis*
Buccella mansfieldi oregonensis
Bulimina alligata
Bulimina blakeleyensis
Bulimina ovata
Bulimina sp. cf. *B. ovata*
Bulimina pupoides
Bulimina pyrula
Buliminella subfusiformis
Cassidulina sp. cf. *C. californica*
Cassidulina crassipunctata
Cassidulina galvinensis
Cassidulina kernensis
Cassidulina margareta

Cassidulina modeloensis
Ceratobulimina washburnensis
Cibicides elmaensis
Cibicides hodgei
Cibicides pseudoungerianus
Cornuspira byramensis
Cyclammina clarki
Cyclammina sp. cf. *C. clarki*
Cyclammina incisa
Cyclammina pacifica
Cyclammina pacifica obesa
Dentalina spp.
Dentalina communis
Dentalina consorbina
Discammina eocenica
Eggerella sp.
Eggerella elongata
Ellipsonodosaria sp. aff. *E. cocoaensis*
Elphidium sp. cf. *E. californicum*
Elphidium sp. cf. *E. clavatum*
Elphidium minutum
Epistomina eocenica
Epistomina sp. cf. *E. ramonensis*
Epistominella parva
Eponides gaviotaensis
Eponides sp. cf. *E. healdi*
Eponides minimus
Gaudryina sp.
Gaudryina alazanensis
Glandulina sp. cf. *G. laevigata*
Globobulimina sp.
Globobulimina sp. cf. *G. hannai*
Globocassidulina globosa
Guttulina franki
Guttulina irregularis
Gyroidina condoni
Gyroidina orbicularis
Gyroidina orbicularis planata
Gyroidina soldanii
Haplophragmoides deflata
Haplophragmoides obliquicamerata
Haplophragmoides trullissata
Hyperammina elongata
Karreriella washingtonensis
Lagena strumosa
Lagena sp. cf. *L. substriata*
Lagena vulgaris
Lenticulina becki
Lenticulina sp. aff. *L. budensis*
Lenticulina sp. cf. *L. chehalensis*
Lenticulina crassa
Lenticulina inornata
Lenticulina limbosa hockleyensis
Lenticulina miocenica
Lenticulina nickobarensis
Lenticulina sp. cf. *L. texanus*
Lenticulina sp. aff. *L. welchi*
Martinottiella eocenica
Melonis pompilioides
Nodosaria sp.
Nonionella longiscata
Nonionella sanctaecrucis
Nonion blakeleyensis
Nonion sp. aff. *N. californiensis*
Nonion incisum
Nonion sp. cf. *N. planatum*
Oridorsalis umbonatus
Plectina garzaensis
Plectofrondicularia? sp.
Praeglobobulimina pupoides
Pseudoglandulina inflata
Pseudoglandulina nallpeensis
Pseudopolymorphina sp.
Pullenia eocenica
Pullenia multilobata
Pullenia sp. cf. *P. quinqueloba*
Pyrgo cowlitzensis (large)
Pyrgo lupheri
Quinqueloculina goodspeedi
Quinqueloculina imperialis
Quinqueloculina imperialis porterensis
Quinqueloculina weaveri
Rhabdammina eocenica
Sigmoilina tenuis
Sigmomorphina schenki
Sigmomorphina sp. aff. *S. schenki*
Sigmomorphina undulata
Siphonodosaria sp. (fragments)
Sphaeroidina variabilis
Textularia sp. cf. *T. adalta*
Trochammina globigeriniformis
Trochammina parva
Uvigerina sp. cf. *U. carmeloensis*
Uvigerina sp. cf. *U. cocoaensis*
Uvigerina garzaensis
Uvigerinella obesa impolita
Vaginulinopsis saundersi
Valvulineria menloensis
Verneuilina? sp.
Verneuilina sp. aff. *V. compressa*

Planktonic Foraminifera

Globigerina sp.

Globigerina sp. cf. *G. bulloides*
Globigerina sp. cf. *G. sellii*

Late Oligocene

Benthic Foraminifera

Adercotryma sp.
Anomalina glabrata
Buccella mansfieldi oregonensis
Buccella sp. cf. *B. parkerae*
Bulimina ovata
Cassidulina sp. cf. *C. crassipunctata*
Cassidulina galvinensis
Cassidulina sp. cf. *C. modeloensis*
Cibicides sp. aff. *C. elmaensis*
Cibicides floridanus
Cibicides sp. cf. *C. mckannai*
Cibicides sp. cf. *C. perlucida*
Cribroelphidium sp. cf. *C. vulgare*
Cyclammina pacifica
Elphidiella sp. cf. *E. californica*
Globobulimina pacifica
Glomospirella sp.
Gyroidina sp. cf. *G. condoni*
Gyroidina orbicularis planata
Gyroidina soldanii
Haplophragmoides obliquecamerata
Haplophragmoides trullissata
Melonis pompilioides
Oridorsalis sp. cf. O. umbonatus
Quinqueloculina sp. cf. *Q. imperialis*
Quinqueloculina sp. cf. *Q. weaveri*

Planktonic Foraminifera

Globigerina praebulloides
Globigerina sp. cf. *G. euapertura*
Globigerina sp. cf. *G. venezuelana*

Early Oligocene

Benthic Foraminifera

Ellipsonodosaria sp.
Guttulina sp.
Lenticulina sp.
Marginulina? sp.
Pseudoglandulina sp. cf. *P. laevigata*
Sphaeroidina variabilis
Trochammina sp. cf. *T. globigeriniformis*
Uvigerina sp. cf. *U. subperegrina*
Valvulineria sp.

Planktonic Foraminifera

Globigerina sp.
Globigerina sp. cf. *G. bulloides*

Late Eocene to early Oligocene

Benthic Foraminifera

Alabamina sp.
Alabamina sp. cf. *A. kernensis*
Alabamina sp. cf. *A. wilcoxensis*
Ammodiscus sp.
Asterigerina crassiformis
Bathysiphon sp.
Cassidulina sp. cf. *C. galvinensis*
Cibicides spiropunctatus
Cyclammina spp.
Cyclammina pacifica
Discorbis sp.
Eggerella sp.
Eggerella elongata
Ellipsonodosaria sp. cf. *E. cocoaensis*
Epistomina eocenica
Eponides sp. cf. *E. frizzelli*
Eponides gaviotaensis
Globobulimina sp.
Guttulina sp. cf. *G. hantkeni*
Gyroidina orbicularis
Gyroidina orbicularis planata
Haplophragmoides sp.
Karreriella sp.
Lagena sp.
Lagena sp. cf. *L. costata*
Lenticulina sp. cf. *L. inornata*
Lenticulina sp. cf. *L. weaveri*
Martinottiella sp. (fragment)
Melonis pompilioides
Oridorsalis umbonatus
Orthomorphina? sp.
Plectofrondicularia? sp.
Praeglobobulimina pupoides
Rhabdammina sp. cf. *R. eocenica*
Sigmomorphina schenki
Spiroplectammina directa
Spiroplectammina sp. cf. *S. tejonensis*
Uvigerina atwilli
Uvigerina churchi
Uvigerina cocoaensis
Uvigerina sp. cf. *U. jacksonensis*
Uvigerina sp. cf. *U. yazooensis*
Valvulineria sp. cf. *V. tumeyensis*

Planktonic Foraminifera
Globigerina sp. cf. *G. bulloides*

Eocene

Late Eocene

Benthic Foraminifera
Alabamina sp. cf. *A. kernensis*
Allomorphina sp.
Allomorphina sp. cf. *A. macrostoma*
Ammodiscus incertus
Ammodiscus sp. cf. *A. macilentus*
Ammodiscus sp. cf. *A. turbinatus*
Anomalina californiensis
Anomalina sp. cf. *A. danvillensis*
Bathysiphon spp.
Bathysiphon sp. cf. *B. eocenica*
Biloculina sp.
Bulimina corrugata
Bulimina sp. cf. *B. ovata*
Bulimina sp. cf. *B. pupoides*
Cassidulina crassipunctata
Cassidulina galvinensis
Cassidulina modeloensis
Ceratobulimina washburni
Cibicides elmaensis
Cibicides sp. cf. *C. martinezensis*
Cibicides perlucidus
Cibicides pseudoungerianus
Cornuspira byramensis
Cribrostomoides sp.
Cyclammina cancellata
Cyclammina cancellata obesa
Cyclammina clarki
Cyclammina incisa
Cyclammina pacifica
Dentalina communis
Discammina? sp.
Ellipsonodosaria sp. cf. *E. cocoaensis*
Epistomina eocenica
Epistomina sp. cf. *E. ramonensis*
Eponides sp.
Eponides kleinpelli
Eponides sp. cf. *E. minuta*
Globobulimina pacifica
Glomospira charoides corona
Gyroidina sp.
Haplophragmoides sp.
Karreriella? sp.
Karreriella chapatoensis
Karreriella monumentensis
Lenticulina spp.
Lenticulina alato-limbata
Lenticulina convergens
Lenticulina inornata
Lenticulina weaveri
Melonis sp. cf. *M. umbonatus*
Osangularia tenuicarinata
Plectofrondicularia sp.
Pseudoglandulina sp.
Pullenia sp. cf. *P. bulloides*
Pullenia sp. cf. *P. eocenica*
Quinqueloculina imperialis
Saracenaria sp.
Sigmoilina tenuis
Sigmomorphina schenckii
Siphogenerina sp. aff. *S. smithi*
Sphaeroidina variabilis
Spiroplectammina? sp.
Spiroplectammina directa
Spiroplectammina texana
Textularia sp.
Trochamminoides sp.
Uvigerina sp. (costate)
Uvigerina atwilli
Uvigerina sp. cf. *U. churchi*
Uvigerina cocoaensiss
Uvigerina sp. cf. *U. gallowayi*
Uvigerina sp. cf. *U. gardneri*
Uvigerina vicksburgensis
Vaginulina sp.
Vaginulinopsis? sp. (fragment)
Vaginulinopsis sp. cf. *V. saundersi*
Valvulineria sp.
Valvulineria sp. cf. *V. childsi*
Valvulineria willapaensis
Verneuilina? sp.

Planktonic Foraminifera
Catapsydrax dissimilis
Catapsydrax unicavus
Globigerina sp. (crushed)
Globigerina angiporoides
Globigerina sp. cf. *G. eocenica*
Globigerina linaperta
Globigerina praebulloides
Globigerina utilisindex
Globigerinatheka semiinvoluta
Globorotalia insolita
Globorotalia opima nana
Globorotaloides carcoselleensis

Middle Eocene

Benthic Foraminifera

Allomorphina sp. cf. *A. macrostoma*
Boldia hodgei
Bolivina sp. cf. *B. scabrata*
Budashaevella sp. cf. *B. multicostata*
Bulimina sp. cf. *B. ampla*
Bulimina sp. cf. *B. corrugata*
Bulimina sp. cf. *B. instabilis*
Bulimina sp. cf. *B. lirata*
Bulimina sp. cf. *B. microcostata*
Bulimina ovata
Bulimina sp. cf. *B. pyrula*
Cassidulina sp. aff. *C. globosa*
Ceratobulimina sp. cf. *C. washburni*
Chilostomella sp. cf. *C. cylindroides*
Chilostomella ovoides
Cibicides sp. cf. *C. fortunatus*
Cibicides sp. aff. *C. spiropunctatus*
Dorothia sp. cf. *D. bulletta*
Eponides mexicanus
Globobulimina pacifica
Globobulimina pacifica oregonensis
Glomospira? sp.
Lenticulina chirana
Lenticulina sp. cf. *L. inornata*
Lenticulina insueta
Lenticulina sp. cf. *L. vortex*
Lenticulina sp. cf. *L. welchi*
Plectofrondicularia sp. cf. *P. jenkensi*
Pleurostomella sp. cf. *P. paleocenica*
Polymorphina sp. cf. *P. ovata*
Reophax sp.
Reticulophragmium (*Alveolophragmium*) sp. cf. *R. amplectens*
Sigmoilina sp.
Spiroplectammina sp.
Textularia sp.
Tritaxilina sp. aff. *T. zealandica*
Trochammina sp.
Uvigerina sp.
Uvigerina sp. cf. *U. churchi*
Uvigerina sp. cf. *U. garzaensis*
Uvigerina sp. cf. *U. yazooensis*
Uvigerinella sp. cf. *U. obesa impolita*
Valvulineria sp.
Valvulineria sp. cf. *V. tumeyensis*
Virgulina sp.

Planktonic Foraminifera

Globigerina eocaena
Globigerina tripartita
"*Turborotalia*" sp. cf. *T. wilsoni*

Late early to early middle Eocene

Benthic Foraminifera

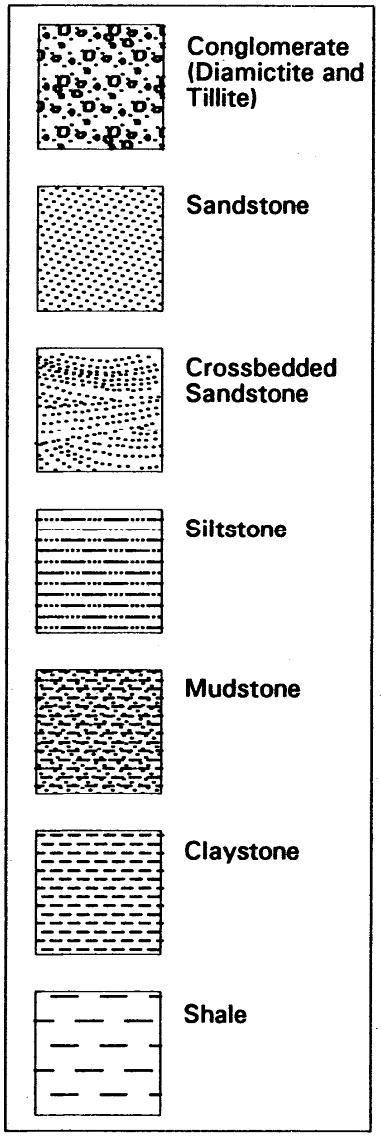
Alveolophragmium sp.
Amphimorphina sp. aff. *A. californica*
Anomalina sp. aff. *A. packardi*
Anomalina sp. aff. *A. tennesseensis*
Anomalina? sp. cf. *A. umbonata*
Bulimina sp. cf. *B. guayabilensis*
Bulimina sp. cf. *B. macilenta*
Cibicides sp. cf. *C. howelli*
Cibicides pseudoungerianus lisbonensis
Cibicides (*Cibicidoides*) sp. cf. *C. subspiratus*
Cibicides (*Cibicidoides*) sp. cf. *C. tuxpamensis*
Cibicides sp. cf. *C. venezuelensis*
Clavulinoides californicus
Cyclammina clarki
Cyclammina incisa
Cyclammina sp. cf. *C. pacifica*
Cyclammina samanica
Dentalina sp. cf. *D. catenula*
Dentalina sp. cf. *D. delicatula*
Dentalina sp. cf. *D. jacksonensis*
Dentalina sp. cf. *D. oolinata*
Dorothia sp. cf. *D. oxycona*
Dorothia sp. cf. *D. trochoides*
Eggerella sp.
Ellipsoglandulina sp. cf. *E. subobesa*
Eponides sp. aff. *E. dorfi*
Eponides sp. cf. *E . ellisorae*
Gaudryina sp. cf. *G. laevigata*
Gaudryina sp. cf. *G. pyramidata*
Gavelinella sp.
Gonatosphaera? sp.
Gonatosphaera eocenica
Gyroidina sp. cf. *G. florealis*
Gyroidina orbicularis
Karreriella sp.
Lagena sp. cf. *L. vulgaris*
Lenticulina sp. cf. *L. alato-limbata*
Lenticulina sp. cf. *L. arcuato-striata*
Lenticulina sp. cf. *L. coaledensis*
Lenticulina sp. cf. *L. insueta*
Lenticulina sp. cf. *L. limbosa*
Lenticulina sp. cf. *L. pseudocultrata*
Lenticulina sp. cf. *L. pseudovortex*
Lenticulina sp. cf. *L. theta*
Nodosaria deliciae
Nodosaria sp. aff. *N. latejugata*

Nodosarella constricta
Nonion? sp. cf. *N. micrum*
Oridorsalis umbonatus
Osangularia sp. cf. *O. culter*
Osangularia sp. cf. *O. tenuicarinata*
Ramulifera? sp. cf. *R. globulifera*
Rotorbinella? sp. cf. *R. collicula*
Tritaxillina sp.
Uvigerina sp. cf. *U. rippensis*
Vaginulinopsis mexicana kerni
Vaginulinopsis mexicana nudicostata
Vaginulinopsis mexicana vacavillensis
Vaginulinopsis verruculosa
Valvulina sp.
Valvulineria sp. aff. *V. cooperensis*

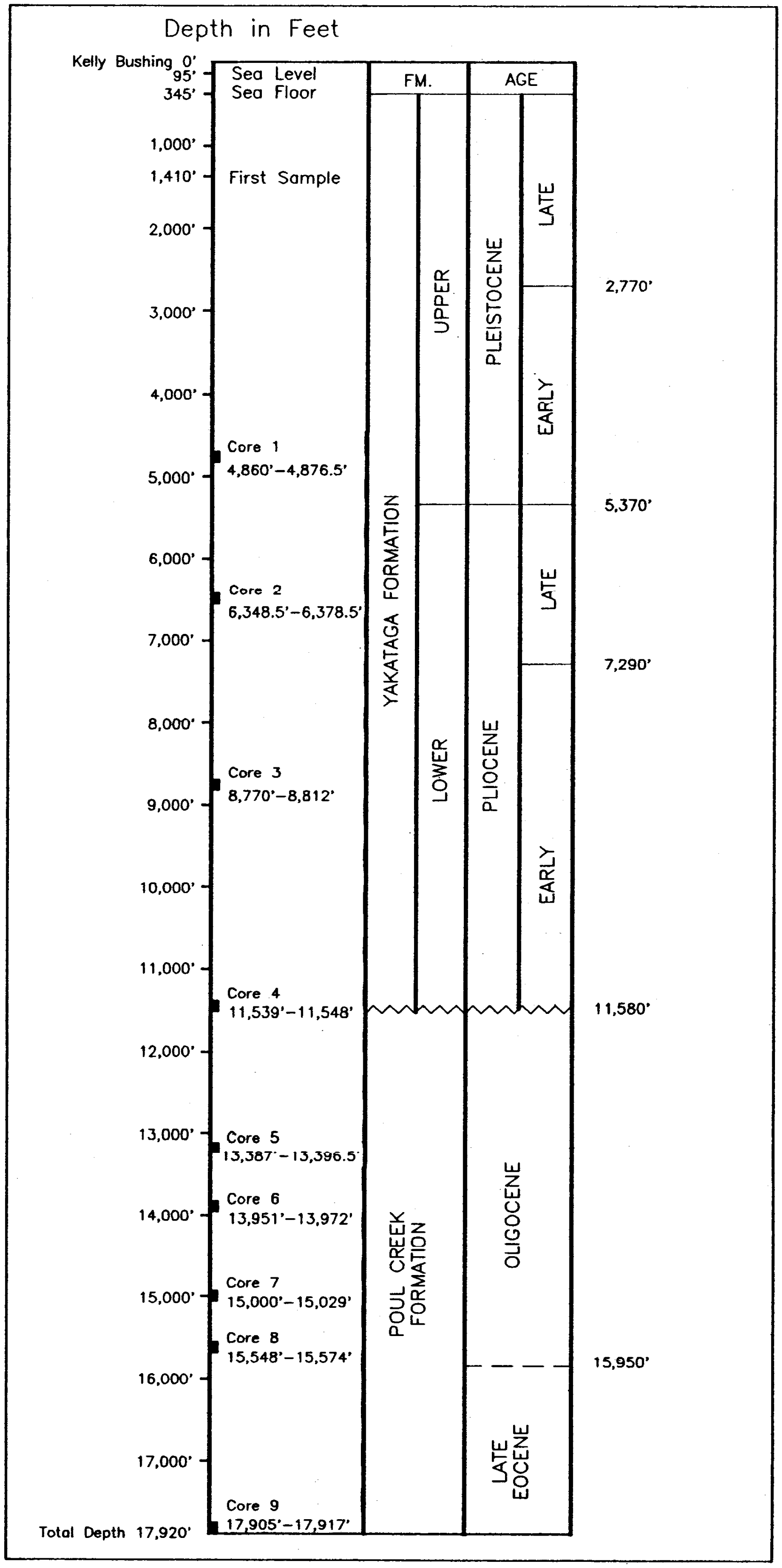
Planktonic Foraminifera

Acarinina broedermani
Acarinina bulbrooki
Acarinina sp. cf. *A. pentacamerata*
Acarinina primitiva
Acarinina sp. cf. *A. spinuloinflata*
Globigerina sp. cf. *G. boweri*
Globigerina sp. cf. *G. cryptomphala*
Globigerina hagni
Globigerina sp. cf. *G. inaequispira*
Morozovella sp. cf. *M. aragonensis*
Planorotalites pseudoscitula
Pseudohastigerina wilcoxensis
Truncorotaloides topilensis
Turborotalia cerroazulensis
Turborotalia cerroazulensis frontosa
Turborotalia griffinae

Appendix B



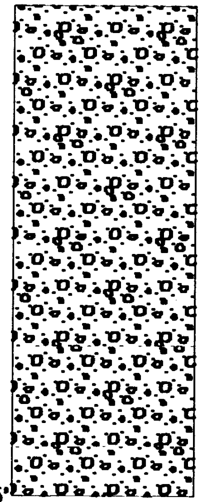
Above. Explanation of symbols used for rock types.



Right. Conventional core locations in the ARCO OCS Y-0007 No. 1 well. Depths are measured from the Kelly bushing, which was 95 feet above sea level. Water depth is 250 feet.

Depth
(Feet)

4,860'
4,865'
4,870'
4,876.5'

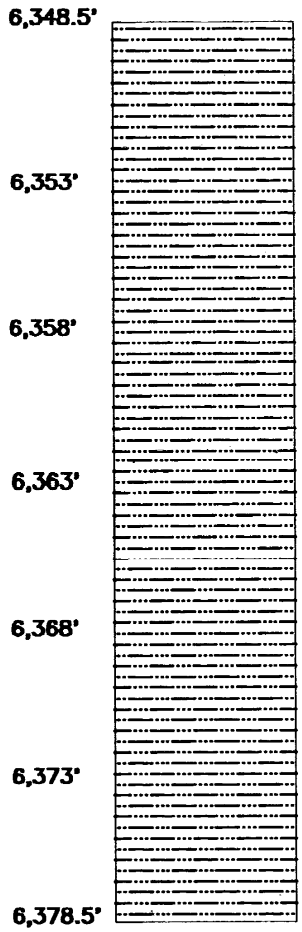


Core 1 consists of medium-gray, matrix-supported conglomerate with a silty, fine- to coarse-grained sandstone matrix containing rounded and subangular pebbles of black siltstone, gray and white volcanic rock fragments, and chert. The largest pebble seen is a lenticular sandstone 1.5 centimeters in length. There are numerous clear to cloudy, angular to subangular, coarse quartz grains about 0.5 millimeter in size "floating" in the finer grained matrix. The igneous rock fragments consist of quartz, feldspar, mica, and hornblende. Rare mollusc shell fragments, glauconite grains, and bronze-colored mica flakes are present. Rare micro-slickensides are also present. There is some calcite cementation.

This core is from the upper Yakataga Formation and is early Pleistocene in age. The environment of deposition was middle to outer neritic.

Conventional core 1. No porosity, permeability, or grain density data were available for this core.

Depth
(Feet)



Core 2 consists of medium-gray, micaceous siltstone. A few calcareous foraminifera and mollusc shell fragments are present as well as rare flakes of bronze-colored mica and thin streaks of small pyrite framboids. Calcite cement is present in most of the siltstone. At 6,360.2 feet, calcite-coated, nearly horizontal micro-slickensides are present as well as faint, horizontal streaks of dark carbonaceous material.

This core is from the lower Yakataga Formation and is late Pliocene in age. The environment of deposition was outer neritic to upper bathyal.

Conventional core 2. No porosity, permeability, or grain density data were available for this core.

Depth (Feet)

8,770'

8,775'

8,780'

8,785'

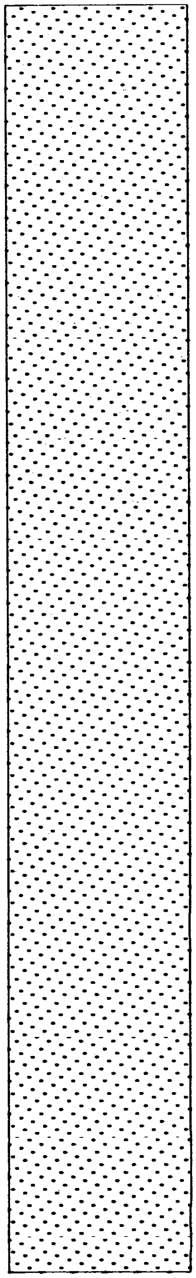
8,790'

8,795'

8,800'

8,805'

8,812'



Porosity	Permeability	Grain Density
19.4	365	2.87
18.3	205	2.72
18.0	211	2.74
18.7	358	2.71
16.5	250	2.70
18.2	271	2.70
20.0	356	2.71
18.9	238	3.69
19.2	345	2.71
18.3	310	2.72
19.0	204	2.70
22.8	388	2.69
20.2	283	2.70
19.7	228	2.71
19.8	479	2.70
19.9	355	2.69
19.8	332	2.70
20.4	295	2.72
20.1	317	2.71
19.9	342	2.70
20.2	411	2.72
19.7	229	2.71
19.4	195	2.72
18.8	288	2.72
18.7	154	2.70
15.4	103	2.72
17.6	223	2.71
19.2	310	2.71
20.5	304	2.70
19.8	285	2.70
19.0	167	2.71
18.4	201	2.69
12.2	48	2.70
18.7	64	2.72
18.9	235	2.71
19.5	279	2.70
19.2	246	2.71
20.3	148	2.71
23.0	344	2.71
20.9	359	2.57
21.7	229	2.69
26.6	129	2.69
24.2	254	2.71

Core 3 consists mainly of medium-grained gray sandstone containing a few rounded pebbles of black siltstone, chert, and plutonic rocks up to 8 millimeters in diameter. The sandstone is made up of angular, clear and cloudy quartz grains and contains rare euhedral rose-colored garnet, green and gray chert grains, rare bronze-colored mica flakes, rare coal, and a minor amount of silt. At 8,789 feet, there is a horizontal layer of fine-grained, gray sandstone about 1 centimeter thick. The sandstone represented by this core has good reservoir rock characteristics.

This core is from the Yakataga Formation and is early Pliocene in age. The environment of deposition was upper bathyal.

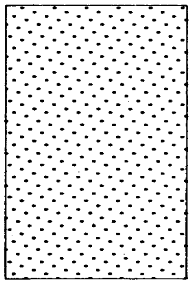
Conventional core 3. Porosity (in percent), permeability (in millidarcies), and grain density (gm/cm^3) data from Core Laboratories reports.

Depth (Feet)

11,539'

11,544'

11,548'



Porosity	Permeability	Grain Density
1.2	0.1	2.73
1.0	0.0	2.69
1.9	0.1	2.76
9.3	0.5	2.68
9.2	0.4	2.70
9.0	0.2	2.67
7.3	0.1	2.67
6.7	0.4	2.67
9.3	0.4	2.69

Core 4 consists of gray, medium- and fine-grained sandstone. The grains are angular and subangular quartz, feldspar, and ferromagnesian minerals. Rare coal and mica are present. There is some calcite cement and slickensides with sparry calcite surfaces. A gastropod shell 12 millimeters long is present at 11,539 feet.

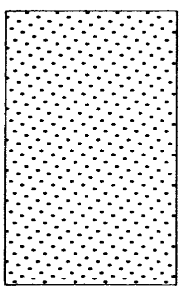
This core is from the lower Yakataga Formation and is early Pliocene in age. The environment of deposition was upper bathyal.

Depth (Feet)

13,387'

13,392'

13,396.5'



Porosity	Permeability	Grain Density
1.2	0.1	2.73
1.0	0.0	2.69
1.9	0.1	2.76
9.3	0.5	2.68
9.2	0.4	2.70
9.0	0.2	2.67
7.3	0.1	2.67
6.7	0.4	2.67
9.3	0.4	2.69

Core 5 consists of light-gray, silty, micaceous, fine- and very fine-grained "salt and pepper" sandstone: the black materials are coal, mica, and ferromagnesian minerals; the light-colored minerals are quartz and feldspar. Faint horizontal bands of dark-colored organic materials are visible at 13,387 feet. The samples taken from 13,391.5, 13,393.5, and 13,395.5 feet contain vertical, gray and white bands up to 1 millimeter in width. A few slickensides are present. The sample at 13,394 feet contains a 5-millimeter-long piece of coal associated with pyrite blebs.

This core is from the Poul Creek Formation and is Oligocene in age. The environment of deposition was middle bathyal.

Conventional cores 4 (top) and 5 (bottom). Porosity (in percent), permeability (in millidarcies), and grain density (gm/cm^3) from Core Laboratories reports.

Depth
(Feet)

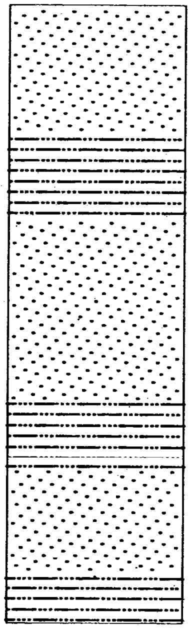
13,951'

13,956'

13,961'

13,966'

13,972'



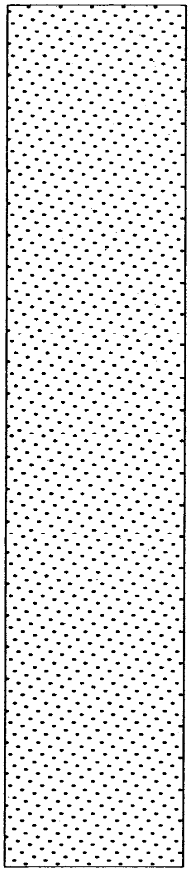
Porosity	Permeability	Grain Density
7.5	0.0	2.69
2.1	0.8	2.74
3.5	0.0	2.72
2.4	0.0	2.74
8.2	0.0	2.71
7.7	0.0	2.70
8.6	0.1	2.70
8.1	0.0	2.70
5.4	0.0	2.69
13.8	0.1	2.73
16.8	0.3	2.73
14.7	0.1	2.71
18.8	0.5	2.72
19.1	0.3	2.71
17.6	0.5	2.72
17.8	0.4	2.72
18.6	0.3	2.72
7.2	0.1	2.71

Core 6 consists of medium-gray, massive, coaly, clayey, micaceous, well-indurated, very fine-grained sandstone and siltstone. Pyrite aggregates up to 2 millimeters in diameter are present. Rare mollusc shells are present, usually associated with pyrite and organic fragments. At 13,963.5 feet, there is a piece of coal 5 millimeters long. The sample from 13,969 feet displays vertical laminations up to 1 millimeter thick composed of light- and medium-gray siltstone.

This core is from the Poul Creek Formation and is Oligocene in age. The environment of deposition was middle bathyal.

Conventional core 6. Porosity (in percent), permeability (in millidarcies), and grain density (gm/cm^3) from Core Laboratories reports.

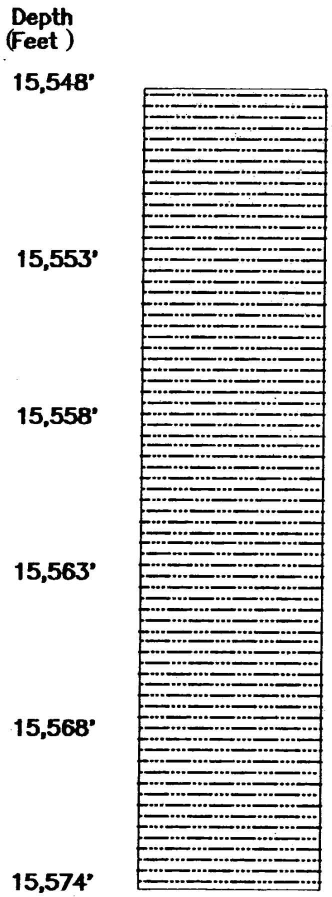
Depth (Feet)	Porosity	Permeability	Grain Density
15,000'	12.3	0.1	2.68
	12.8	0.2	2.69
	11.8	0.0	2.69
	12.7	0.1	2.68
	12.8	0.1	2.69
15,005'	11.7	0.0	2.68
	12.5	0.0	2.68
	11.7	0.1	2.68
	12.2	4.6	2.68
15,010'	12.0	0.1	2.67
	11.7	0.1	2.68
	11.5	0.1	2.67
	12.4	0.1	2.68
	11.7	0.1	2.68
15,015'	11.5	0.1	2.58
	12.7	0.1	2.67
	13.1	0.1	2.68
	12.0	0.1	2.68
	11.9	0.1	2.68
15,020'	12.0	0.1	2.67
	12.4	0.0	2.58
	9.6	0.0	2.69
	14.5	0.2	2.69
	11.7	0.1	2.70
15,025'	15.9	0.3	2.70
	17.4	0.4	2.71
	5.2	0.0	2.68
	1.9	0.0	2.67
15,029'	9.4	0.1	2.67



Core 7 consists of medium-gray, well-indurated, silty, massive, micaceous, moderately coaly, very fine-grained quartz sandstone. Pyrite is rare, usually associated with coal fragments. Rare mollusc shell fragments and foraminifera are present as well as rare flakes of biotite, muscovite, and phlogopite.

This core is from the Poul Creek Formation and is Oligocene in age. The environment of deposition was middle bathyal.

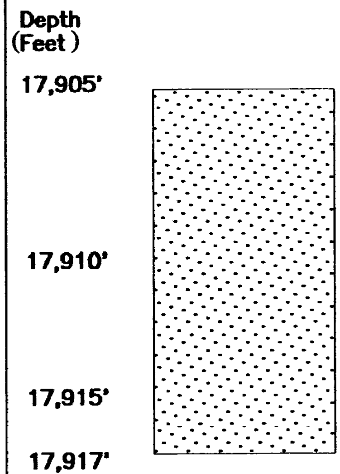
Conventional core 7. Porosity (in percent), permeability (in millidarcies), and grain density (gm/cm^3) from Core Laboratories reports.



Core 8 consists of medium-gray, well-indurated, micaceous, clayey, carbonaceous siltstone. Rare molluscan fragments, foraminifera, and streaks of pyrite are present. The sample from 15,558 feet contains a bivalve 8 millimeters long. The sample from 15,554 feet exhibits faint, darker gray color banding inclined about 15 degrees from the horizontal. The sample from 15,555 feet contains a burrow, 15 millimeters in diameter, filled with slightly darker siltstone. All of the samples below 15,562 feet exhibit slickensides, some with calcite coating on the surfaces.

This core is from the Poul Creek Formation and is Oligocene in age. The environment of deposition was middle bathyal.

Conventional core 8. No porosity, permeability, or grain density data were available for this core.



Core 9 consists of medium-gray, silty, carbonaceous, micaceous, fine- and very fine-grained sandstone. Rare pyrite blebs are associated with finely disseminated organic material. There are randomly oriented burrows up to 14 millimeters in length filled with slightly darker siltstone. The sample from 17,915 feet displays carbonaceous and micaceous laminae up to 2 millimeters thick.

This core is from the Poul Creek Formation and is late Eocene in age. The environment of deposition was middle bathyal.

Conventional core 9. No porosity, permeability, or grain density data were available for this core.

OCS Y-0007 No. 1 well sidewall core data (modified from Core Laboratories reports)				
Depth (feet)	Porosity (percent)	Permeability (millidarcies)	Grain Density (gm/cm^3)	Lithologic Description
1,756	23.0	354	2.81	clayey sandy conglomerate
1,757	18.2	35	2.78	medium- and fine-grained clayey sandstone
2,034	25.0	153	2.72	fine- and very fine-grained sandstone
2,076	11.0	2.6	2.77	sandy conglomerate
2,079	28.5	137	2.74	fine- and very fine-grained sandstone
2,097	22.4	96	2.75	medium- and fine-grained sandstone
2,126	21.4	2.9	2.73	fine- and very fine-grained sandstone
2,170	25.8	13	2.72	fine- and very fine-grained sandstone
2,190	27.7	160	2.73	fine- and very fine-grained sandstone
2,194	21.7	122	2.70	fine- and very fine-grained sandstone
2,227	14.9	6.3	2.77	medium- and fine-grained pebbly sandstone
2,415	18.8	8.5	2.78	fine- and very fine-grained sandstone
2,418	22.5	8.8	2.77	very fine-grained sandstone
2,564	17.8	10	2.72	very fine-grained silty clayey sandstone
2,570	21.3	19	2.76	very fine-grained silty sandstone
2,852	26.4	48	2.73	medium- and fine-grained clayey sandstone
2,857	24.5	51	2.68	fine- and very fine-grained clayey sandstone
3,182	18.3	0.9	2.75	clayey siltstone
3,494	18.0	76	2.73	clayey pebbly siltstone

(continued)

(continued: OCS Y-0007 No. 1, sidewall core data)

Depth (feet)	Porosity (percent)	Permeability (millidarcies)	Grain Density (gm/cm^3)	Lithologic Description
4,028	18.3	4.8	2.70	fine- and very fine-grained pebbly clayey sandstone
4,050	13.5	126	2.69	fine-grained clayey sandstone and siltstone
4,104	21.8	39	2.70	medium- and fine-grained clayey sandstone
4,650	15.9	15	2.72	very fine-grained silty clayey sandstone
4,718	19.2	8.5	2.78	very fine-grained silty clayey sandstone
4,861	15.3	69	2.72	very fine-grained silty clayey sandstone
4,992	32.9	4.8	2.78	very fine-grained silty clayey sandstone
5,404	25.5	24	2.74	very fine-grained silty clayey sandstone
7,458	22.0	18	2.73	very fine-grained silty clayey sandstone
7,938	31.3	3.8	2.70	very fine-grained silty clayey sandstone
7,998	24.3	33	2.69	fine- and very fine-grained sandstone
8,010	25.3	4.1	2.73	very fine-grained silty clayey sandstone
8,020	23.5	244	2.68	very fine-grained silty clayey sandstone
8,035	23.5	12	2.65	fine- and very fine-grained sandstone
8,750	18.2	0.9	2.73	pebbly siltstone
8,762	20.6	31	2.70	very fine-grained silty sandstone
8,763	28.1	84	2.74	very fine-grained sandstone
8,764	31.5	59	2.79	fine- and very fine-grained sandstone
8,765	24.4	416	2.73	fine- and very fine-grained sandstone

(continued)

(continued: OCS Y-0007 No. 1, sidewall core data)

Depth (feet)	Porosity (percent)	Permeability (millidarcies)	Grain Density (gm/cm^3)	Lithologic Description
8,766	24.8	173	2.71	medium- to very fine-grained sandstone
8,768	22.2	59	2.74	medium- to very fine-grained sandstone
8,769	22.5	83	2.74	medium- to very fine-grained sandstone
8,770	29.7	132	2.67	medium- to very fine-grained sandstone
8,771	30.1	25	2.67	fine- and very fine-grained clayey sandstone
8,772	25.7	158	2.71	very fine-grained conglomeratic sandstone
8,773	24.8	77	2.71	medium- to very fine-grained sandstone
8,775	24.2	189	2.70	medium- to very fine-grained sandstone
8,776	22.1	40	2.72	medium- to very fine-grained sandstone
8,777	22.7	33	2.71	medium- to very fine-grained sandstone
8,779	25.4	264	2.72	medium- to very fine-grained sandstone
8,781	23.4	47	2.65	medium- to very fine-grained sandstone
8,782	20.8	13	2.74	fine- and very fine-grained sandstone
8,783	25.2	37	2.68	fine- and very fine-grained sandstone
8,784	25.9	6.3	2.69	medium- and fine-grained sandstone
8,785	26.0	145	2.74	fine-grained sandstone
8,786	24.7	47	2.74	medium-grained sandstone
8,787	25.5	39	2.72	medium- and fine-grained sandstone
8,788	27.8	57	2.69	medium- and fine-grained pebbly sandstone

(continued)

(continued: OCS Y-0007 No. 1, sidewall core data)

Depth (feet)	Porosity (percent)	Permeability (millidarcies)	Grain Density (gm/cm^3)	Lithologic Description
8,789	22.5	55	2.71	very fine-grained conglomeratic sandstone
8,790	23.3	152	2.68	medium- to very fine-grained sandstone
8,791	24.4	36	2.72	medium- to very fine-grained sandstone
8,792	23.3	28	2.71	medium- to very fine-grained sandstone
8,793	23.5	95	2.71	medium- to very fine-grained sandstone
8,794	23.0	25	2.72	fine- and very fine-grained sandstone
8,795	24.8	104	2.74	fine- and very fine-grained sandstone
8,796	26.7	48	2.69	fine- and very fine-grained sandstone
8,797	27.2	98	2.72	fine- and very fine-grained sandstone
8,799	24.4	36	2.77	fine- and very fine-grained sandstone
8,800	21.6	23	2.74	medium- to very fine-grained sandstone
8,801	27.2	33	2.74	medium- to very fine-grained sandstone
8,802	24.7	286	2.69	fine- and very fine-grained sandstone
8,803	24.1	38	2.70	fine- and very fine-grained sandstone
8,804	22.7	17	2.71	fine- and very fine-grained sandstone
8,805	29.2	322	2.71	fine- and very fine-grained sandstone
8,806	28.9	45	2.73	medium- to very fine-grained pebbly sandstone
8,808	25.5	56	2.72	fine- and very fine-grained sandstone
8,809	26.1	97	2.71	very fine-grained silty sandstone

(continued)

(continued: OCS Y-0007 No. 1, sidewall core data)

Depth (feet)	Porosity (percent)	Permeability (millidarcies)	Grain Density (gm/cm^3)	Lithologic Description
8,811	25.5	30	2.68	very fine-grained sandstone
8,812	26.2	102	2.71	very fine-grained sandstone
8,813	25.9	179	2.69	very fine-grained sandstone
8,814	23.6	22	2.68	very fine-grained sandstone
8,815	25.3	93	2.72	very fine-grained sandstone
8,816	23.6	264	2.73	very fine-grained sandstone
8,817	27.3	60	2.74	fine- and very fine-grained clayey sandstone
8,830	27.8	109	2.67	fine- and very fine-grained clayey sandstone
8,840	26.4	105	2.73	fine- and very fine-grained clayey sandstone
8,749	20.2	41	2.74	very fine-grained silty clayey sandstone
8,754	21.1	5.1	2.70	medium- and fine-grained clayey sandstone
8,758	15.1	9.2	2.70	fine-grained silty clayey sandstone
8,761	18.0	12	2.70	very fine-grained silty clayey sandstone
8,860	27.1	292	2.73	fine- and very fine-grained clayey sandstone
8,870	25.4	241	2.76	fine- and very fine-grained clayey sandstone
8,880	27.2	324	2.74	medium- to very fine-grained clayey sandstone
8,900	21.3	31	2.73	medium- to very fine-grained clayey sandstone
8,990	24.1	146	2.72	medium- to very fine-grained clayey sandstone
8,999	27.0	487	2.72	medium- to very fine-grained clayey sandstone

(continued)

(continued: OCS Y-0007 No. 1, sidewall core data)

Depth (feet)	Porosity (percent)	Permeability (millidarcies)	Grain Density (gm/cm^3)	Lithologic Description
9,013	20.2	36	2.74	very fine-grained conglomeratic clayey sandstone
9,019	29.2	200	2.70	fine- and very fine-grained sandstone
9,169	26.2	326	2.72	fine- and very fine-grained sandstone
9,272	25.6	345	2.80	fine- and very fine-grained sandstone
9,278	27.4	71	2.79	very fine-grained silty sandstone
9,298	29.7	103	2.78	fine- and very fine-grained silty sandstone
9,310	27.9	—	2.69	very fine-grained silty sandstone
9,317	29.7	83	2.83	very fine-grained sandstone and siltstone
9,347	28.5	88	2.86	very fine-grained silty sandstone
9,360	27.4	65	2.82	very fine-grained silty sandstone
9,368	25.6	39	2.78	very fine-grained silty sandstone
9,407	25.9	92	2.83	fine- and very fine-grained silty sandstone
9,685	18.1	7.8	2.68	very fine-grained silty clayey sandstone
9,853	13.6	0.9	2.70	very fine-grained silty clayey sandstone
10,054	21.9	15	2.80	very fine-grained clayey sandstone
10,423	24.4	34	2.67	fine- and very fine-grained sandstone
10,468	26.8	88	2.70	very fine-grained clayey sandstone
10,760	22.5	16	2.73	very fine-grained silty clayey sandstone
10,782	24.1	13	2.71	fine- and very fine-grained clayey sandstone

(continued)

(continued: OCS Y-0007 No. 1, sidewall core data)

Depth (feet)	Porosity (percent)	Permeability (millidarcies)	Grain Density (gm/cm^3)	Lithologic Description
10,896	20.1	1.1	2.76	very fine-grained silty clayey sandstone
11,070	21.0	23	2.70	very fine-grained silty clayey sandstone
11,089	27.6	359	2.74	very fine-grained silty clayey sandstone
11,119	20.7	10	2.72	very fine-grained silty clayey sandstone
11,140	12.4	0.1	2.71	very fine-grained silty clayey sandstone
11,147	17.5	46	2.71	very fine-grained silty clayey sandstone
11,155	19.3	50	2.68	very fine-grained silty clayey sandstone
11,183	23.0	533	2.86	fine- and very fine-grained sandstone
11,288	18.1	13	2.69	very fine-grained silty sandstone
11,323	21.4	17	2.67	medium-grained conglomeratic sandstone
11,638	19.5	27	2.72	very fine-grained sandstone
11,642	24.8	106	2.66	very fine-grained sandstone
11,645	19.3	4.2	2.72	very fine-grained sandstone
11,663	27.4	133	2.76	very fine-grained sandstone
12,111	22.4	42	2.61	very fine-grained sandstone
12,432	12.5	0.4	2.68	very fine-grained silty sandstone
12,436	20.9	29	2.65	very fine-grained silty sandstone
12,710	17.5	43	2.64	very fine-grained silty sandstone
12,742	13.8	3.0	2.63	very fine-grained silty sandstone

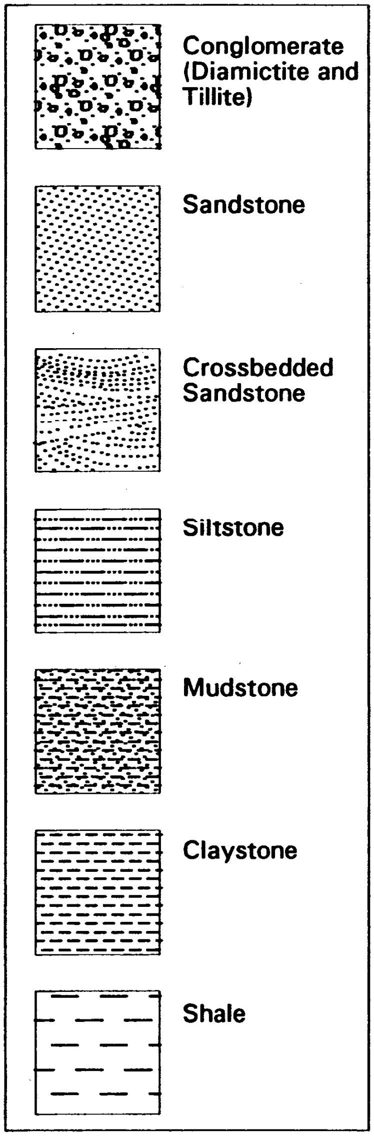
(continued)

(continued: OCS Y-0007 No. 1, sidewall core data)

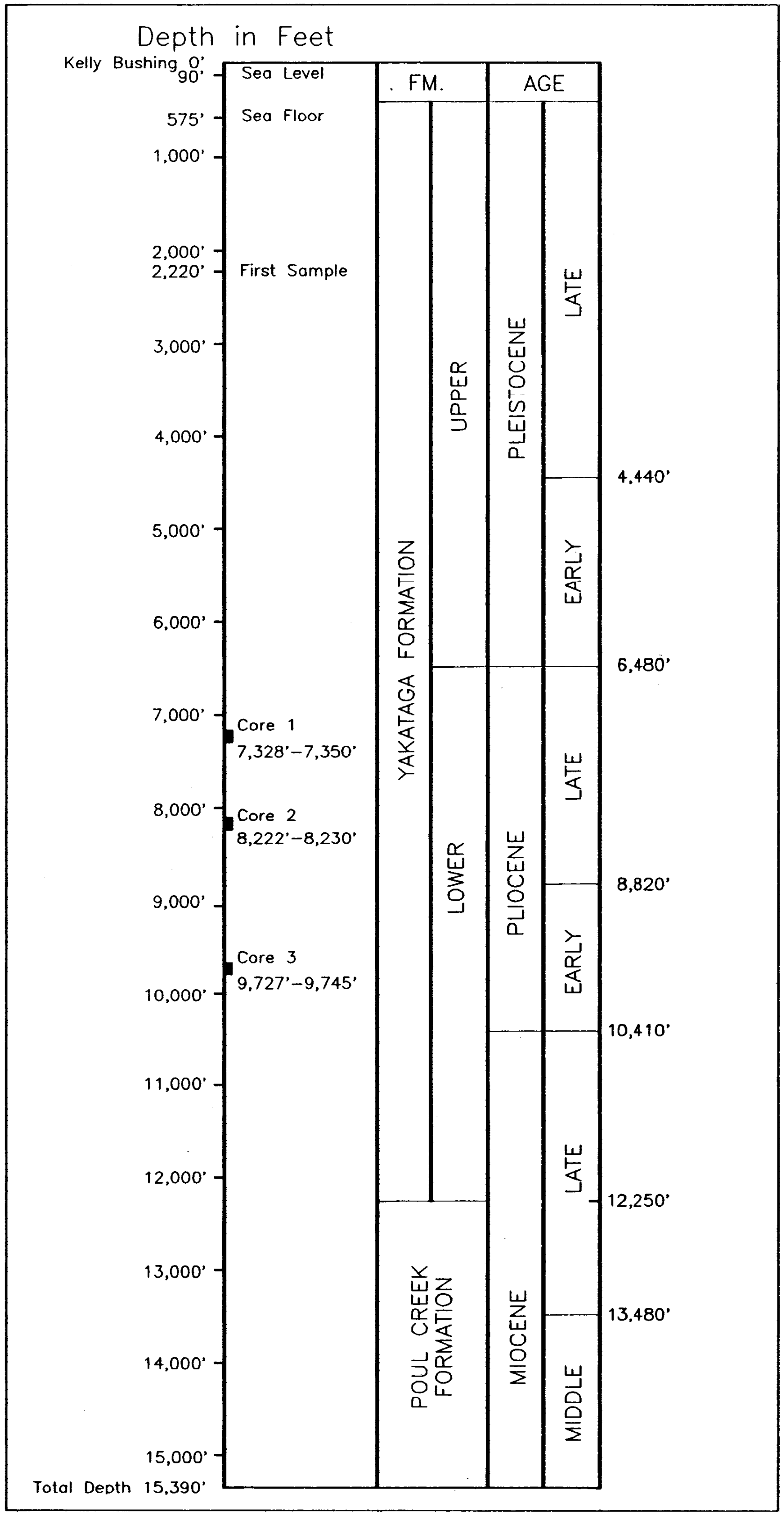
Depth (feet)	Porosity (percent)	Permeability (millidarcies)	Grain Density (gm/cm^3)	Lithologic Description
12,753	16.4	52	2.64	very fine-grained silty sandstone
12,832	18.8	162	2.61	very fine-grained silty sandstone
16,916	21.0	33	2.63	very fine-grained silty sandstone
16,986	21.1	41	2.62	very fine-grained silty sandstone

Appendix C

Appendix C. Shell Oil Company OCS Y-0014 No. 1 and No. 2 (redrill) well



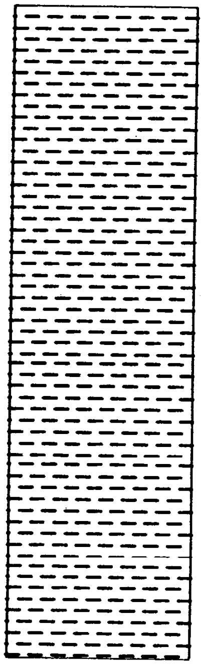
Above. Explanation of symbols used for rock types.



Right. Conventional core locations in the Shell OCS Y-0014 No. 1 and No. 2 (redrill) well. Depths are measured from the Kelly bushing, which was 90 feet above sea level. Water depth is 485 feet.

Depth
(Feet)

7,328'
7,333'
7,338'
7,343'
7,348'
7,350'



Core 1 consists of silty, medium- and dark-gray, well- indurated claystone containing abundant detrital material ranging from very fine-grained sand to pebbles up to 2 centimeters in diameter. The pebbles are rounded to angular, randomly distributed, and are composed of sedimentary, metamorphic, and igneous rock. There is some calcite cement and fine pyrite present in the top 2 feet of the core. There are some faintly visible laminae dipping 5 to 10 degrees from the horizontal and some small-scale crossbedding. At 7,346 feet, there is a diorite cobble greater than 10 centimeters in diameter.

This core is from the lower Yakataga Formation and is Pliocene in age. The environment of deposition was outer neritic to upper bathyal.

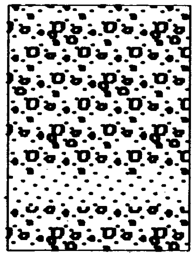
Conventional core 1. No porosity, permeability, or grain density data were available for this core.

Depth
(Feet)

8,222'

8,227'

8,230'



Core 2 was badly broken, coming out of the core barrel in fragments, making orientation difficult. Exact depths within the cored interval cannot be determined.

The top two-thirds of the core, from 8,222 to approximately 8,227 feet, is composed of diamictite with a matrix consisting of silty claystone, siltstone, and fine- and very fine-grained sandstone. The clasts are well-rounded to angular rocks of volcanic, plutonic, metamorphic, and sedimentary origin. The maximum clast size is about 8 centimeters in diameter. The next 15 inches of the core are composed of angular to subrounded very fine- and fine-grained gray sandstone with a dip of about 17 degrees from the horizontal. There is some calcite cement. The rest of the core is composed of diamictite, similar to the upper portion above the sandstone layer, but with the maximum size of the clasts about 2 centimeters in diameter.

This core is from the lower Yakataga Formation and is Pliocene in age. The environment of deposition was outer neritic to upper bathyal.

Conventional core 2. No porosity, permeability, or grain density data were available for this core.

Depth (Feet)

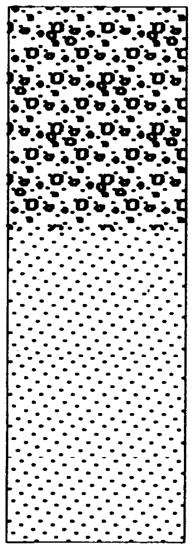
9,727'

9,732'

9,737'

9,742'

9,745'



Porosity	Permeability	Grain Density
14.2	155	2.74
15.7	78	2.72
12.8	20	2.73
17.0	95	2.69
37.1	31	2.73
18.3	212	2.72
18.3	138	2.72

Core 3 was retrieved from the core barrel, after coring for 9.7 hours, as unconsolidated sand and broken fragments of rock.

The upper 8 feet of the core consists of diamictite. Sizes range from clay to rocks 15 centimeters in diameter. Many of the angular and subangular clasts are dark-gray shale; others are of igneous and metamorphic origin. The lower 10 feet of the core is composed of friable, light- and medium-gray, poorly sorted, pebbly, clayey and silty sandstone. The pebbles are angular to subrounded. There is some calcite cement present. The entire core appears to have poor visible porosity and permeability.

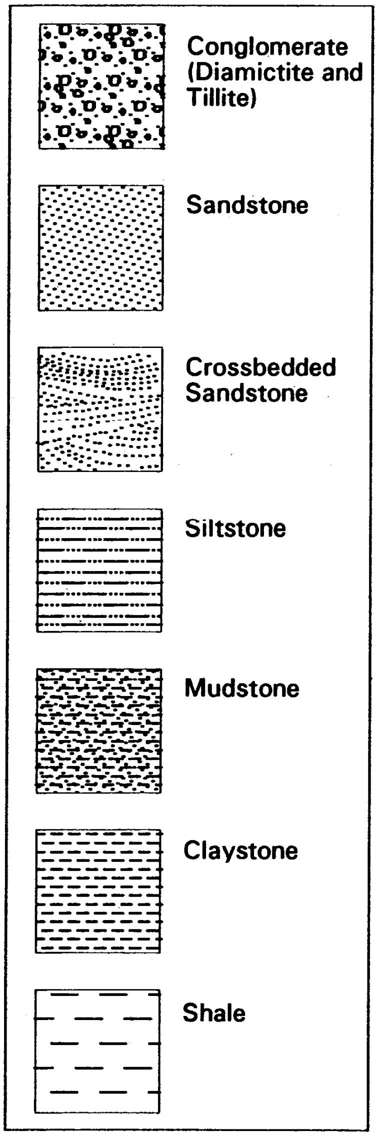
This core is from the lower Yakataga Formation and is Pliocene in age. The environment of deposition was outer neritic to upper bathyal.

Conventional core 3. Porosity (in percent), permeability (in millidarcies), and grain density (gm/cm^3) from Core Laboratories reports.

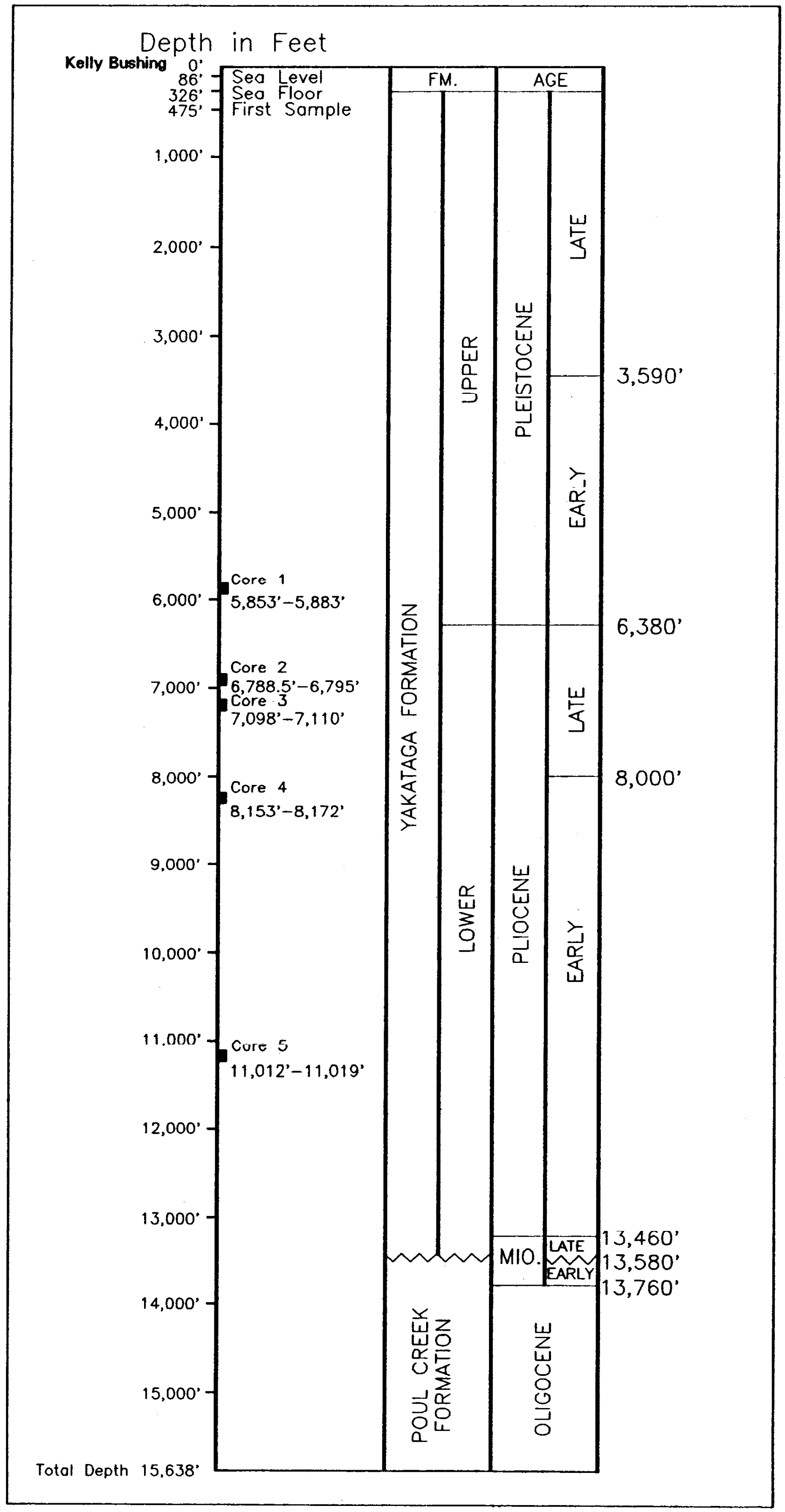
OCS Y-0014 No. 1 and 2 wells sidewall core data (modified from Core Laboratories reports)

Depth (feet)	Porosity (percent)	Permeability (millidarcies)	Grain Density (gm/cm^3)
5,995	27.1	32	2.89
7,304	24.2	1,600 (fractured)	2.74
7,306	29.2	—	3.63
7,309	29.0	182	2.91
7,310	32.8	—	3.19
7,316	23.4	14	3.08
7,317	25.6	77	2.71
7,320	24.8	53	2.85
7,322	29.1	370	2.70
7,324	30.7	390	2.76
7,326	23.2	45	2.74
7,328	30.3	—	2.71

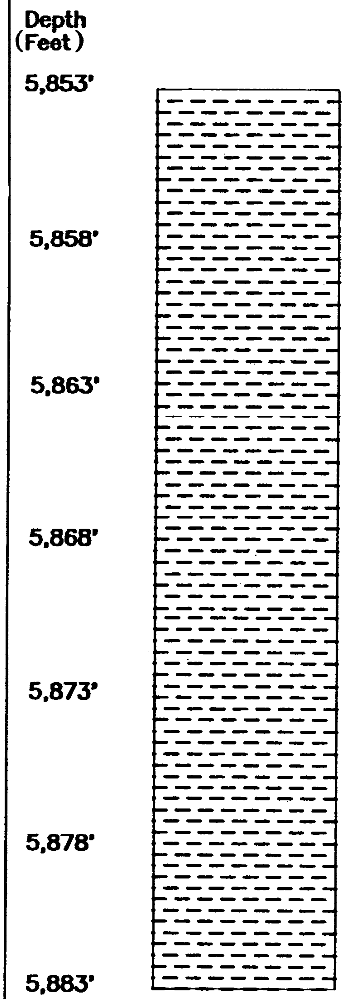
Appendix D



Above. Explanation of symbols used for rock types.



Right. Conventional core locations in the Texaco OCS Y-0032 No. 1 well. Depths are measured from the Kelly bushing, which was 86 feet above sea level. Water depth is 240 feet.



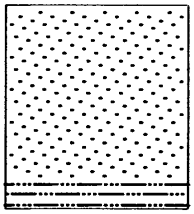
Core 1 consists of medium- to dark-gray, calcareous, silty, well-indurated claystone containing suspended fine to coarse, well-rounded sand grains and pebbles composed of igneous and metamorphic rock fragments up to 5 centimeters in diameter. There are no visible bedding planes. Mollusc shell fragments are common.

This core is from the upper Yakataga Formation and is early Pleistocene in age. The environment of deposition was outer neritic to upper bathyal.

Conventional core 1. No porosity, permeability, or grain density data were available for this core.

Depth (Feet)

6,788.5'



6,795'

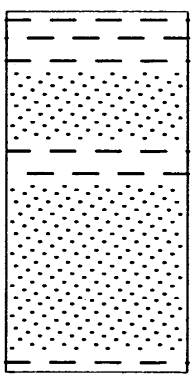
Porosity	Permeability	Grain Density
2.9	0.1	2.73
13.8	7.7	2.70
14.4	5.6	2.72
15.1	10.0	2.72
9.9	0.2	2.71
14.1	1.9	2.72

The upper 5.5 feet of core 2 consists of medium-gray, fine- and very fine-grained argillaceous, friable, silty sandstone. The clasts are 75 percent clear, subangular to subrounded quartz grains, 20 percent metamorphic and igneous rock fragments, and 5 percent calcareous silty claystone. There are a few nearly horizontal laminae of very fine, dark-gray, carbonaceous material, and tan clay. There is a fracture pattern about 15 degrees from the horizontal. The lower 1 foot of the core consists of light-gray, friable, carbonaceous, argillaceous siltstone. Clay and organic laminae are common and somewhat deformed.

This core is from the lower Yakataga Formation and is late Pliocene in age. The environment of deposition was inner to middle neritic.

Depth (Feet)

7,098'



7,103'

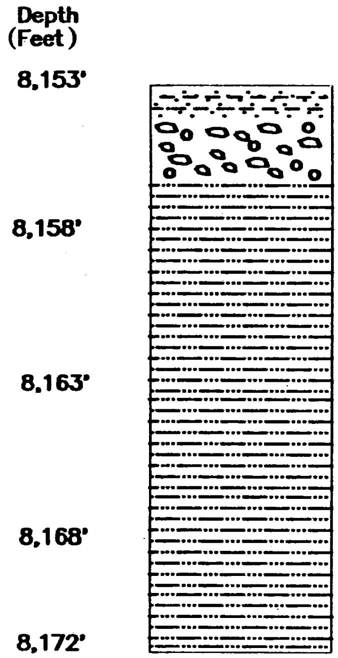
7,110'

Porosity	Permeability	Grain Density
8.7	0.1	2.72
9.8	0.4	2.71
25.2	142.0	2.73
24.6	176.0	2.71
24.0	152.0	2.70
24.0	124.0	2.71

The top 2 feet of core 3 consists of dark-gray, fissile, slightly calcareous shale that grades to sandstone at the lower contact. The interval from 7,100 to 7,102 feet is gray, friable, argillaceous, calcareous, very fine- and fine-grained sandstone containing quartz grains, mica, and lithic fragments. This interval is bounded by thin shale layers and laminations. This is followed by a 1.5-foot layer of shale similar to that at the top of the core. The interval from 7,103.5 to 7,109 feet is similar to the overlying sandstone. The bottom foot of the core is dark-gray, hard, calcareous, shale with very fine- to coarse-grained sand lenses 2 to 3 millimeters thick, and pebbles up to 8 millimeters in length.

This core is from the lower Yakataga Formation and is late Pliocene in age. The environment of deposition was inner to middle neritic.

Conventional cores 2 and 3. Porosity (in percent), permeability (in millidarcies), and grain density (gm/cm^3) data are modified from Core Laboratories reports.



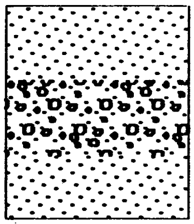
Core 4 consists of sandstone, siltstone, and conglomerate. The top foot is alternating calcareous, argillaceous, silty sandstone and silty shale. The color is light to dark gray. The sandstone is very fine and fine grained. There are some light-green chlorite schist cobbles in the lower part of this upper foot. The interval from 8,154 to 8,156 feet is conglomerate with a medium-dark-gray, calcareous, argillaceous, sandy siltstone matrix containing pebble-sized clasts of shale and igneous and metamorphic rock. A granodiorite cobble is present at 8,155 feet. Porosity and permeability are poor. The interval from 8,156 to 8,162 feet is argillaceous, sandy siltstone with dark-gray shale pebbles scattered throughout. The subangular to subrounded quartz sand grains are very fine to fine in size. The clay matrix is calcareously cemented and is without visible porosity or permeability. Near the bottom of this interval, there is a large andesite cobble and a 5-centimeter-long shale pebble. From 8,162 to 8,163 feet, the rock is medium- and dark-gray argillaceous siltstone containing very fine- to coarse-grained quartz sand and pebble-sized lithic fragments. The interval from 8,163 to 8,172 feet consists of argillaceous, massive, calcareous, sandy siltstone with about a 25-percent content of lithic fragments.

This core is from the lower Yakataga Formation and is early Pliocene in age. The environment of deposition was outer neritic to upper bathyal.

Conventional core 4. No porosity, permeability, or grain density data were available for this core.

Depth
(Feet)

11,012'



11,019'

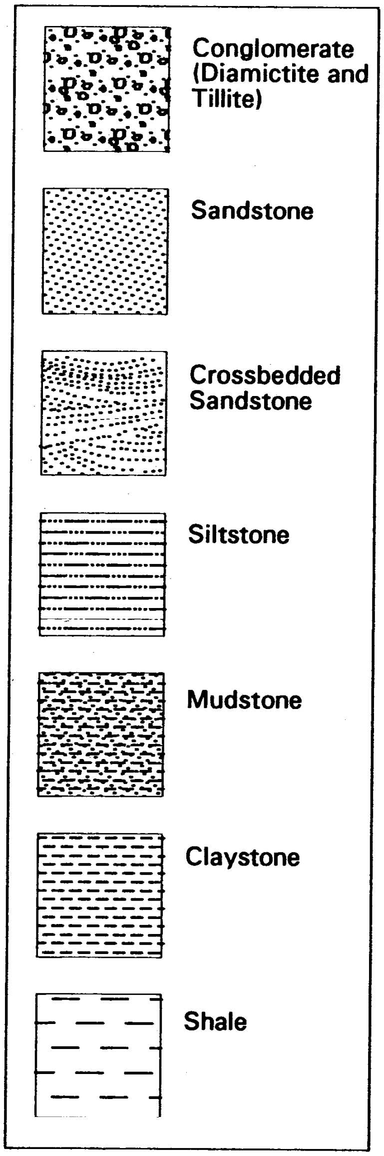
Porosity	Permeability
2.7	0.0
13.6	0.9
19.7	237.0
19.8	204.0
21.6	281.0

Core 5 consists of sandstone and conglomerate. The top 2 feet, from 11,012 to 11,014 feet, are composed of gray, silty, calcareous, very fine-grained sandstone. The interval from 11,014 to 11,017 feet is conglomerate. The matrix of the conglomerate is silty, very fine- to medium-grained gray sandstone. The pebbles and cobbles of metamorphic and sedimentary rock are both rounded and angular and up to 10 centimeters in size. The lower interval from 11,017 to 11,019 feet is composed of gray and brown, medium-grained sandstone containing quartz grains, chert, biotite mica, feldspar, rare pyrite, plutonic and metamorphic rock fragments, rare organic material, magnetite, foraminifera, and rare mollusc shell fragments.

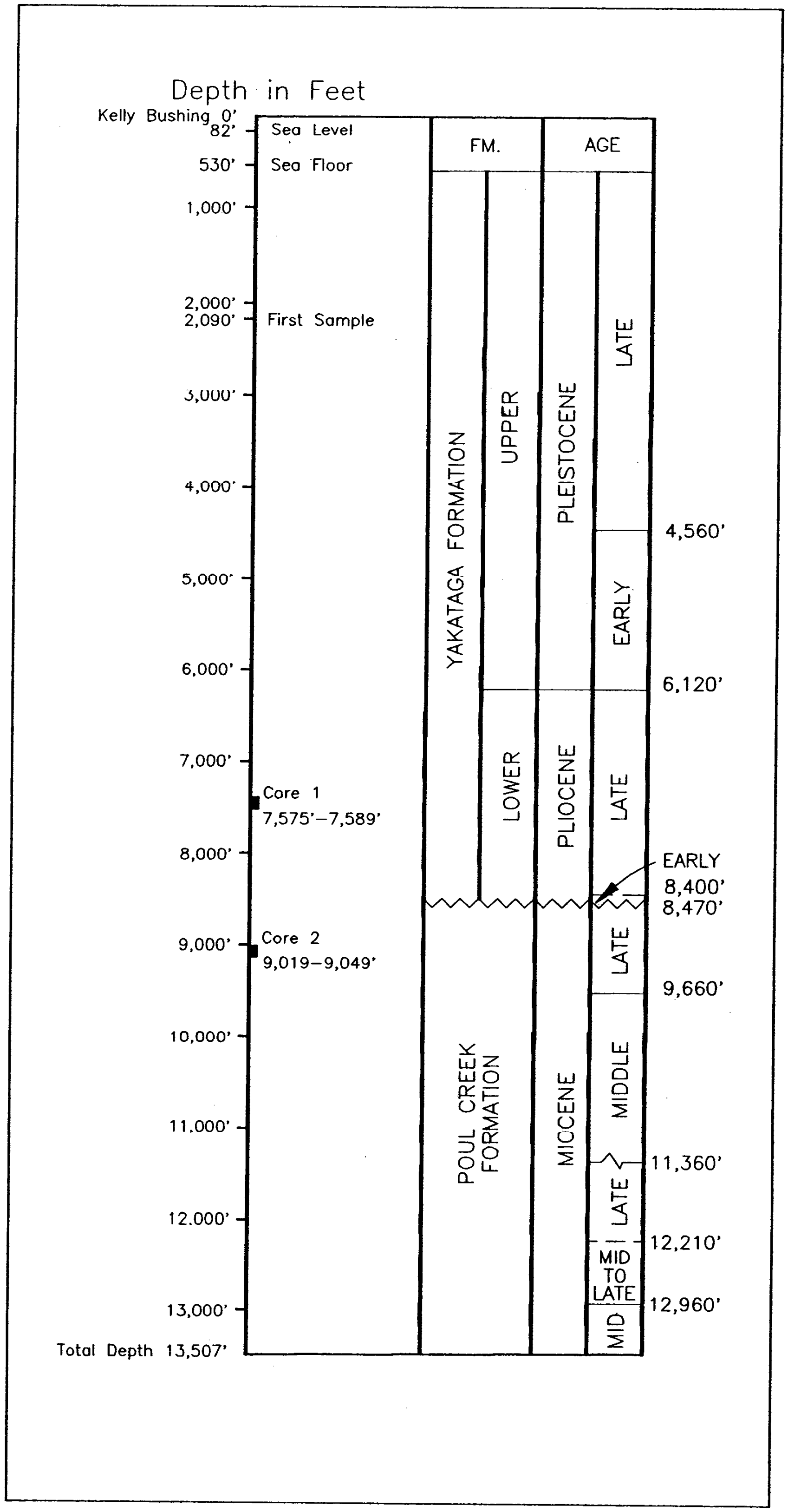
This core is from the lower Yakataga Formation and is early Pliocene in age. The environment of deposition was middle neritic.

Conventional core 5. Porosity (in percent) and permeability (in millidarcies) data are modified from Core Laboratories reports.

Appendix E



Above. Explanation of symbols used for rock types.



Right. Conventional core locations in the Exxon OCS Y-0080 No. 1 well. Depths are measured from the Kelly bushing, which was 82 feet above sea level. Water depth is 448 feet.

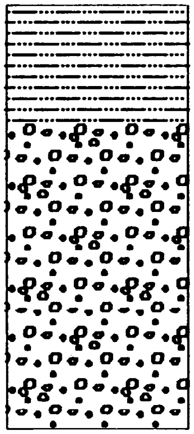
Depth
(Feet)

7,575'

7,580'

7,585'

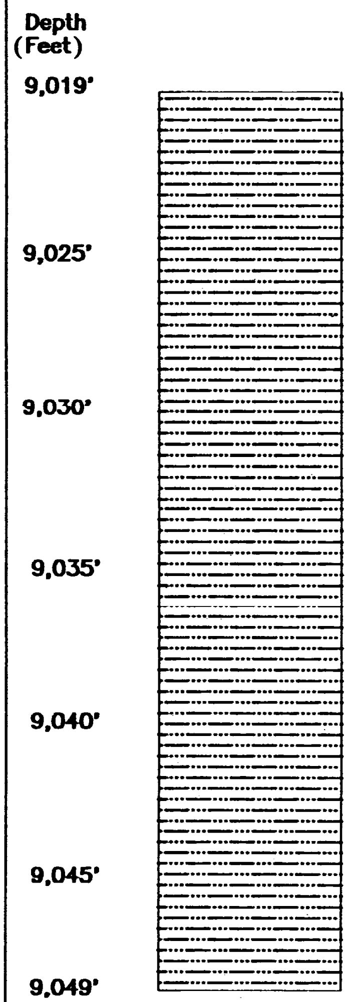
7,589'



The upper 3 feet (7,575 to 7,578) of core 1 consists of gray, friable, micaceous, clayey siltstone with rare pyrite and lenses of horizontally oriented tests of the foraminifera *Quinqueloculina akneriana*. The interval from 7,578 to 7,589 feet is made up of matrix-supported conglomerate. The gray, clayey, micaceous siltstone matrix contains rounded pebbles of quartzite, igneous rock, siltstone, and metamorphic rock that range from 1 to 15 millimeters in length. Scattered foraminifera fragments and very coarse quartz grains are also present. Faint bedding planes and evidence of bioturbation are visible at 7,578 feet. At 7,581 feet a light-green and gray, glassy volcanic pebble 15 millimeters in length is present. The lower 5 feet of the core is a matrix-supported conglomerate with a matrix that is coarser grained than that at the top of the core, with grain sizes ranging from silt to very coarse sand. The rounded pebbles are composed of black siltstone, quartzite, and plutonic rock.

This core is from the upper Yakataga Formation and is early Pleistocene in age. The environment of deposition was probably outer neritic to upper bathyal.

Conventional core 1. No porosity, permeability, or grain density data were available for this core.



All 8 available samples of core 2 consist of tan and gray, micaceous, glauconitic siltstone.

This core is from the Poul Creek Formation and is probably late Miocene in age. The environment of deposition was upper to middle bathyal.

Conventional core 2. No porosity, permeability, or grain density data were available for this core.

OCS Y-0080 No. 1 well sidewall core data (modified from Core Laboratories reports)

Depth (feet)	Porosity (percent)	Permeability (millidarcies)	Grain Density (gm/cm^3)	Lithologic Description
2,194	31.5	1.7	2.66	sandy silty claystone
2,203	26.5	1.2	2.72	sandy silty claystone
2,206	30.2	0.7	2.72	sandy silty claystone
2,444	27.0	0.8	2.73	sandy silty claystone
2,498	25.7	1.5	2.69	sandy silty claystone
2,825	17.1	3.9	2.75	fine- and very fine-grained conglomeratic sandstone
2,842	15.7	5.8	2.68	fine- and very fine-grained conglomeratic sandstone
2,844	14.9	3.6	2.72	fine- and very fine-grained conglomeratic sandstone
2,846	19.0	137	2.72	fine- and very fine-grained conglomeratic sandstone
2,873	15.6	0.7	2.72	fine- and very fine-grained pebbly silty sandstone
2,879	16.0	1.4	2.74	fine- and very fine-grained pebbly silty sandstone
2,900	19.3	1.4	2.66	fine- and very fine-grained pebbly silty sandstone
2,921	13.9	4.6	2.71	fine- and very fine-grained pebbly silty sandstone
2,993	24.0	172	2.69	very coarse- and coarse-grained silty sandstone
3,005	10.3	7.2	2.73	medium- to very fine-grained conglomeratic clayey sandstone
3,095	31.8	1.3	2.73	sandy clayey siltstone
3,103	19.2	0.6	2.68	fine- and very fine-grained silty clayey sandstone
3,110	34.1	1.3	2.73	sandy clayey siltstone
3,119	33.6	2.2	2.69	sandy clayey siltstone

(continued)

(continued: OCS Y-0080 No. 1, sidewall core data)

Depth (feet)	Porosity (percent)	Permeability (millidarcies)	Grain Density (gm/cm^3)	Lithologic Description
3,121	33.5	2.5	2.67	sandy clayey siltstone
3,191	29.4	1.7	2.68	sandy clayey siltstone
3,213	31.8	1.5	2.66	sandy clayey siltstone
3,216	28.2	1.9	2.69	sandy clayey siltstone
3,394	19.3	3.9	2.70	coarse- to fine-grained silty clayey sandstone
3,400	17.8	1.0	2.71	fine- and very fine-grained silty clayey sandstone
3,461	30.0	1.8	2.72	sandy clayey siltstone
3,467	31.8	1.2	2.73	sandy clayey siltstone
3,477	31.1	0.9	2.76	sandy clayey siltstone
3,539	34.1	1.2	2.70	sandy clayey siltstone
3,683	30.2	0.7	2.70	sandy clayey siltstone
3,734	18.6	0.3	2.73	pebbly sandy clayey siltstone
5,412	14.8	12.0	2.73	medium- to very fine-grained silty clayey sandstone
5,462	12.2	4.2	2.73	conglomerate
5,688	16.4	1.3	2.70	fine- and very fine-grained pebbly silty sandstone
5,695	15.4	1.2	2.74	fine- and very fine- grained pebbly silty sandstone
5,770	18.1	0.3	2.67	pebbly sandy clayey siltstone
5,899	12.0	3.7	2.73	conglomerate
6,159	10.8	2.5	2.71	conglomerate

(continued)

(continued: OCS Y-0080 No. 1, sidewall core data)

Depth (feet)	Porosity (percent)	Permeability (millidarcies)	Grain Density (gm/cm^3)	Lithologic Description
6,331	17.0	0.2	2.69	pebbly sandy clayey siltstone
6,333	18.5	1.4	2.70	pebbly sandy clayey siltstone
6,335	19.7	1.6	2.72	pebbly sandy clayey siltstone
6,388	17.2	3.7	2.69	very fine-grained silty clayey sandstone
6,420	20.8	2.6	2.72	very fine-grained silty clayey sandstone
6,424	22.5	7.4	2.69	fine- and very fine-grained silty clayey sandstone
6,426	21.7	6.2	2.69	fine- and very fine-grained silty clayey sandstone
6,494	26.5	27.0	2.67	fine- and very fine-grained silty sandstone
6,496	21.6	22.0	2.74	fine- and very fine-grained silty sandstone
6,499	23.8	28.0	2.68	fine- and very fine-grained silty sandstone
6,594	21.8	1.1	2.73	clayey siltstone
6,690	18.2	0.4	2.73	clayey siltstone
6,787	18.9	1.3	2.69	pebbly sandy clayey siltstone
6,840	17.7	0.3	2.74	pebbly sandy clayey siltstone
6,854	18.0	0.6	2.69	very fine-grained silty clayey sandstone
7,455	23.3	8.4	2.67	very fine-grained silty clayey sandstone
7,477	18.5	0.7	2.69	very fine-grained silty clayey sandstone
7,479	17.1	0.2	2.69	clayey siltstone
7,486	25.0	49.0	2.65	fine- and very fine-grained silty sandstone

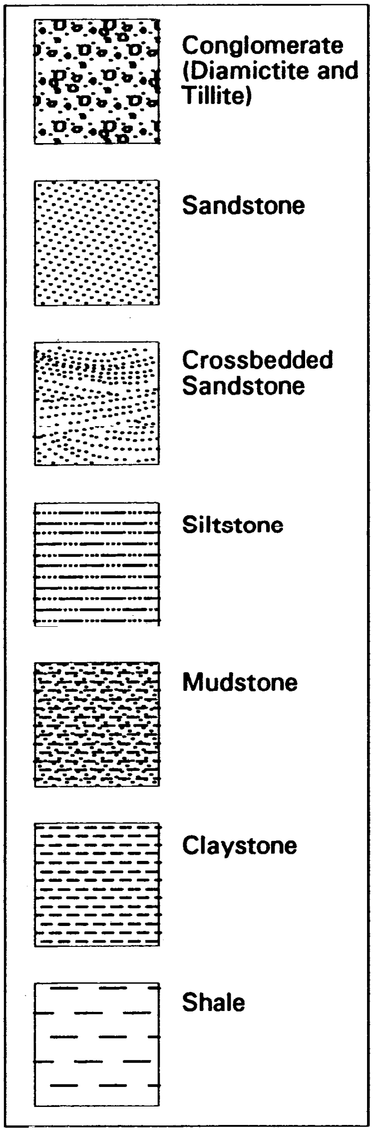
(continued)

(continued: OCS Y-0080 No. 1, sidewall core data)

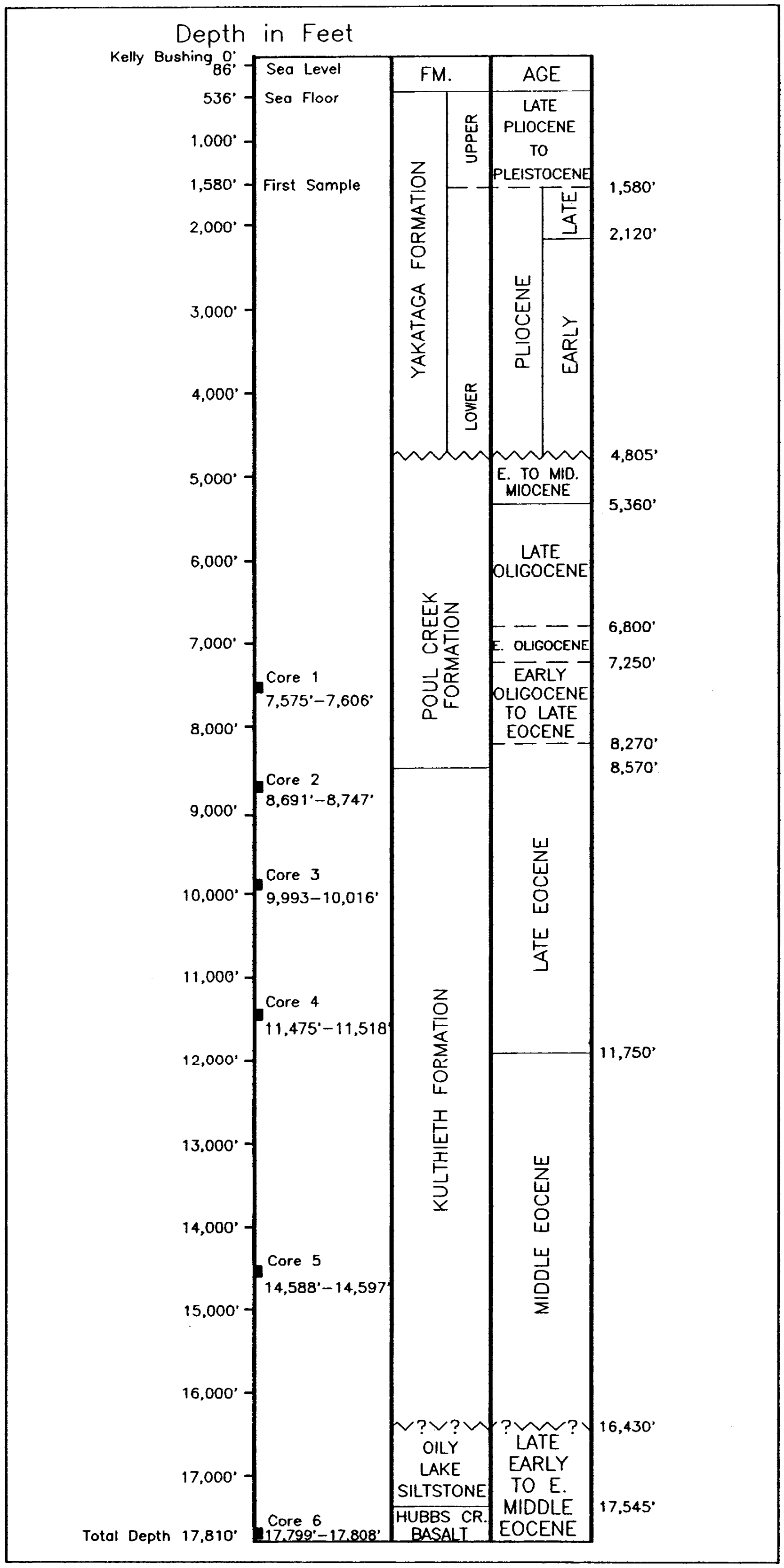
Depth (feet)	Porosity (percent)	Permeability (millidarcies)	Grain Density (gm/cm^3)	Lithologic Description
7,505	28.2	81.0	2.72	fine- and very fine-grained silty sandstone
7,514	27.1	83.0	2.65	fine- and very fine-grained silty sandstone
7,615	26.2	158.0	2.65	fine- and very fine-grained silty sandstone
7,695	14.7	2.2	2.67	fine- and very fine-grained silty clayey sandstone
7,717	20.9	39.0	2.71	fine- and very fine-grained silty clayey sandstone
7,800	15.7	0.2	2.70	clayey siltstone
7,920	10.5	0.0	2.66	clayey siltstone
7,938	13.2	0.1	2.67	clayey siltstone
7,947	15.3	0.2	2.70	clayey siltstone
7,964	14.4	0.0	2.68	clayey siltstone
8,050	15.3	0.1	2.69	clayey siltstone
8,063	16.8	0.3	2.66	clayey siltstone
8,137	21.0	0.7	2.69	clayey siltstone
8,290	25.4	41.0	2.69	fine- and very fine-grained silty clayey sandstone

Appendix F

Appendix F. ARCO OCS Y-0211 No. 1 well

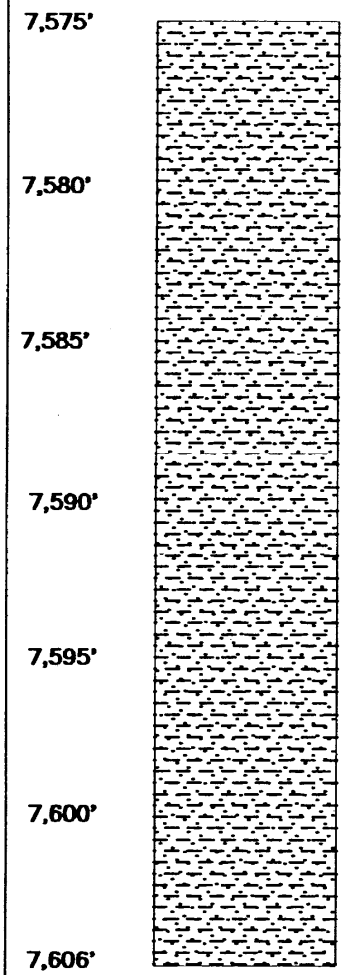


Above. Explanation of symbols used for rock types



Right. Conventional core locations in the ARCO OCS Y-0211 No. 1 well. Depths are measured from the Kelly bushing, which was 86 feet above sea level. Water depth is 450 feet.

Depth
(Feet)

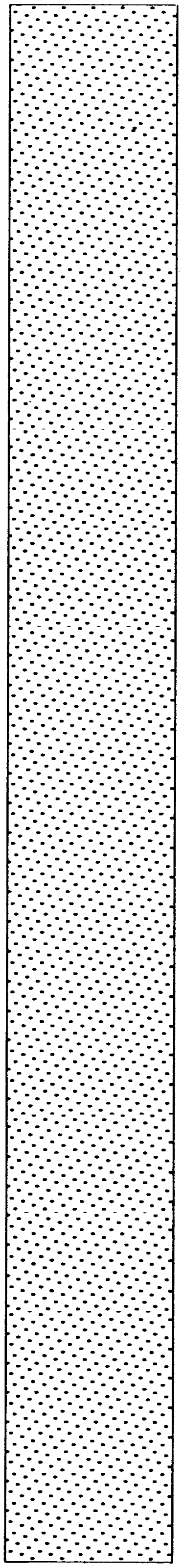


Core 1 consists mainly of medium-gray, very silty, micaceous mudstone. Foraminifera, mollusc shell fragments, pyritized wood, pyritized diatoms, coal, and very fine-grained sand are present locally in varying amounts. A gastropod shell 8 millimeters long was observed at 7,605 feet. Minerals present include quartz, feldspar, biotite, muscovite, chlorite, pyrite, glauconite, clays, and calcite cement. Bioturbation is represented by pyrite-filled burrows 0.5 millimeter in diameter and 3.5 millimeters long at 7,605 feet. A few slickensides are present, indicating that there was some movement after consolidation. The porosity is visually estimated to be less than 2 percent.

This core is from the Poul Creek Formation and is early Oligocene to late Eocene in age. The environment of deposition was upper bathyal.

Conventional core 1. No porosity, permeability, or grain density data were available for this core.

Depth (Feet)
8,691'
8,695'
8,700'
8,705'
8,710'
8,715'
8,720'
8,725'
8,730'
8,735'
8,740'
8,745'
8,747'



Porosity	Permeability	Grain Density
9.3	0.05	2.75
7.9	0.02	2.73
23.4	1.38	2.70
21.7	0.18	2.70
11.6	0.07	2.73
23.3	2.11	2.70
24.2	6.84	2.70
26.0	6.42	2.70
25.2	6.02	2.68
22.7	0.97	2.69
23.3	1.10	2.69
18.1	0.35	2.69
18.3	0.58	2.69
24.4	7.75	2.69
24.7	4.71	2.69
25.0	12.00	2.69
17.1	0.14	2.71
16.6	0.07	2.69
18.0	0.18	2.70
15.6	0.16	2.68
18.0	0.16	2.69
20.0	0.25	2.69
16.6	0.18	2.57
16.8	0.07	2.70
17.4	0.16	2.70
20.8	0.51	2.69

Core 2 consists of light-gray, well-indurated, micaceous, silty sandstone with a few darker gray laminations. The grain size ranges from very fine to medium. Sorting is moderate to poor and the grains are angular to subround. The sandstone is made up of quartz, feldspar, biotite, muscovite, clay, and rock fragments. Pyrite and glauconite are present in very small amounts. Possible zeolite minerals are present at 8,724 feet. Foraminifera are also present. Vertical burrows and minor rip-up clasts are present at 8,729 feet. A leaf fragment 1 centimeter in diameter is present at 8,729 feet. Flattened coal fragments up to several millimeters in diameter are present. Most of the coal fragments are in the finer grained laminae. Calcareous cement is irregularly distributed.

The ARCO well site geologist reported pale yellow, green, blue, and white fluorescence of the pores, and a faint "diesel" smell, primarily on freshly broken surfaces.

This core is from the Kulthieth Formation and is late Eocene in age. The environment of deposition was outer neritic to upper bathyal.

Conventional core 2. Porosity (in percent), permeability (in millidarcies), and grain density (gm/cm^3) from Core Laboratories reports.

Depth (Feet)

9,993'

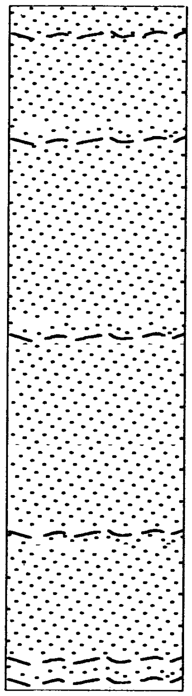
9,995'

10,000'

10,005'

10,010'

10,016'



Porosity	Permeability	Grain Density
11.6	0.16	2.67
16.6	0.69	2.66
17.4	0.66	2.68
17.4	0.73	2.66
18.9	1.26	2.67
18.3	2.00	2.65
15.0	0.46	2.65
12.4	0.51	2.63
16.7	0.16	2.68
11.9	0.23	2.67
17.9	5.86	2.66

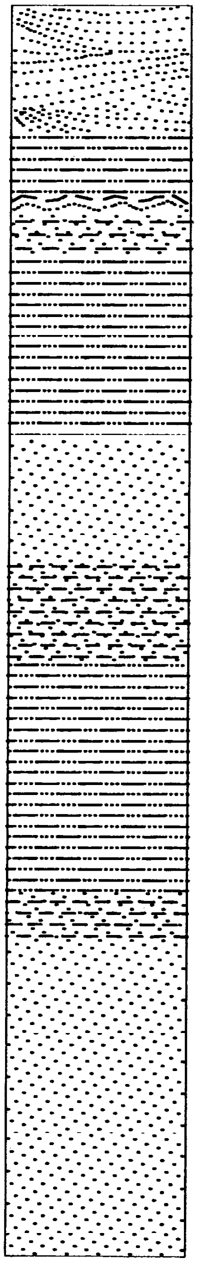
Core 3 sampled a light-gray, micaceous, well-indurated, sandstone interbedded with 1-foot-thick horizontal, wavy, and lenticular units composed of dark-gray, thinly laminated mudstone and clayey siltstone containing mica and organic material. Subangular, very fine to coarse sand grains are present. The grains are moderately well sorted. Minerals present include quartz, feldspar, biotite, muscovite, calcite, clays, pyrite, and glauconite. Some rock fragments are present. Coal and lignite fragments are scattered throughout, often in nearly horizontal layers. Mollusc shell fragments and foraminifera are present. Pyrite appears as burrow-filling and cement. Calcite cement is locally present.

This core is from the Kulthieth Formation and is late Eocene in age. The environment of deposition was outer neritic to upper bathyal.

Conventional core 3. Porosity (in percent), permeability (in millidarcies), and grain density (gm/cm^3) from Core Laboratories reports.

Depth (Feet)

11,475'
11,480'
11,485'
11,490'
11,495'
11,500'
11,505'
11,510'
11,515'
11,518'



Porosity	Permeability	Grain Density
5.7	0.04	2.67
3.4	0.03	2.69
11.3	0.04	2.69
10.2	0.09	2.69
15.3	0.17	2.67
17.5	7.68	2.57
12.6	0.13	2.67
15.0	0.20	2.66
12.9	0.10	2.68
14.6	0.15	2.68
14.1	0.55	2.68
9.8	2.24	2.69
9.3	0.04	2.68
13.9	0.30	2.70
14.8	0.48	2.66
14.9	0.76	2.70
16.4	11.00	2.64
16.7	8.72	2.65
13.0	0.04	2.66
15.1	7.92	2.66
13.8	3.20	2.67
6.1	0.39	2.69
4.7	0.02	2.68
4.1	0.02	2.69
4.1	0.02	2.69
8.0	0.04	2.67
13.9	0.50	2.66
15.6	1.06	2.65
15.8	0.90	2.66
15.6	0.85	2.66
14.9	0.73	2.67

Core 4 consists of light-gray and tan, locally crossbedded, micaceous sandstone interbedded with gray, thinly laminated, micaceous siltstone and mudstone. The sand is moderately well sorted. The subangular sand grains range in size from very fine to medium. Minerals present include quartz, feldspar, biotite, muscovite, clay, calcite, and rare pyrite. The calcite occurs mainly as cement and as subhedral, sparry vein filling. The sediments are tan colored and more indurated in zones of extensive calcite cementation. There is also some clay and silica cement. A few dark-gray, black, and green lithic fragments are present. Lignite and coal fragments occur throughout the core but are more concentrated in mudstone and siltstone laminae. Slickensides are locally present, indicating minor movement after consolidation. Some soft sediment deformation is also apparent.

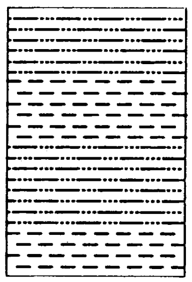
A "diesel" odor was noted and there was fluorescence on fractured surfaces, but no visible oil staining.

This core is from the Kulthieth Formation and is late Eocene in age. The environment of deposition was outer neritic to upper bathyal.

Conventional core 4. Porosity (in percent), permeability (in millidarcies), and grain density (gm/cm^3) from Core Laboratories reports.

Depth (Feet)

14,588'
14,590'
14,595'
14,597'



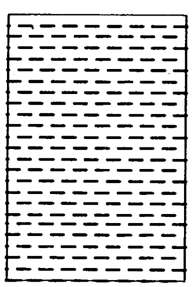
Porosity	Permeability	Grain Density
15.3	1.32	2.73
9.8	0.22	2.74
9.6	3.20	2.72

Core 5 consists of well-indurated, gray and tan, horizontally laminated, micaceous siltstone and claystone. Fine-grained quartz sand is present in minor amounts. Abundant fractures, some with slickensides, are filled with a soft, white, crystalline vein-filling made up of clays, calcite, and possibly zeolites. Coal fragments and rare pyrite are present.

This core is from the Kulthicth Formation and is middle Eocene in age. The environment of deposition was outer neritic to upper bathyal.

Depth (Feet)

17,799'
17,804'
17,808'



Core 6 consists of dark-gray and black, well-indurated silty claystone. Microfractures exhibiting slickensides or filled with crystalline calcite and clay are present. Pyrite is sparsely disseminated throughout the rock but is more concentrated in randomly oriented burrows.

This core is from the Oily Lake siltstone and is early to middle Eocene in age. The environment of deposition was middle to lower bathyal.

Conventional cores 5 and 6. Porosity (in percent), permeability (in millidarcies), and grain density (gm/cm^3) from Core Laboratories reports.

OCS Y-0211 No. 1 well sidewall core data (modified from Core Laboratories reports)

Depth (feet)	Porosity (percent)	Permeability (millidarcies)	Grain density (gm/cm^3)	Lithologic Description
5,724.0	34.1	50.0	2.75	fine- and very fine-grained silty clayey sandstone
5,741.0	36.5	76.0	2.75	fine- and very fine-grained silty clayey sandstone
8,600.0	28.1	76.0	2.72	fine- and very fine-grained sandstone with siltstone laminations
8,624.0	28.5	34.0	2.72	fine- and very fine-grained sandstone with siltstone laminations
8,668.0	26.3	25.0	2.72	fine- and very fine-grained sandstone with siltstone laminations
8,687.0	27.5	26.0	2.72	fine- and very fine-grained silty sandstone
8,974.0	26.7	23.0	2.67	fine- and very fine-grained silty sandstone
9,010.0	26.8	41.0	2.67	fine- and very fine-grained silty sandstone
9,038.0	27.1	30.0	2.67	fine- and very fine-grained silty sandstone
9,064.0	27.1	60.0	2.65	fine- and very fine-grained silty sandstone
9,166.0	27.5	50.0	2.69	fine- and very fine-grained silty sandstone
9,200.2	22.5	78.0	2.66	fine- and very fine-grained silty sandstone
9,330.0	22.5	26.0	2.70	fine- and very fine-grained sandstone with fine carbonaceous inclusions
9,336.0	22.3	14.0	2.69	very fine-grained shaly sandstone
9,347.0	25.7	26.0	2.67	fine- and very fine-grained calcareous silty sandstone
9,374.0	23.0	18.0	2.69	fine- and very fine-grained calcareous silty sandstone
9,390.0	23.5	11.0	2.68	fine- and very fine-grained calcareous silty sandstone
9,422.0	23.9	5.82	2.71	fine- and very fine-grained calcareous silty sandstone

(continued)

(continued: OCS Y-0211 No. 1, sidewall core data)

Depth (feet)	Porosity (percent)	Permeability (millidarcies)	Grain density (gm/cm^3)	Lithologic Description
9,444.0	28.7	-	2.70	fine- and very fine-grained calcareous silty sandstone
9,490.0	23.8	13.0	2.68	fine- and very fine-grained calcareous silty sandstone
9,602.0	26.3	47.0	2.64	fine- and very fine-grained calcareous silty carbonaceous sandstone
9,624.0	24.5	76.0	2.65	fine- and very fine-grained calcareous silty carbonaceous sandstone
9,640.0	26.2	-	2.65	fine- and very fine-grained calcareous silty carbonaceous sandstone
9,690.0	25.0	41.0	2.67	fine- and very fine-grained calcareous silty carbonaceous sandstone
9,728.0	22.7	43.0	2.68	fine- and very fine-grained shaly sandstone
9,769.0	27.4	53.0	2.74	fine- and very fine-grained calcareous silty sandstone
9,816.0	25.5	14.0	2.71	fine- and very fine-grained calcareous silty shaly sandstone
9,848.0	28.6	43.0	2.65	fine- and very fine-grained silty sandstone
9,870.0	25.1	63.0	2.63	coarse-, medium-, and fine-grained calcareous silty sandstone
9,894.0	25.9	66.0	2.63	coarse-, medium-, and fine-grained calcareous silty shaly sandstone
9,934.0	24.8	33.0	2.67	fine- and very fine-grained silty sandstone with carbonaceous laminations
9,962.0	26.3	23.0	2.65	fine- and very fine-grained silty sandstone with carbonaceous laminations
10,274.0	21.9	3.51	2.65	fine- and very fine-grained calcareous silty sandstone
10,311.0	23.3	15.0	2.64	fine- and very fine-grained calcareous silty sandstone with carbonaceous laminations

(continued)

(continued: OCS Y-0211 No. 1, sidewall core data)

Depth (feet)	Porosity (percent)	Permeability (millidarcies)	Grain density (gm/cm^3)	Lithologic Description
10,460.0	18.7	-	2.61	fine- and very fine-grained calcareous silty sandstone with carbonaceous laminations
10,477.0	23.0	-	2.63	fine- and very fine-grained calcareous silty sandstone with carbonaceous laminations
10,522.0	21.9	-	2.67	fine- and very fine-grained calcareous silty sandstone with carbonaceous laminations
10,604.0	21.3	-	2.62	fine- and very fine-grained calcareous silty sandstone
10,635.0	22.0	-	2.60	fine- and very fine-grained calcareous silty sandstone
10,942.0	18.8	2.09	2.68	fine- and very fine-grained calcareous silty shaly sandstone
11,148.0	23.4	-	2.64	fine- and very fine-grained calcareous sandstone
11,457.0	19.2	-	2.61	fine- and very fine-grained calcareous sandstone
11,660.0	18.0	-	2.61	fine- and very fine-grained calcareous sandstone
12,712.0	22.6	-	2.62	fine- and very fine-grained calcareous sandstone
14,012.0	22.5	-	2.67	very fine-grained calcareous sandstone
14,024.0	22.5	-	2.73	very fine-grained calcareous sandstone
14,091.0	28.2	-	2.65	very fine-grained calcareous sandstone
14,597.7	6.8	0.10	2.72	laminated shale and siltstone
14,768.0	23.3	-	2.61	fine- and very fine-grained calcareous sandstone
14,870.0	31.1	-	2.58	fine- and very fine-grained calcareous sandstone

Appendix G

Appendix G. FID pyrolysis and R_0 values from Gulf of Alaska onshore wells

		Depth (feet)	FID Pyrolysis[1]				R_o[2] ± 2σ @ 95% Confidence Level[3]
			TOC (wt. %)	S_1 (mg/g)	S_2 (mg/g)	S_2/TOC (mg/g)	
Richfield White River No. 2 well (1962)							
Pliocene–Pleistocene	Yakataga Fm	120–220					recycled
		1,200–1,320					recycled
		2,000–2,100					0.39 ± 0.07
		2,940–3,100					0.41 ± 0.08
Oligocene	Poul Creek Fm	4,040–4,160					0.59 ± 0.12
		5,020–5,140					0.52 ± 0.14
mid to late Eocene	Kulthieth Fm	6,100–6,200					insuffi. vitrinite
		6,940–7,060					0.52 ± 0.13
		7,820–7,940	0.35	0.028	0.011	3	0.52 ± 0.14
		8,540–8,874	0.79	0.035	0.092	12	0.56 ± 0.11
		9,320–9,460	0.32	0.038	0.040	13	0.50 ± 0.12
		9,700–9,860	0.50	0.042	0.046	9	0.52 ± 0.12
		10,280–10,500	0.45	0.046	0.057	13	0.50 ± 0.12
		10,900–11,020	0.64	0.035	0.082	13	0.44 ± 0.13
		11,440–11,620	0.53	0.029	0.083	16	0.45 ± 0.11
		12,100–12,340	0.90	0.072	0.321	35	0.51 ± 0.16
		TD: 12,417					

[1]FID pyrolysis performed by Mobil Exploration and Producing U.S., Inc.
[2]R_o values determined by Bujak Davies Group, Calgary, Alberta, Canada.
[3]Mean random vitrinite reflectance plus or minus two standard deviations at 95-percent confidence level.

		Depth (feet)	FID Pyrolysis[1] TOC (wt. %)	S_1 (mg/g)	S_2 (mg/g)	S_2/TOC (mg/g)	R_o[2] ± 2σ @ 95% Confidence Level[3]
Phillips Kerr McGee Sullivan No. 1 well (1954–1955)							
Oligocene	Poul Creek Fm	1,070–1,130					0.59 ± 0.13
		2,170–2,230					0.54 ± 0.09
		2,670–2,740					0.52 ± 0.10
		3,190–3,260					0.53 ± 0.13
late Eocene	Kulthieth Fm	4,210–4,320	0.52	0.073	0.051	10	0.51 ± 0.08
		4,900–4,970	0.60	0.095	0.123	21	0.51 ± 0.11
		5,560–5,590	0.54	0.038	0.005	1	0.49 ± 0.10
		6,030–6,080	0.52	0.064	0.005	1	0.49 ± 0.16
		6,550–6,610	0.28	0.045	0.001	0.4	0.50 ± 0.11
		7,030–7,060	0.64	0.078	0.139	22	0.53 ± 0.13
		7,870–7,930	0.72	0.062	0.406	56	0.52 ± 0.10
		TD: 10,013					
Phillips Kerr McGee Sullivan No. 2 well (1956–1957)							
Eocene–Oligocene(?)	Poul Creek Fm(?)	1,680–1,750					0.50 ± 0.11
		3,600–3,670	1.02	0.048	0.228	22	0.52 ± 0.15
late Eocene	Kulthieth Fm	4,240–4,300	0.64	0.038	0.086	13	0.49 ± 0.13
		4,700–4,760	0.77	0.029	0.073	9	0.52 ± 0.13
		6,070–6,100	0.14	0.010	0	0	0.59 ± 0.27
Oligocene	Poul Creek Fm (overturned strata)	6,600–6,650	0.59	0.038	0.059	10	0.56 ± 0.16
		7,160–7,200	0.62	0.044	0.065	10	0.59 ± 0.18
		7,740–7,790	0.58	0.035	0.055	9	0.55± 0.16
		8,270–8,370	0.29	0.018	0	0	0.55 ± 0.17
		9,390–9,430	0.35	0.052	0	0	0.55 ± 0.12
early–middle(?) Miocene		9,910–10,210	0.51	0.031	0	0	0.55 ± 0.12
		10,870–10,960	0.54	0.411	0.003	0.6	0.51± 0.11
		11,600–11,680	0.37	0.037	0.001	0.3	0.62 ± 0.09
		TD: 12,054					

[1]FID pyrolysis performed by Mobil Exploration and Producing U.S., Inc.
[2]R_o values determined by Bujak Davies Group, Calgary, Alberta, Canada.
[3]Mean random vitrinite reflectance plus or minus two standard deviations at 95-percent confidence level.

		Depth (feet)	FID Pyrolysis[1]				R_o[2] $\pm 2\sigma$ @ 95% Confidence Level[3]
			TOC (wt. %)	S_1 (mg/g)	S_2 (mg/g)	S_2/TOC (mg/g)	
Colorado Oil and Gas Co. Malaspina No. 1-A well (1962)							
Pliocene–Pleistocene	Yakataga Fm	900–9,270					recycled
		1,920–2,130					recycled
		3,090–3,270					recycled
		4,200–4,410					recycled
		5,490–5,760					recycled
		6,600–6,900					recycled
Eocene	Kulthieth Fm	8,280–8,580					0.53 ± 0.10
		9,090–9,270	0.27	0.047	0		0.51 ± 0.11
		9.810–9,990	0.27	0.029	0		0.53 ± 0.12
		10,560–10,740	0.50	0.023	0.004	0.8	0.50 ± 0.09
		11,160–11,370	0.44	0.021	0.040	9.1	0.52 ± 0.11
		11,880–12,060	0.26	0.051	0		0.53 ± 0.11
		12,510–12,750	0.19	0.013	0		0.54 ± 0.11
Cretaceous	Yakutat Group	13,350–13,560	0.51	0.034	0.001	0.20	0.73 ± 0.14
		13,816–13,823	0.73	0.021	0.069	9.0	0.80 ± 0.19
		TD: 13,823					

[1]FID pyrolysis performed by Mobil Exploration and Producing U.S., Inc.
[2]R_o values determined by Bujak Davies Group, Calgary, Alberta, Canada.
[3]Mean random vitrinite reflectance plus or minus two standard deviations at 95-percent confidence level.

		Depth (feet)	FID Pyrolysis[1]				R_o[2] ± 2σ @ 95% Confidence Level[3]
			TOC (wt. %)	S_1 (mg/g)	S_2 (mg/g)	S_2/TOC (mg/g)	
Colorado Oil and Gas Company Yakutat No. 1 well (1957)							
Eocene	Kulthieth Fm	6,480–6,640	0.65	0.077	0.005	0.77	
		7,145–7,285	2.79	0.089	0.493	18	
		7,965–8,155	1.33	0.056	0.273	21	
		8,515–8,575	0.86	0.022	0.075	9	
		9,165–9,295	1.12	0.075	0.104	9	
		TD: 9,314					
Colorado Oil and Gas Company Yakutat No. 2 well (1957–1958)							
Pliocene–Pleist. (?)	Yakataga Fm	1,980–2,210	0.90	0.147	0.302	34	
		2,700–2,760	0.46	0.034	0.022	5	
Cretaceous	Yakutat Group	3,300–3,390	0.51	0.103	0.148	29	
		3,690–4,140	0.40	0.028	0.001	0.25	
		4,590–4,680	0.37	0.024	0.011	3	
		5,310–5,430	0.48	0.088	0.062	13	
		5,910–6,030	0.45	0.084	0.071	16	
		6,480–6,600	0.44	0.104	0.043	10	
		7,110–7,230	0.59	0.169	0.090	15	
		7,740–7,860	0.36	0.046	0.009	2.5	
		8,280–8,370	0.58	0.066	0.056	10	
		8,850–8,970	0.45	0.107	0.029	6	
		9,480–9,600	0.52	0.235	0.166	32	
		10,110–10,230	0.59	0.125	0.114	19	
		10,700–10,790	0.80	0.605	0.332	41	
		11,120–11,210	0.83	0.766	0.326	39	
		11,600–11,720	0.63	0.102	0.130	21	
		TD: 11,765					

[1]FID pyrolysis performed by Mobil Exploration and Producing U.S., Inc.
[2]R_o values determined by Bujak Davies Group, Calgary, Alberta, Canada.
[3]Mean random vitrinite reflectance plus or minus two standard deviations at 95-percent confidence level.

		Depth (feet)	FID Pyrolysis[1]				R_o[2] ± 2σ @ 95% Confidence Level[3]
			TOC (wt. %)	S_1 (mg/g)	S_2 (mg/g)	S_2/TOC (mg/g)	
Colorado Oil and Gas Company Yakutat No. 3 well (1958–1959)							
Eocene	Kulthieth Fm	3,150–3,240	0.24	0.025	0		
		4,320–4,440	0.76	0.015	0.005	0.66	
		5,110–5,400	0.98	0.085	0.085	9	
		6,060–6,240	0.34	0.003	0		
		6,780–6,930	0.90	0.006	0.423	47	
Cretaceous	Yakutat Group	7,590–7,800	0.55	0.009	0.033	6	
		8,270–8,450	0.46	0.059	0.011	2	
		8,900–9,050	0.66	0.116	0.121	18	
		9,530–9,640	0.48	0.069	0.007	1	
		10,090–10,220	0.48	0.046	0		
		10,550–10,730	0.27	0.111	0.006	2	
		TD: 10,494					

[1]FID pyrolysis performed by Mobil Exploration and Producing U.S., Inc.
[2]R_o values determined by Bujak Davies Group, Calgary, Alberta, Canada.
[3]Mean random vitrinite reflectance plus or minus two standard deviations at 95-percent confidence level.

		Depth (feet)	FID Pyrolysis[1]				R_o[2] $\pm 2\sigma$ @ 95% Confidence Level[3]
			TOC (wt. %)	S_1 (mg/g)	S_2 (mg/g)	S_2/TOC (mg/g)	
Colorado Oil and Gas Company Dangerous River No. 1 well (1960)							
Pleistocene (?)	Yakataga Fm	920–1030					0.46 ± 0.11
		1,550–1,620	0.07	0.012	0		recycled
Cretaceous	Yakutat Group	1,810–1,890	0.30	0.008	0		1.07 ± 0.33
		2,390–2,500	0.68	0.003	0.015	2	1.07 ± 0.35
		2,980–3,070	0.59	0.007	0.021	4	1.01 ± 0.30
		3,510–3,610	0.50	0.025	0.008	16	insuffi. vitrinite
		3,990–4,120	0.68	0.047	0.027	4	0.98 ± 0.28
		4,560–4,660	0.49	0.029	0		0.95 ± 0.28
		5,090–5,210	0.52	0.043	0		1.19 ± 0.24
		5,690–5,820	0.75	0.067	0.085	11	1.21 ± 0.32
		6,300–6,420	0.64	0.095	0		1.16 ± 0.31
		6,910–6,990	0.67	0.063	0.069	10	1.26 ± 0.27
		7,500–7,590	0.51	0.053	0		no vitrinite
		8,510–8,610	0.31	0.019	0		1.49 ± 0.33
		TD: 8,630					

[1]FID pyrolysis performed by Mobil Exploration and Producing U.S., Inc.
[2]R_o values determined by Bujak Davies Group, Calgary, Alberta, Canada.
[3]Mean random vitrinite reflectance plus or minus two standard deviations at 95-percent confidence level.

Appendix H

Appendix H. Mud-additive petrography

Several drilling-mud additives were submitted to the Bujak Davies Group and to the Mineral Industries Research Laboratory of the University of Alaska for petrographic analyses to determine if these substances could be confused with indigenous organic matter and influence R_o determinations. These analyses were conducted primarily to determine whether mud additives could have caused the anomalous R_o values recorded in the upper 10,000 feet of the OCS Y-0211 No. 1 well. The additives submitted for analysis were provided by Magcobar/IMCO and NL Baroid of Anchorage or were obtained from other drilling projects. Unfortunately, none of the samples analyzed actually came from muds used during the drilling of the OCS Y-0211 No. 1 well. The results of these analyses are listed below.

Records from the OCS Y-0211 well contain references to the additives XP-20, Spercene, and Soltex. Significant amounts of the first two additives, XP-20 and Spercene, were used during drilling runs that produced the 0.47-percent (GeoChem Laboratories, Inc.) and 0.61-percent (Bujak Davies Group) populations. Dr. P. D. Rao of the University of Alaska (written comm., July 1989) reported that XP-20 contains 15.6 percent vitrinite and vitrinite-like material with a mean reflectance of 0.21 percent, 5.3 percent liptinitic macerals, and 79.1 percent mineral matter or transparent material. The Spercene contained 25 percent vitrinite-like material and 75 percent transparent material. The vitrinite-like material from the Spercene exhibited a reflectance below measurable limits. Spercene, particularly, reacted with the epoxy mounting medium producing strong fluorescence. The XP-20 did not react as vigorously with the epoxy but the liptinitic coal macerals did fluoresce. Another additive, Soltex, was mentioned by the operations geologist on the drill rig. The geologist noted that some of the traces of coal he logged might actually be Soltex. However, Bujak Davies (1988) said that it was not likely to be confused with vitrinite.

Four other additives were also analyzed—Carbonox (Baroid), Carbonox (Navarin Basin COST well), Durenex, and Q-Broxin—because they are in common use and because their names imply that carbonaceous material might be a significant constituent of the additive. Of these, only Carbonox offers any real potential for confusion with indigenous vitrinite. The Bujak Davies Group (1988) warned that Baroid Carbonox would be virtually indistinguishable from coaly materials of similar rank. In a sample of higher rank it could be mistaken for caved material. The Carbonox from the Navarin Basin COST No. 1 well might present a greater potential for confusion because it contained a second, higher reflectance population. No reference to Carbonox was encountered in the records from the OCS Y-0211 well that were available to the Minerals Management Service.

Mean reflectances of vitrinite and vitrinite-like substances in drilling-mud additives.

Mud Additive	Mean Reflectance (percent) (N = number of measurements)	Comments
XP-20 (Magcobar/IMOC)	0.21	Contains fluorescing liptinite and produces fluorescence in the epoxy mounting medium.
Spercene (Magcobar/IMOC)	Below detectable limits	Reacts with epoxy mounting medium to produce strong fluorescence.
Carbonox (Baroid)	0.392 ± 0.041, N=50	Potential for confusion with indigenous vitrinite population.
Carbonox (Navarin Basin COST well)	0.35 ± 0.03, N=21 0.51 ± 0.05, N=29	Potential for confusion with indigenous vitrinite population.
Durenex (Baroid)	$0.2 < R_o < 0.8$, N=10	Contains few but large vitrinite fragments.
Soltex (Navarin Basin COST well)		Contains no vitrinite and is unlikely to be confused with vitrinite.
Q-Broxin (Baroid, ferro-chrome ligno-sulfonate)		Contains no vitrinite and is unlikely to be confused with vitrinite.

Appendix I

Appendix I. Crude oil and biomarker analysis, Katalla No. 36 well

Analysis performed for the Minerals Management Service by GeoChem Laboratories, Inc., Houston, Texas, 1991.

Crude oil analysis results

Client I.D. No.: GI66A6P Katalla #36 PPCo

GROSS COMPOSITION	
Less than C_{15}+	37.0%
C_{15}+	63.0%
C_{15}+ COMPOSITION	
Paraffin-Naphthene Hydrocarbons (P-N)	57.0%
Aromatic Hydrocarbons (AROM)	19.2%
Asphaltene (ASPH)	13.0%
Eluted NSO Compounds (NSO)	4.8%
Noneluted NSO Compounds (NSO)	6.0%

RATIOS

$\frac{P-N}{AROM} = 3.0$ $\frac{ASPH}{NSO} = 1.2$

TABLE II-A. SATURATE HYDROCARBON ANALYSES

SUMMARY OF PARAFFIN-NAPHTHENE DISTRIBUTION

CRUDE OIL

GeoChem Sample	Interval	% Paraffin	% Isoprenoid	% Naphthene	CPI Index A[1]	CPI Index B[2]	ipC19/ ipC20	ipC20/ nC19	ipC20/ nC20
4061-001		33.3	4.8	61.9	1.03	1.13	2.64	.39	.46

TABLE II-B. SATURATE HYDROCARBON ANALYSES

NORMALIZED PARAFFIN DISTRIBUTION

CRUDE OIL

GeoChem Sample No.	1 nC15	2 nC16	3 nC17	4 ipC19	5 nC18	6 ipC20	7 nC19	8 nC20	9 nC21	10 nC22	11 nC23	12 nC24	13 nC25	14 nC26	15 nC27	16 nC28	17 nC29	18 nC30	19 nC31	20 nC32	21 nC33	22 nC34	23 nC35
4061-001	3.9	7.3	7.0	9.1	8.7	3.5	8.8	7.5	7.0	6.9	6.1	5.4	4.9	4.0	3.6	2.7	1.9	.8	.5	.2	.2	.1	.0

[1]C.P. Index A $= \dfrac{\dfrac{C_{21}+C_{23}+C_{25}+C_{27}}{C_{22}+C_{24}+C_{26}+C_{28}} + \dfrac{C_{21}+C_{23}+C_{25}+C_{27}}{C_{20}+C_{22}+C_{24}+C_{26}}}{2}$

[2]C.P. Index B $= \dfrac{\dfrac{C_{25}+C_{27}+C_{29}+C_{31}}{C_{26}+C_{28}+C_{30}+C_{32}} + \dfrac{C_{25}+C_{27}+C_{29}+C_{31}}{C_{24}+C_{26}+C_{28}+C_{30}}}{2}$

TABLE III.

CARBON ISOTOPE COMPOSITION (parts per mil, PDB)

SATURATES	AROMATICS
-26.67	-25.02

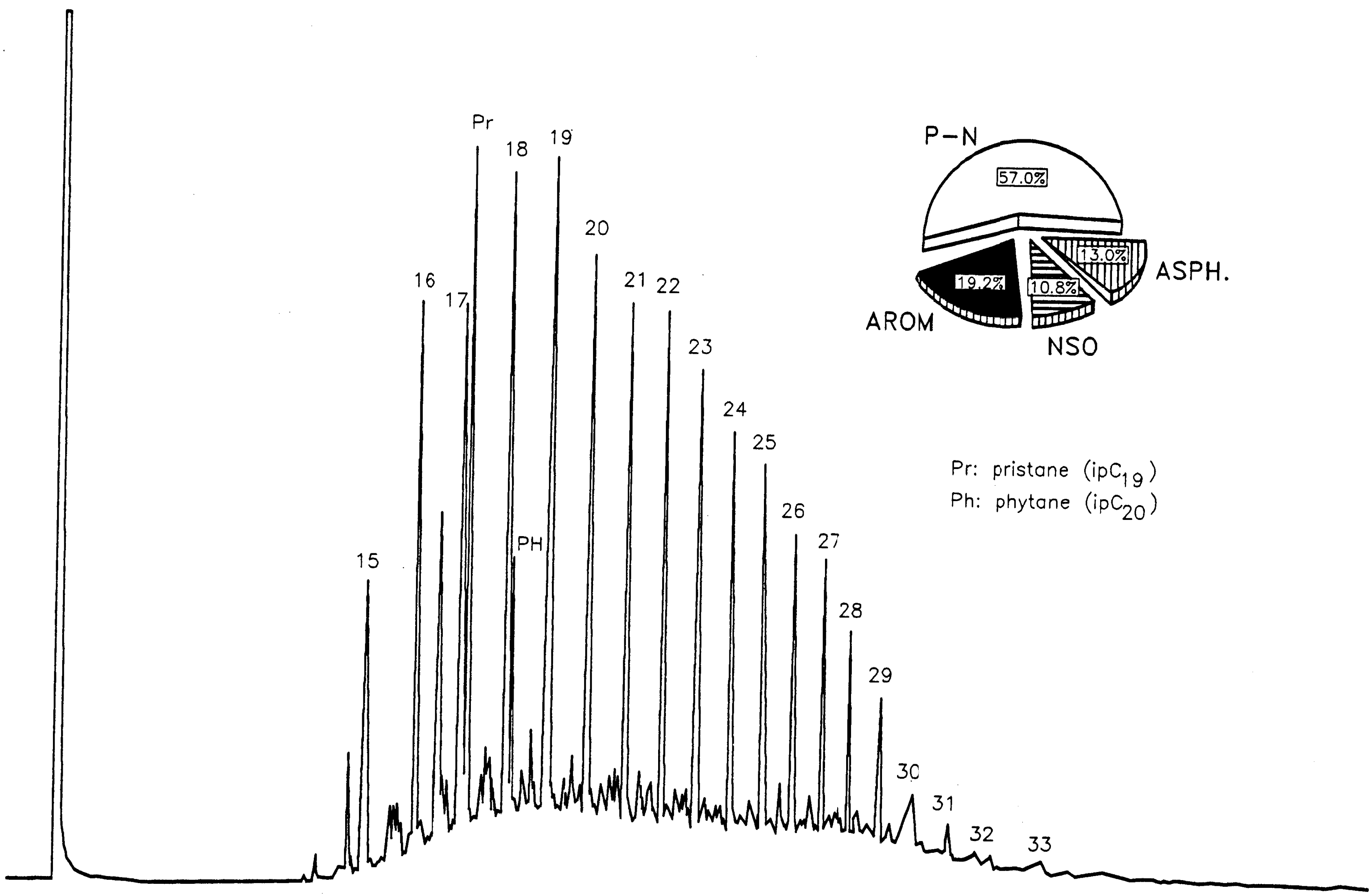

Pr
PH
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
P–N
57.0%
AROM
19.2%
NSO
10.8%
ASPH.
13.0%
Pr: pristane (ipC_{19})
Ph: phytane (ipC_{20})

TABLE IV

RELATIVE QUANTIFICATION OF STERANES

Chromatographic Identifier	Structural Assignment	m/z 217
A*	13B, 17a-Diacholestane (20S)	996
B*	13B, 17a-Diacholestane (20R)	634
C*	13a, 17B-Diacholestane (20S)	196
D*	13a, 17B-Diacholestane (20R)	137
E*	24-Methyl-13B, 17a-Diacholestane (20S)	259
F*	24-Methyl-13B, 17a-Diacholestane (20R)	627
G*	24-Methyl-13a, 17B-Diacholestane (20S) + 14a, 17a-Cholestane (20S)	1222
H*	24-Ethyl-13B, 17a-Diacholestane (20S) + 14B, 17B-Cholestane (20R)	1288
I*	14B, 17B-Cholestane (20S) + 24-Methyl-13a, 17B-Diacholestane (20R)	1242
J*	14a, 17a-Cholestane (20R)	1074
K*	24-Ethyl-13B, 17a-Diacholestane (20R)	1253
L*	24-Ethyl-13a, 17B-Diacholestane (20S) + 24-Methyl-14a, 17a-Cholestane (20S)	1135
M*	24-Methyl-14B, 17B-Cholestane (20R)	1251
N*	24-Ethyl-13a, 17B-Diacholestane (20R)	1144
O*	24-Methyl-14B, 17B-Cholestane (20S)	0
P*	24-Methyl-14a, 17a-Cholestane (20R)	1407
Q*	24-Ethyl-14a, 17a-Cholestane (20S)	1381
R*	24-Ethyl-14B, 17B-Cholestane (20R)	1107
S*	24-Ethyl-14B, 17B-Cholestane (20S)	988
T*	24-Ethyl-14a, 17a-Cholestane (20R)	1276

TABLE V

RELATIVE QUANTIFICATION OF TRI- AND PENTACYCLIC TERPANES

Chromatographic Identifier	Structural Assignment	m/z 191
A*	18a(H), 21B(H)-22, 29, 30-Trisnorhopane (Ts)	610
B*	17a(H), 21B(H)-22, 29, 30-Trisnorhopane (Tm)	467
Z*	17a(H), 18a(H), 21B(H)-28, 30-Bisnorhopane	0
C*	17a(H), 21B(H)-Norhopane	4036
C1*	C_{29} Terpane	1956
X*	C_{30} Terpane	872
D*	17B(H), 21a(H)-30-Normoretane	434
E*	17a(H), 21B(H)-Hopane	11484
F*	17B(H), 21a(H)-Moretane	2064
G*	17a(H), 21B(H)-Homohopane (22S)	3288
H*	17a(H), 21B(H)-Homohopane (22R)	2174
G1*	Gammacerane	0
I*	17B(H), 21a(H)-Homomoretane	198
J*	17a(H), 21B(H)-Bisnorhopane (22S)	1366
J1*	17a(H), 21B(H)-Bisnorhopane (22R)	1120
K*	17a(H), 21B(H)-Trisnorhopane (22S)	864
K1*	17a(H), 21B(H)-Trisnorhopane (22R)	561
L*	17a(H), 21B(H)-Tetrakis Homohopane (22S)	500
L1*	17a(H), 21B(H)-Tetrakis Homohopane (22R)	310
M*	17a(H), 21B(H)-Pentakis Homohopane (22S)	167
M1*	17a(H), 21B(H)-Pentakis Homohopane (22R)	254

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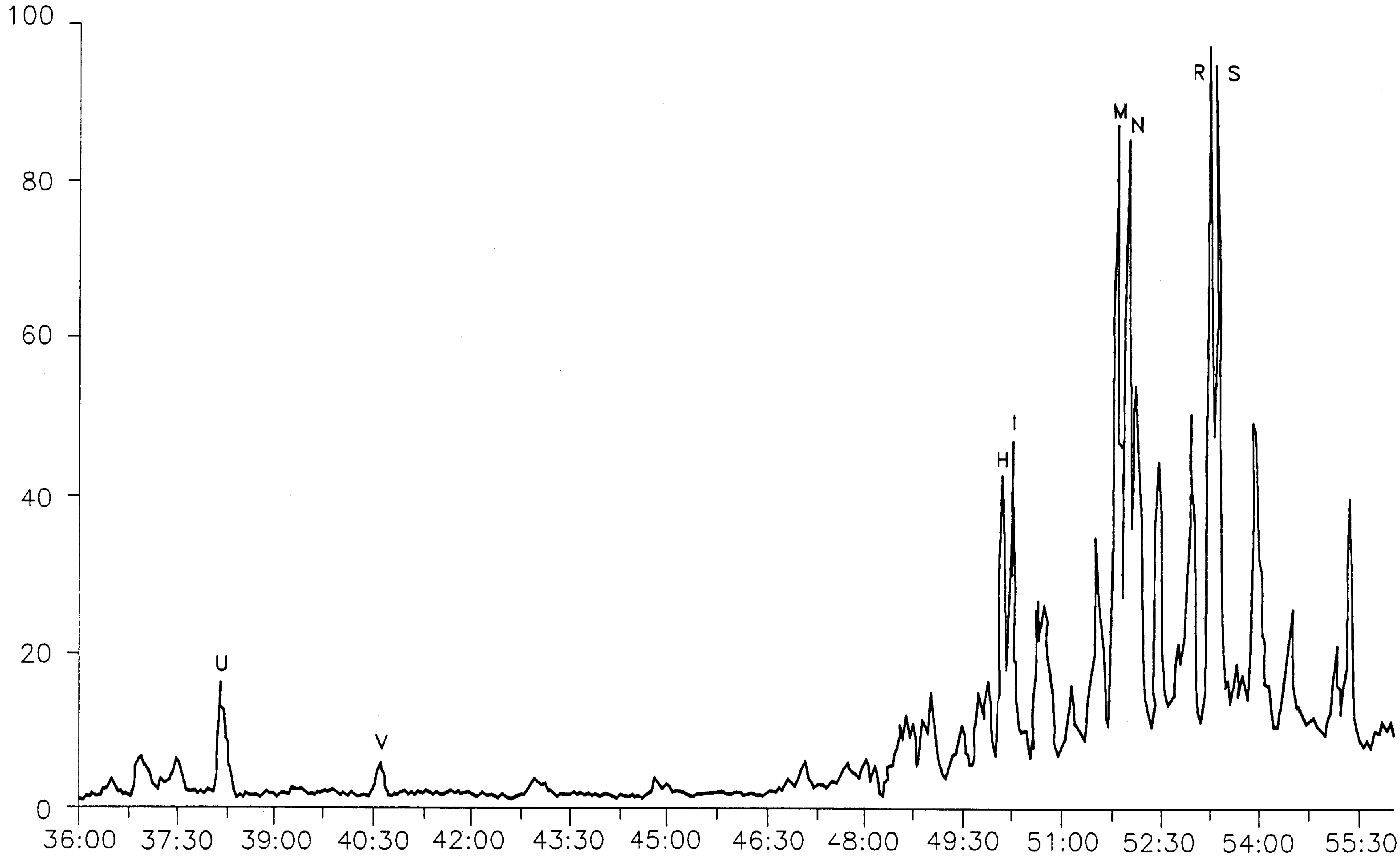

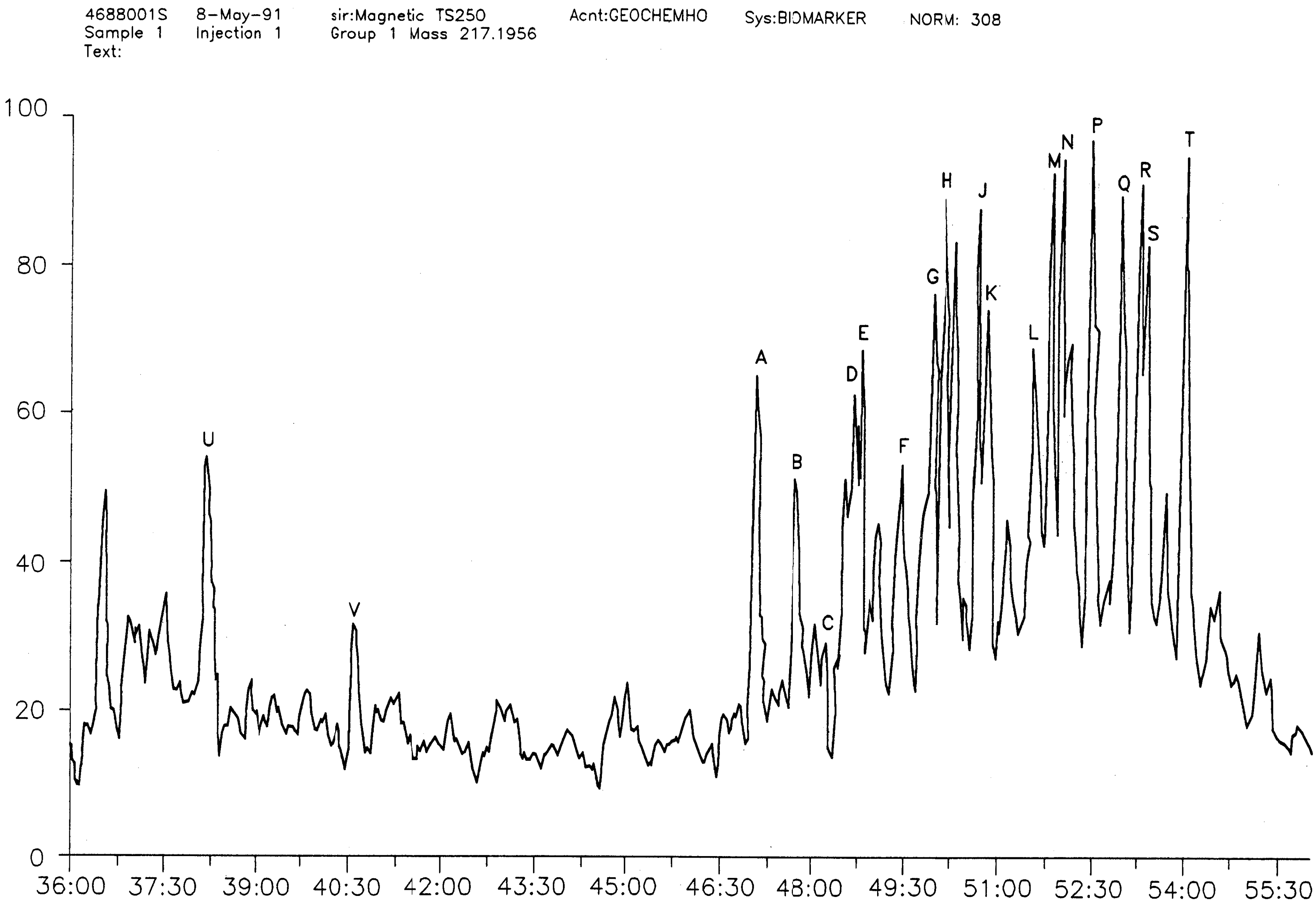
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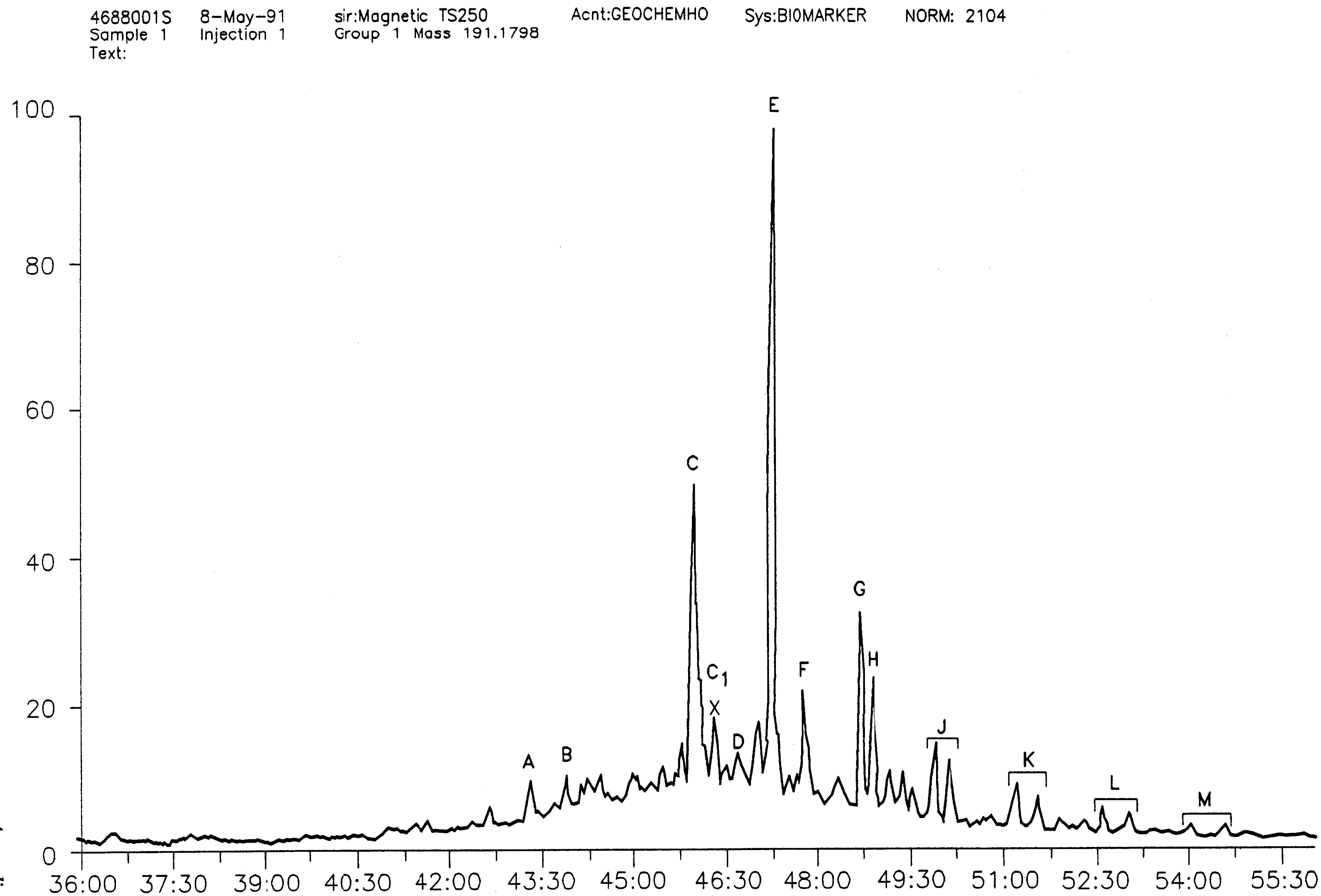
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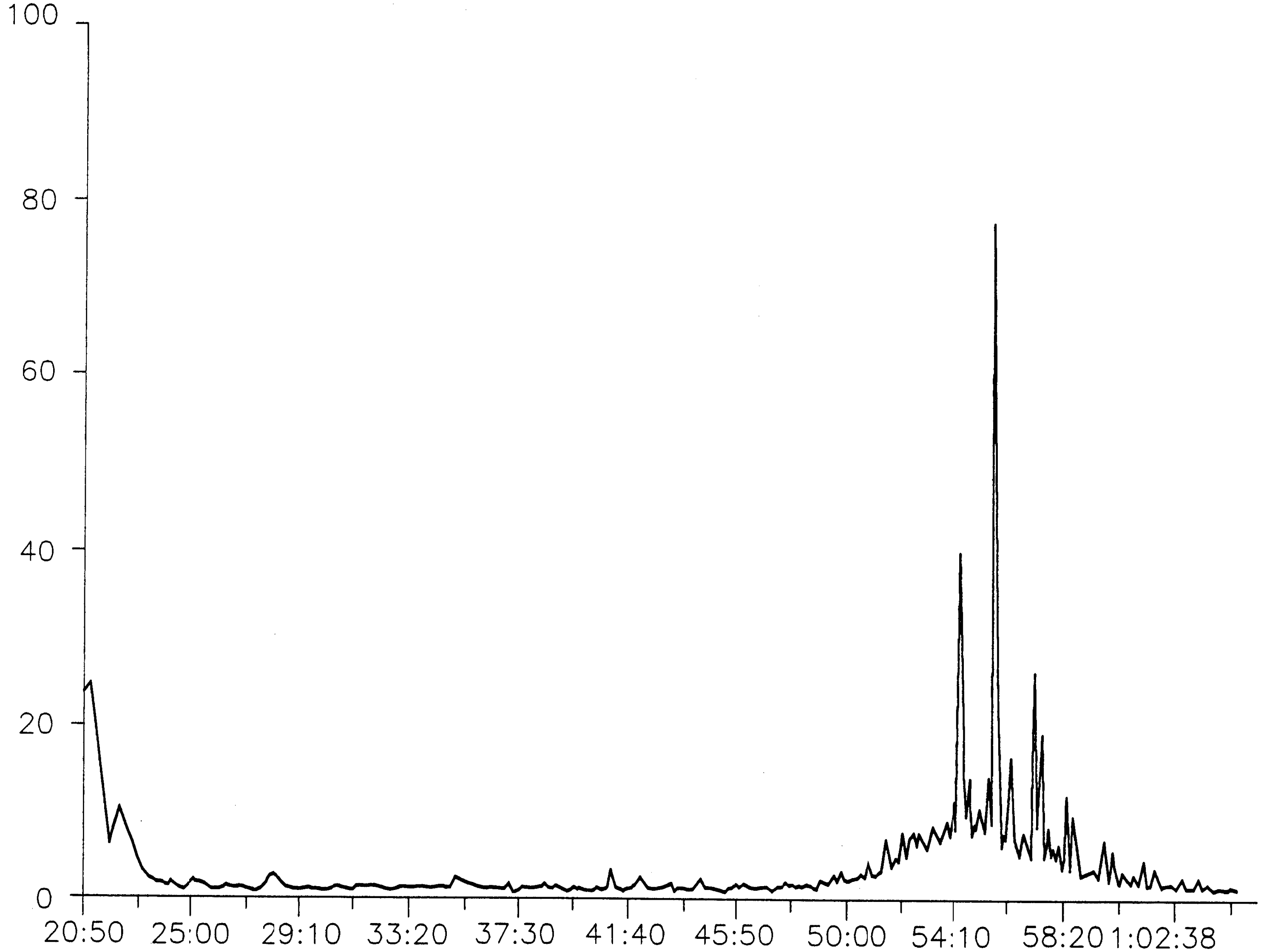

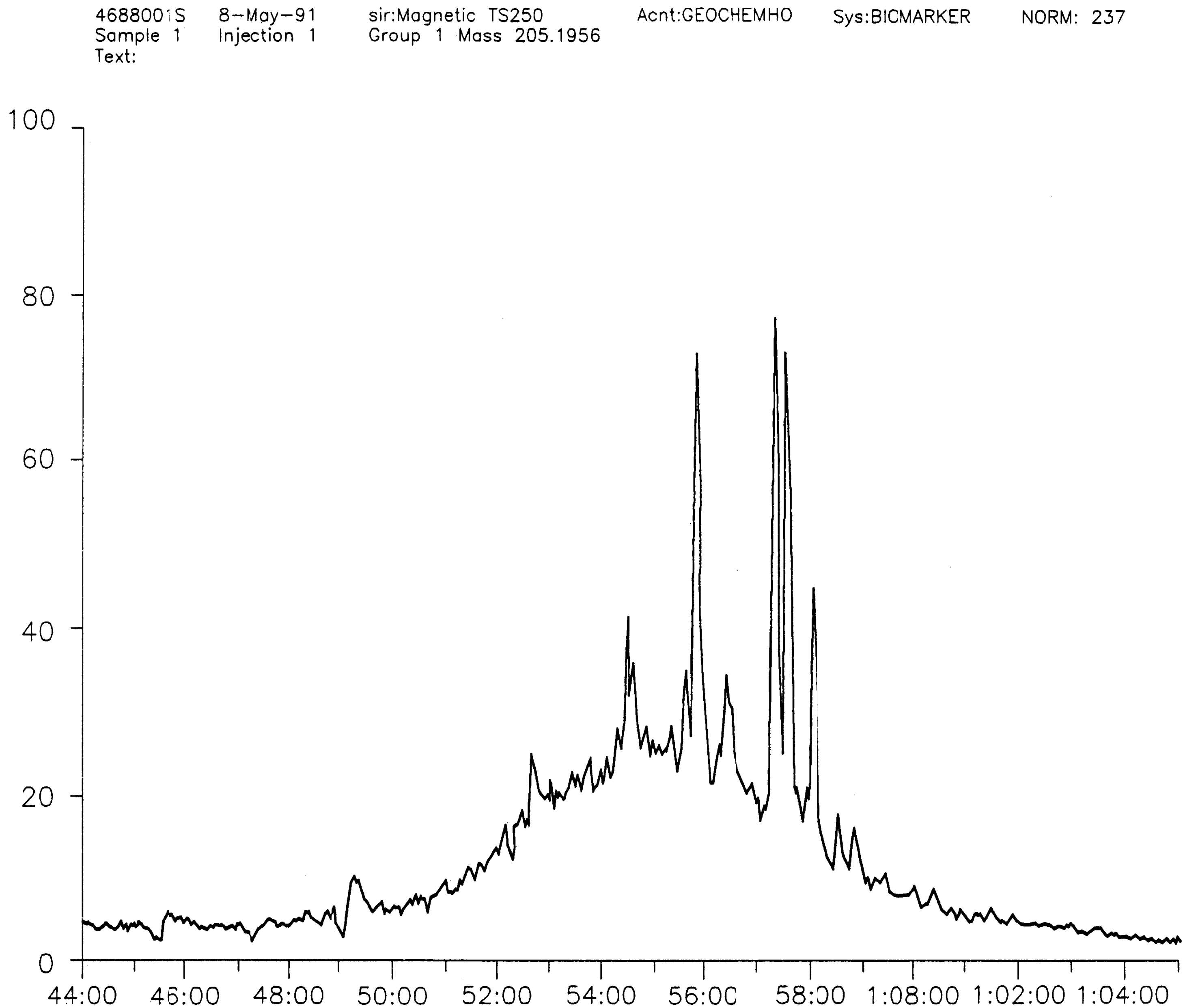

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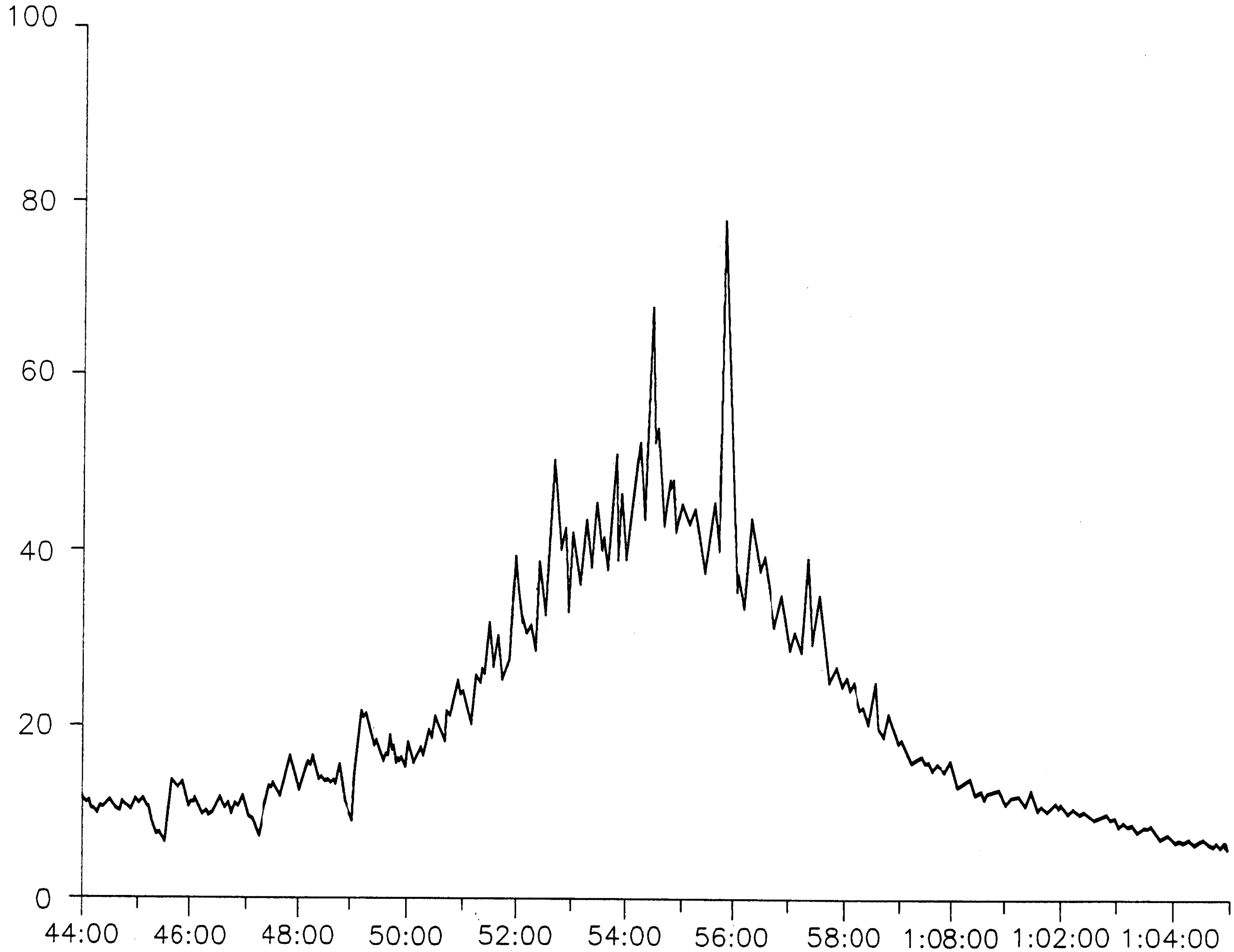

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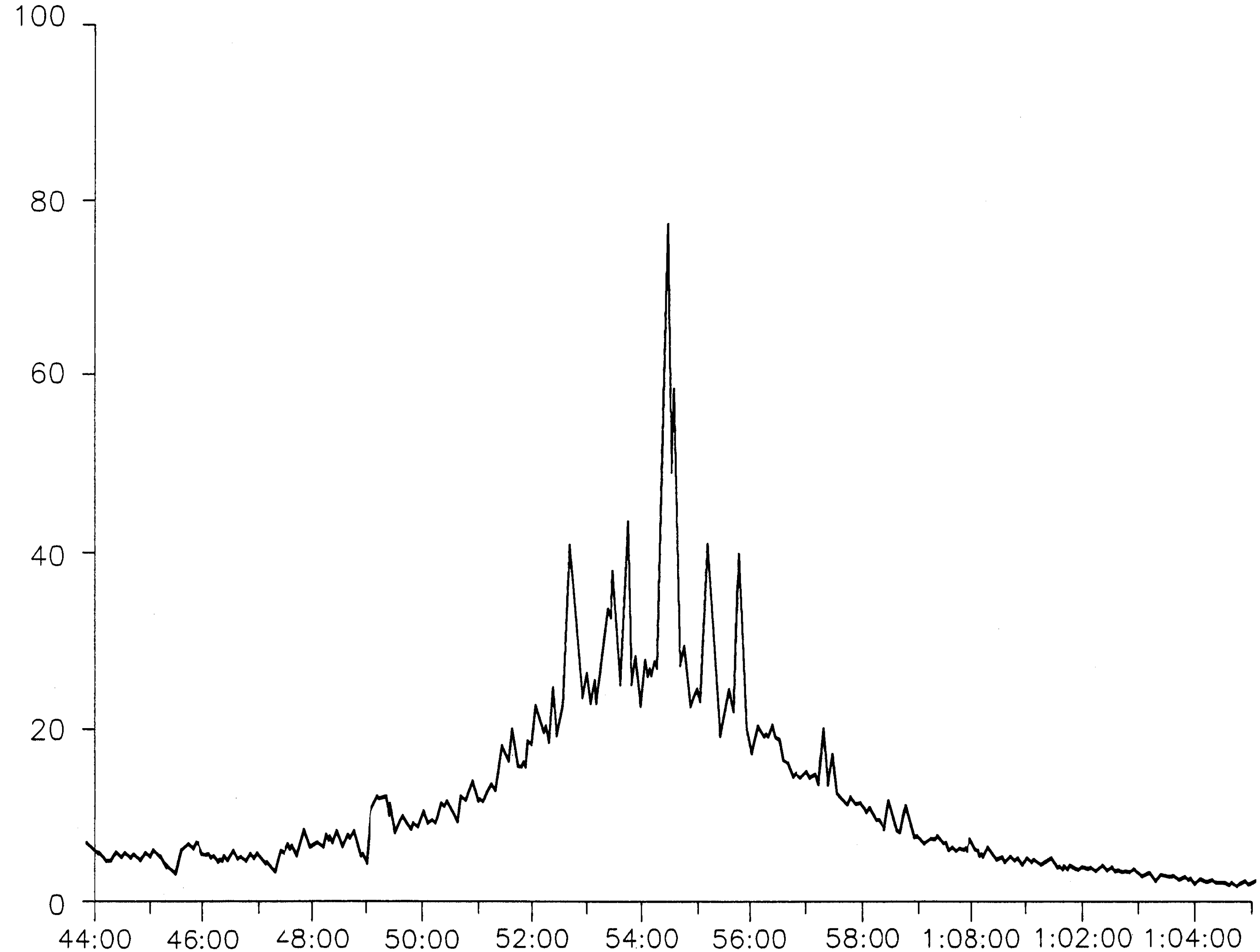

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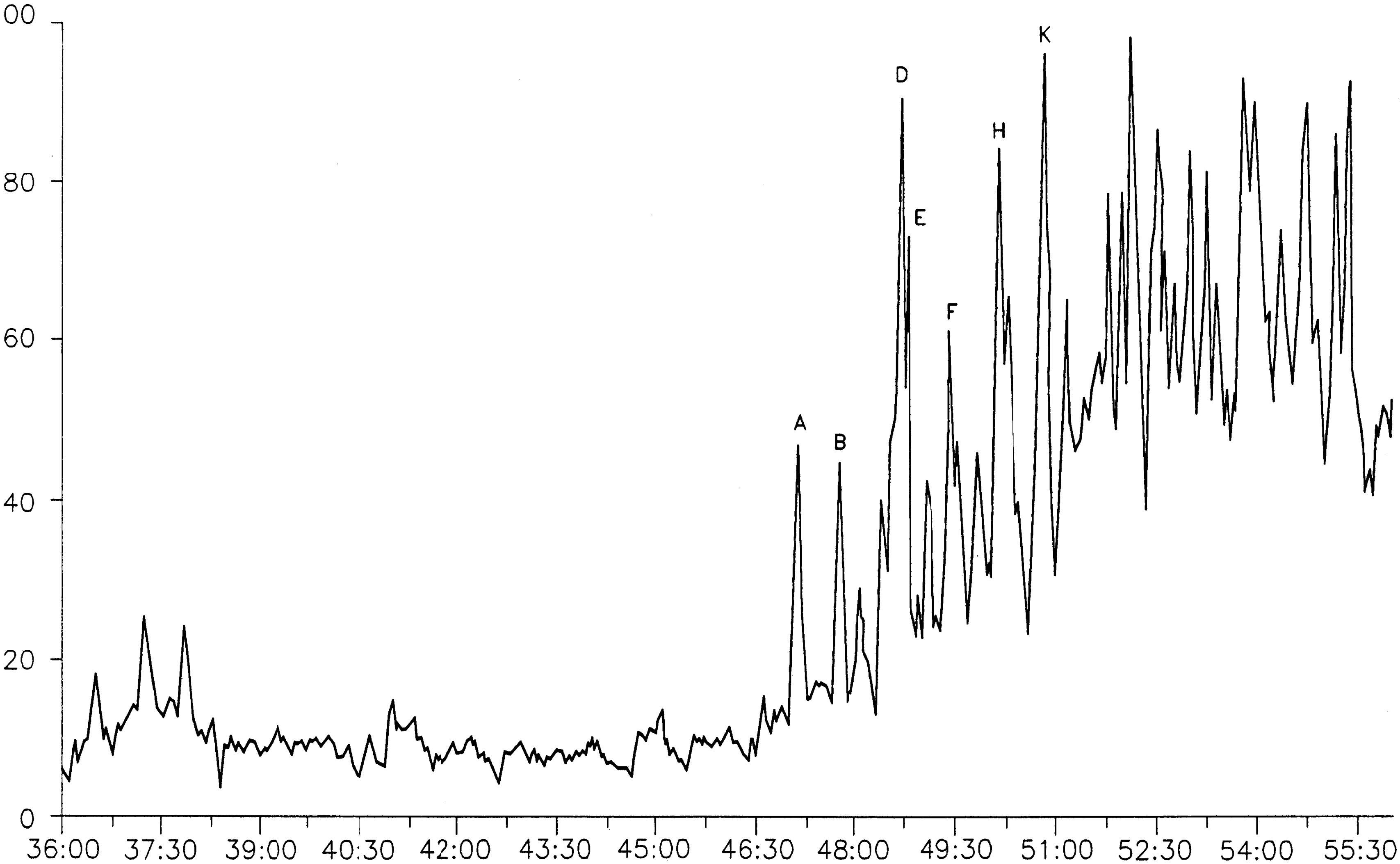

TABLE VI

QUANTITATIVE REVIEW

1. Relative composition of Tri- and Pentacyclic Terpanes and Steranes by Carbon Number

Steranes (m/z 218)		Tri- and Pentacyclic Terpanes (m/z 191)	
C_{27}	20.0	C_{27}	3.29
C_{28}	38.3	C_{28}	0.00
C_{29}	41.7	C_{29}	19.64
	———	C_{30}	44.06
	100.00	C_{31}	17.30
		C_{32}	7.60
		C_{33}	4.35
		C_{34}	2.48
		C_{35}	1.28
			———
			100.00

2. The relative percentages of Steranes and Terpanes calculated using m/z 217 and m/z 191:

   Steranes 36.3
   Terpanes 63.7

3. Maturity Ratio - Ratio of 17B(H) Normoretane to the sum of it and 17B(H) norhopane:

   Ratio: 0.10

4. Maturity Ratio - Ratio of 17a(H) 22S Homohopane to the sum of it and 17a(H) 22R Homohopane:

   Percent: 60.2

5. The ratio of the 22S/22R Epimers of the 17a(H), 21B(H)-Homohopanes (C_{31}-C_{35}) reach equilibrium at approximately 60/40 ratio (1 . 500) in a mature oil. Immature oils are lower.

   Ratio: 1.40

6. The ratio of Primary/Secondary Terpanes approaches one (decreases) as maturity increases:

   Ratio: 19.36

7. The ratio of 17a(H)-22, 29, 30-Trisnorhopane (Tm) / 18a(H)-22, 29, 30-Trisnorhopane II (Ts) decreases as maturity increases and migration occurs.

   Ratio: 0.77

8. The ratio of 17a(H), 21B(H)-Hopane/17B(H), 21a(H)-Moretane + 17B(H), 21a(H)-30-Normoretane increases as maturity increases.

   Ratio: 4.60

9. Percent of C_{29} 20S-Steranes to total C_{29} Steranes. (20S- / 20R- & 20S-Steranes) (Maturity and migration).

   Percent: 51.98%

10. A source character is the ratio of C_{29} Cholestane (20S & 20R) to C_{29} Isocholestane (20S & 20R): (Internal ratio of 5a-Steranes).

    Ratio: 1.27

11. A source character which is insensitive to maturation is 5a C_{28}/C_{29}:

    Ratio: 0.92

12. The ratio of 13B(H), 17a(H)(20R) C_{27} Sterane/13B(H), 17a(H)(20S) C_{27} Sterane increases with increasing biodegradation.

    Ratio: 0.64

(Table VI continued)

13. Source character - Ratio of Gammacerane to the sum of Gammacerane and 17a(H), 21B(H) Hopane.

    Ratio: 0.00

14. The ratio of $\frac{5a(H),\ 14B(H),\ 17B(H)}{5a(H),\ 14B(H),\ 17B(H) + 5a(H),\ 14a(H),\ 17a(H)}$ C_{29} Steranes increases with maturation.

    Percent: 44.09

15. The ratio of $\frac{22S}{22S + 22R}$ 17a(H), 21B(H), C_{32} Hopanes reaches to an equilibrium value of 0.55 to 0.60 due to maturation.

    Ratio: 0.55

16. The temperature dependent ratio of $\frac{17a(H),\ 21B(H)}{17a(H),\ 21B(H) + 17B(H),\ 21a(H)}$ C_{30} Hopanes increases with the conversion of less stable 17B(H), 21a(H) Isomer to its more stable 17B(H), 21B(H). This ratio can rise as high as unity with increasing maturity.

    Ratio: 0.85

Interpretive Aids

Sterane and triterpane analyses have been proven to be a practical and reliable means of classification and correlation of oils and source rock. Information obtained from the sterane and triterpane fingerprints allows determination of four key parameters: (1) Source, (2) Maturation, (3) Migration, (4) Biodegradation. The following are a list of referenced rules used to interpret each parameter. Also included is a glossary of commonly used terms.

A. Source Parameters

* Internal terpane ratios are source parameters. This includes the tricyclic terpanes and the hopanes. [8, 10, 11]
* Internal ratios 5α steranes are source parameters. [8, 10, 11]
* Internal ratios of mono-aromatic steranes are source parameters. [8, 10, 13]
* The presence of 17α(H),21β(H)-28,30-Bisnorhopane may indicate oil formation from fern constituents. [3]
* High concentrations of oleananes reflect a greater contribution of terrigenous biota to the source rock. [13, 2]
* Low oleananes and higher hopane fingerprints are expected for non-terrigenous (aquatic) source rock. [2]
* 5α C28/C29 sterane ratio is source specific and insensitive to maturation. [13]

B. Maturation Parameters

* The ratio of primary/secondary terpanes approaches one as maturity increases. [8]
* The ratio of 17α(H)-22,29,30-Trisnorhopane (Tm)/18α(H)-22,29,30-Trisnorhopane II (Ts) decreases as maturity increases. [8,13]
* The increase in paraffins and the decrease in biomarkers indicates either maturity or migration. [8]
* The concentration of 17α(H),21β(H)-28,30-Bisnorhopane decreases with increasing maturity. The ratio of 17β(H),21α,(H)-28,30-Bisnorhopane/17α(H),21β(H)-Hopane decreases as maturity increases. [3]
* The ratio of 17α(H),21β(H)-Hopane/(17β(H),21α(H)-Moretane + 17β(H),21α(H)-30-Normoretane) increases as maturity increases. [5, 7, 12, 13]
* The ratio of 17α(H)-22,29,30-Trisnorhopane (Tm)/17β(H)-22,29,30-Trisnorhopane increases as maturity increases. Occurrence of 17β(H)-22,29,30-Trisnorhopane is observed in petroleum and source rock only in isolated cases of extremely mild diagenesis conditions. [7,12]
* The presence of 17β(H),21β(H)-Hopanes indicates the lack of thermal stress and immaturity. The 17β(H),21β(H) isomers are found in living organisms and shales of little thermal stress. [5, 12, 13]
* The ratio of the 22S/22R epimers of the 17α(H),21β(H)-homohopanes (C31-C34) reach equilibrium at a 60/40 ratio in a mature oil. Immature oils are dominated by the 22R isomer. [10, 11, 12, 13]
* The ratio of Mm1/Mm2 (two C28 mono-aromatic steranes) increases for oils of less maturity. This is strictly a maturation parameter. [8]
* The ratio of 5α(20S) steranes/5α(20R) steranes increases with increasing maturity. [5, 11, 13]
* The ratio of Mm (C28 mono-aromatic sterane)/Ms (C20 mono-aromatic sterane) approaches zero for a mature oil. [8]
* The ratio of Ms' (C21 mono-aromatic sterane)/Ms (C20 mono-aromatic sterane) approaches zero for a mature oil. [8]
* 5α steranes are thermodynamically more stable than 5β steranes. The ratio of 5α steranes/5β steranes should increase for increasing maturity. [6]

C. Migration Parameters

* The increase in paraffins and the decrease in biomarkers indicates either migration or maturation. [8]
* The ratio of 5β/5α steranes increases with increased migration. This is strictly a migration parameter. [8]
* Tricyclic terpanes migrate faster than the 17α(H)-hopanes. Ratio of 17α(H),21β(H)-hopanes/tricyclic terpanes increases with increasing migration. [13]

* The ratio of 17α(H)-22,29,30-Trisnorhopane (Tm)/18α-22,29,30-Trisnorhopane II (Ts) decreases with migration and maturity. [11, 13]
* The ratio of 5β steranes/17α(H),21β(H)-hopanes is a migration parameter. The ratio increases with migration for oils of a common source. [8]
* The ratio of (C27 + C28 + C29) 13β,17α(20S)/5α,14α,17α(20R)(C27 + C28 + C29) increases with increased migration. [10]

D. Biodegradation Parameters

* Regular steranes are destroyed by biodegradation. [1, 9]
* Diasteranes (rearranged steranes) survive biodegradation but do decrease in concentration. [1, 9]
* Tricyclic triterpanes survive even heavy biodegradation. [1, 9]
* Biodegradation causes decrease in the n-paraffin content. [1, 9]
* Biodegradation causes decrease in the isoprenoid compounds. [1, 9]
* Biodegradation is thought to at least partially degrade the pentacyclic terpanes (primarily the hopane series). [1]
* The ratio of 13β(H),17α(H)(20R)C27 sterane/13β(H),17α(H)20S)C27 sterane increases with increasing biodegradation. [9]

E. Glossary of Terms

* Primary terpanes - C29 + C30 hopanes (Norhopanes + Hopanes) [8]
* Secondary terpanes - C27 + C28 hopanes (Trisnorhopanes + Bisnorhopanes). [5]
* Tm - 17α(H)-22,29,30-Trisnorhopane - A C27 hopane structure. [8]
* Ts - 18α(H)-22,29,30-Trisnorhopane - A C27 terpane structure. [8]
* Regular steranes - steranes with the methyl groups on the ring system at the 10 and 13 positions. [7, 8, 9, 10]
* Diasteranes (rearranged steranes) - steranes with methyl groups on the ring system at the 5 and 14 positions. [7, 8, 9, 10]
* Mm1 - A C28 mono-aromatic sterane. [8, 10, 13]
* Mm2 - A C28 mono-aromatic sterane. [8, 10, 13]
* Ms - A C20 mono-aromatic sterane. [8, 10, 13]
* Ms' - A C21 mono-aromatic sterane. [8, 10, 13]

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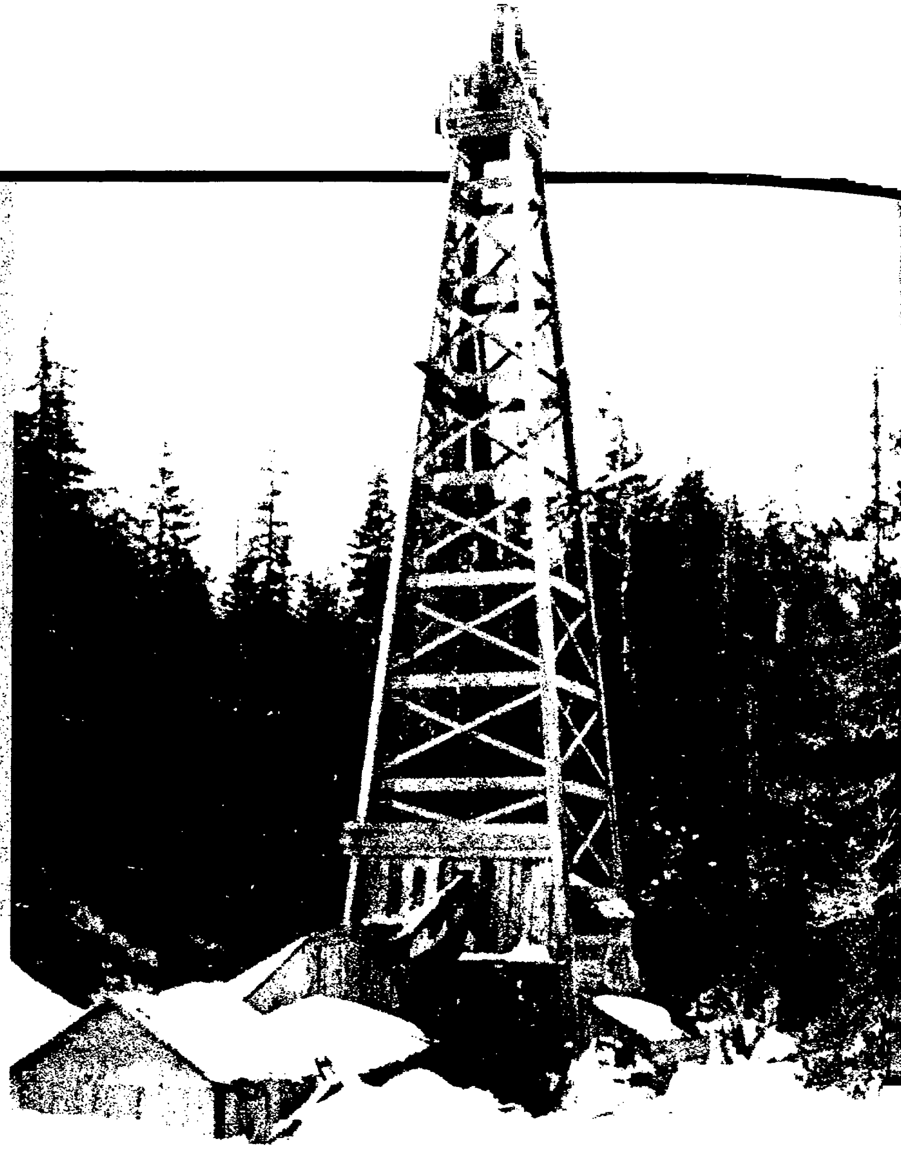

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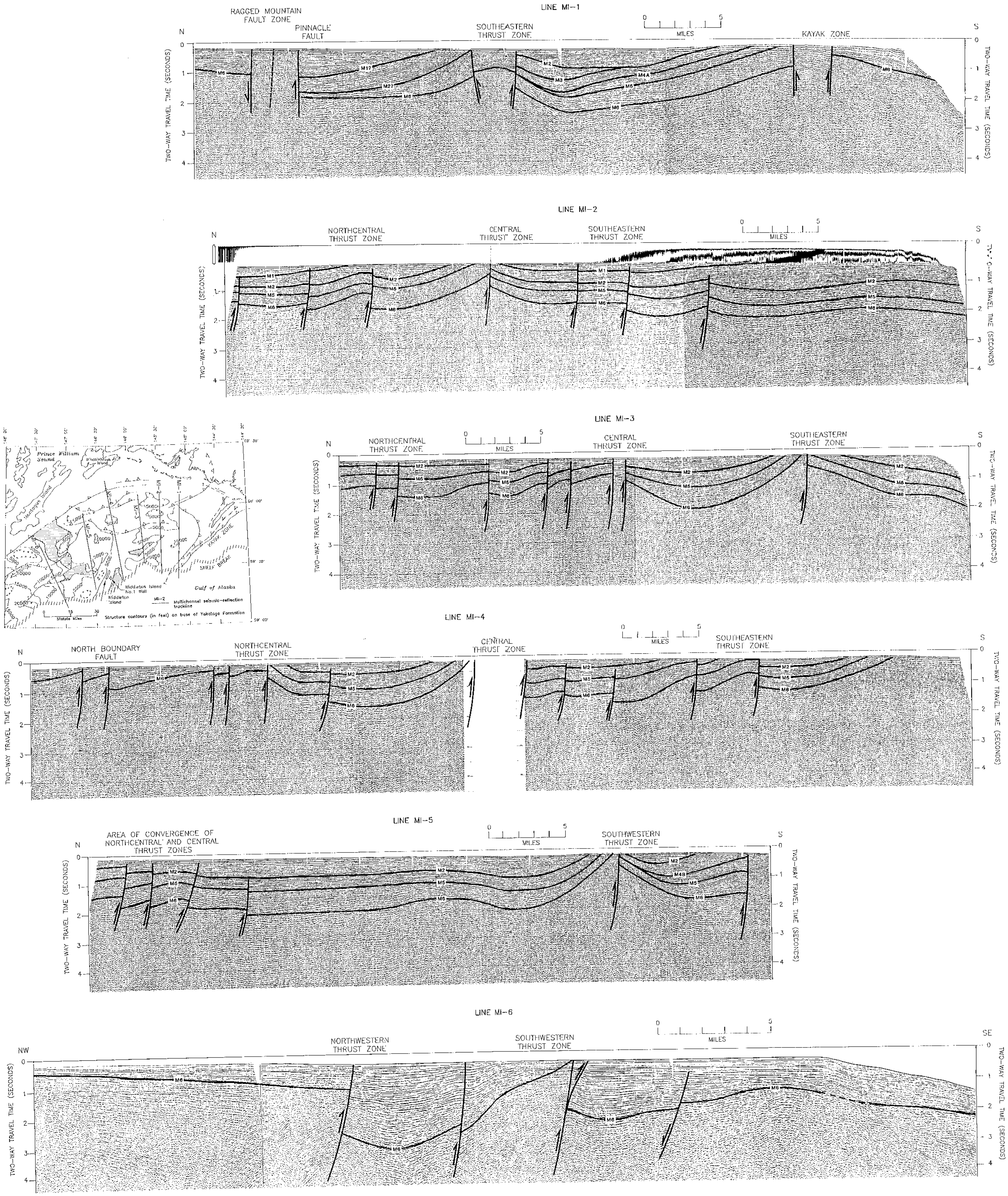


PLATE 1. Multichannel seismic–reflection profiles across the Middleton segment of the Gulf of Alaska continental margin, displaying the stratigraphic framework and structural geology. Lines MI–1 through MI–5 courtesy of Petroleum Information. Line MI–6 courtesy of Digicon Geophysical Corporation.

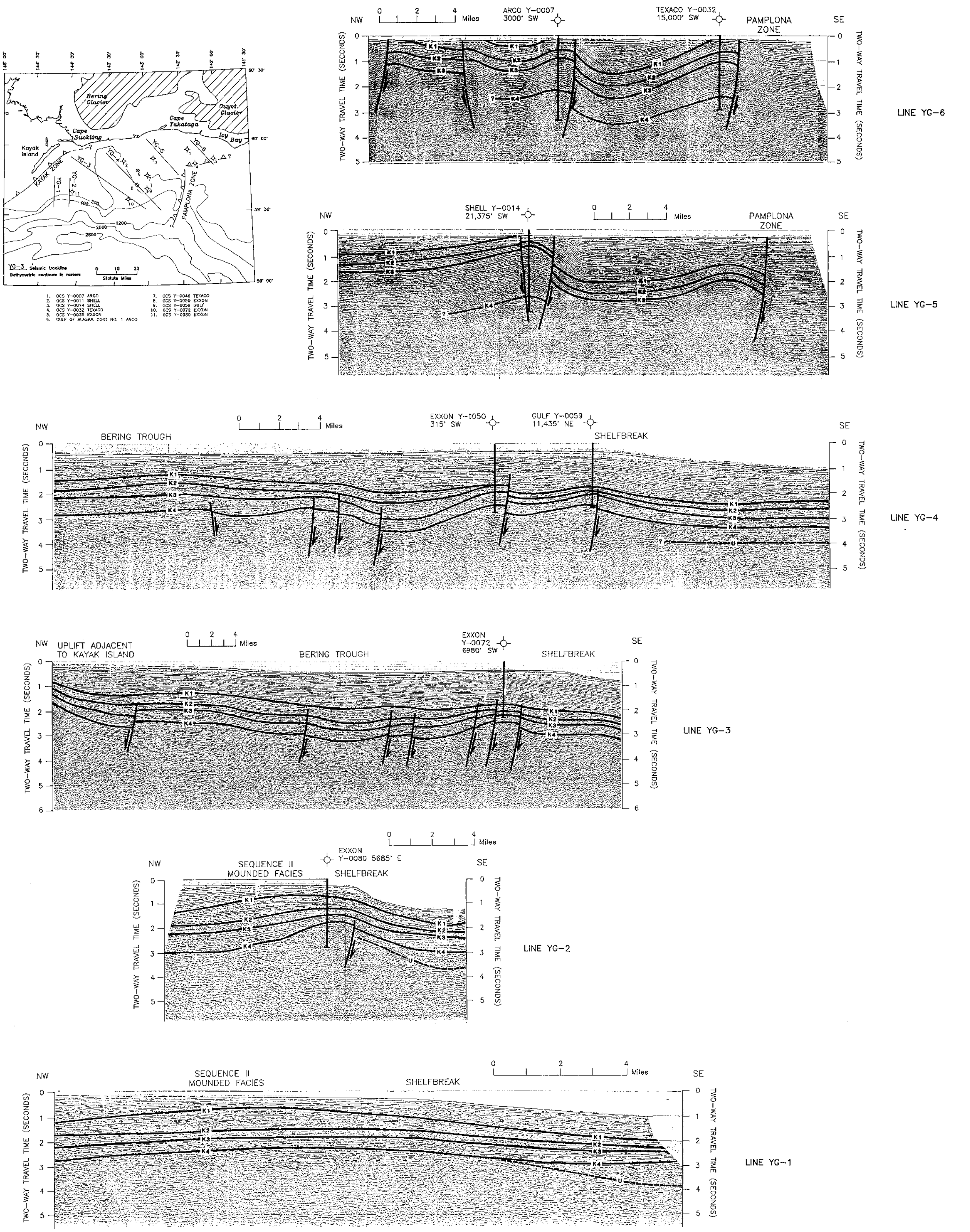


PLATE 2. Multichannel seismic-reflection profiles across the Yakataga segment of the Gulf of Alaska continental margin, displaying the stratigraphic framework and structural geology. Lines YG-1, YG-2, and YG-4 through YG-6 courtesy of Amoco Production Company. Line YG-3 courtesy of Grant-Norpac.

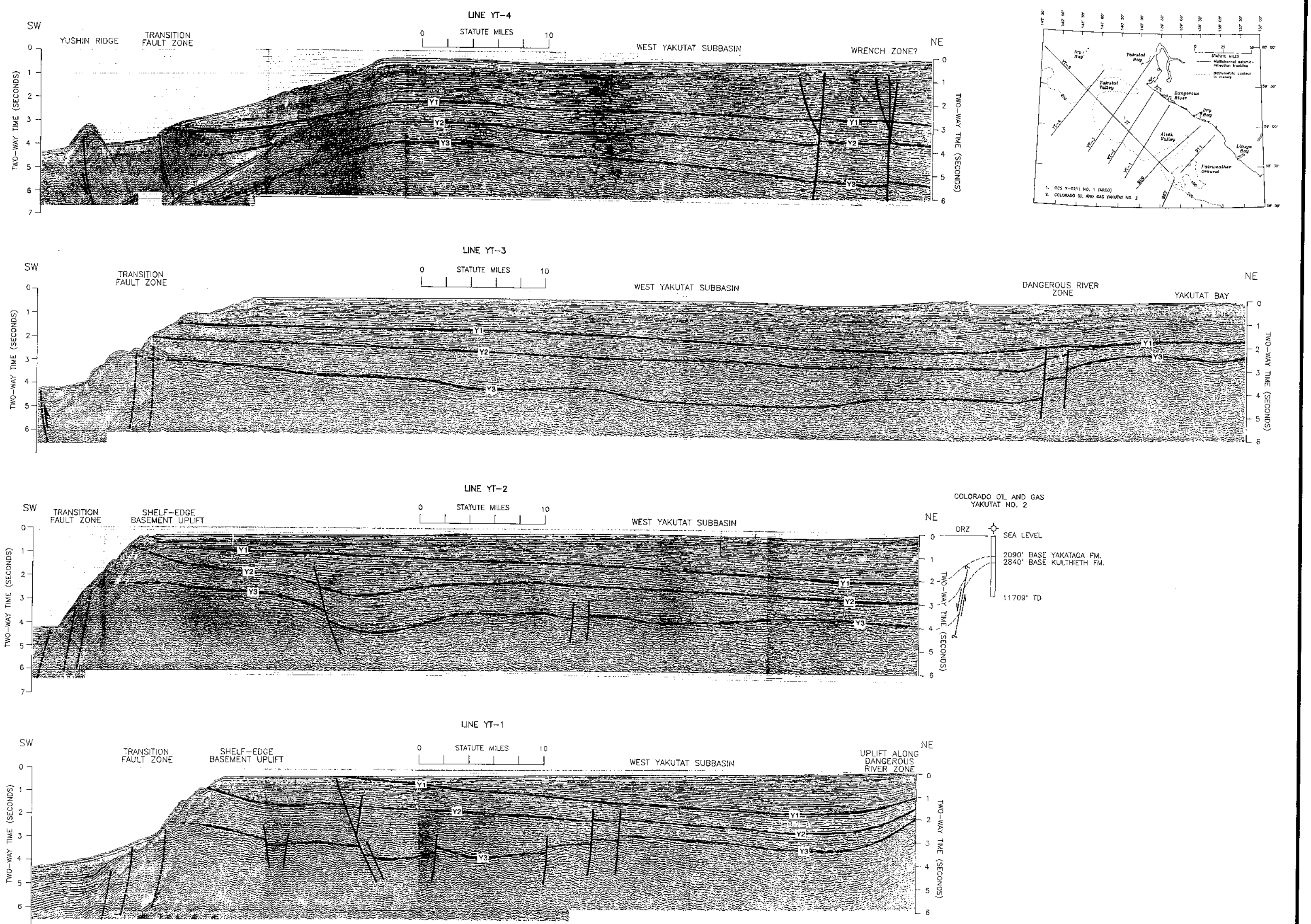


PLATE 3A. Multichannel seismic–reflection profiles across the Yakutat segment of the Gulf of Alaska continental margin, displaying the stratigraphic framework and structural geology. Seismic profiles YT–1 through YT–4 courtesy of an anonymous donor.

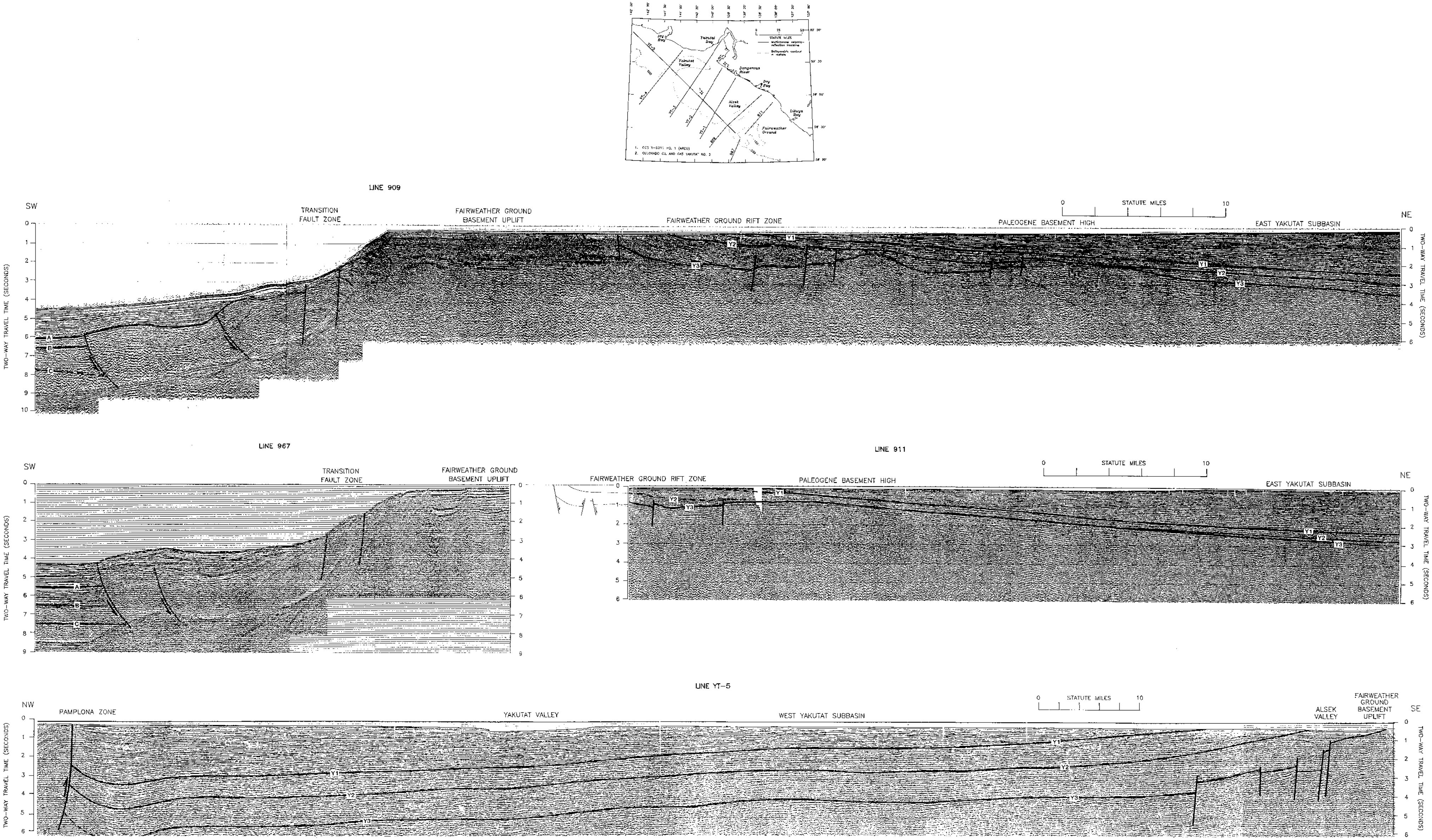


PLATE 3B. Multichannel seismic-reflection profiles across the Yakutat segment of the Gulf of Alaska continental margin, displaying the stratigraphic framework and structural geology. Seismic profile YT-5 courtesy of an anonymous donor. Lines 909 and 911 acquired by the U.S. Geological Survey in 1977. Line 967 acquired by the U.S. Geological Survey in 1978.

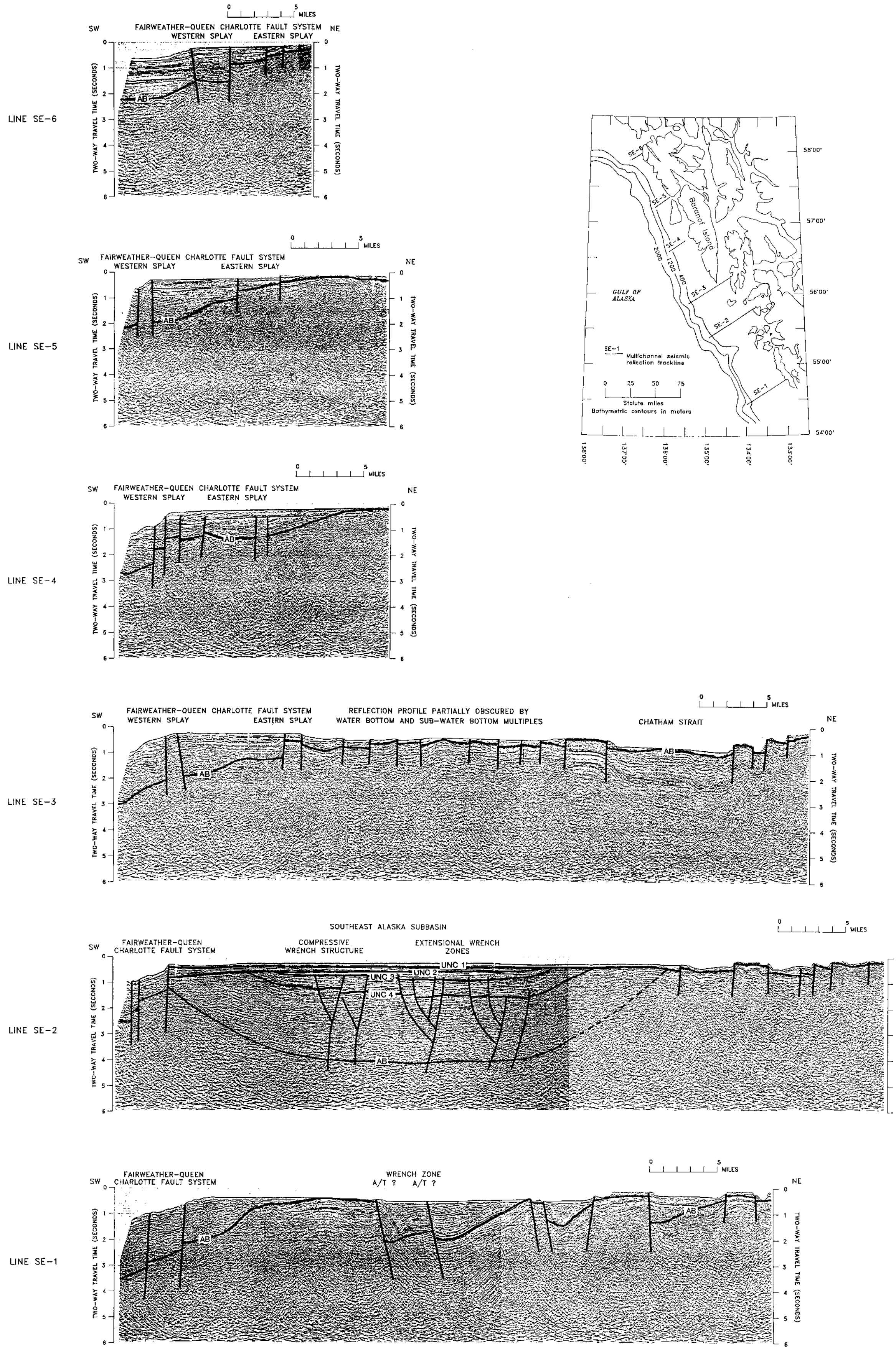
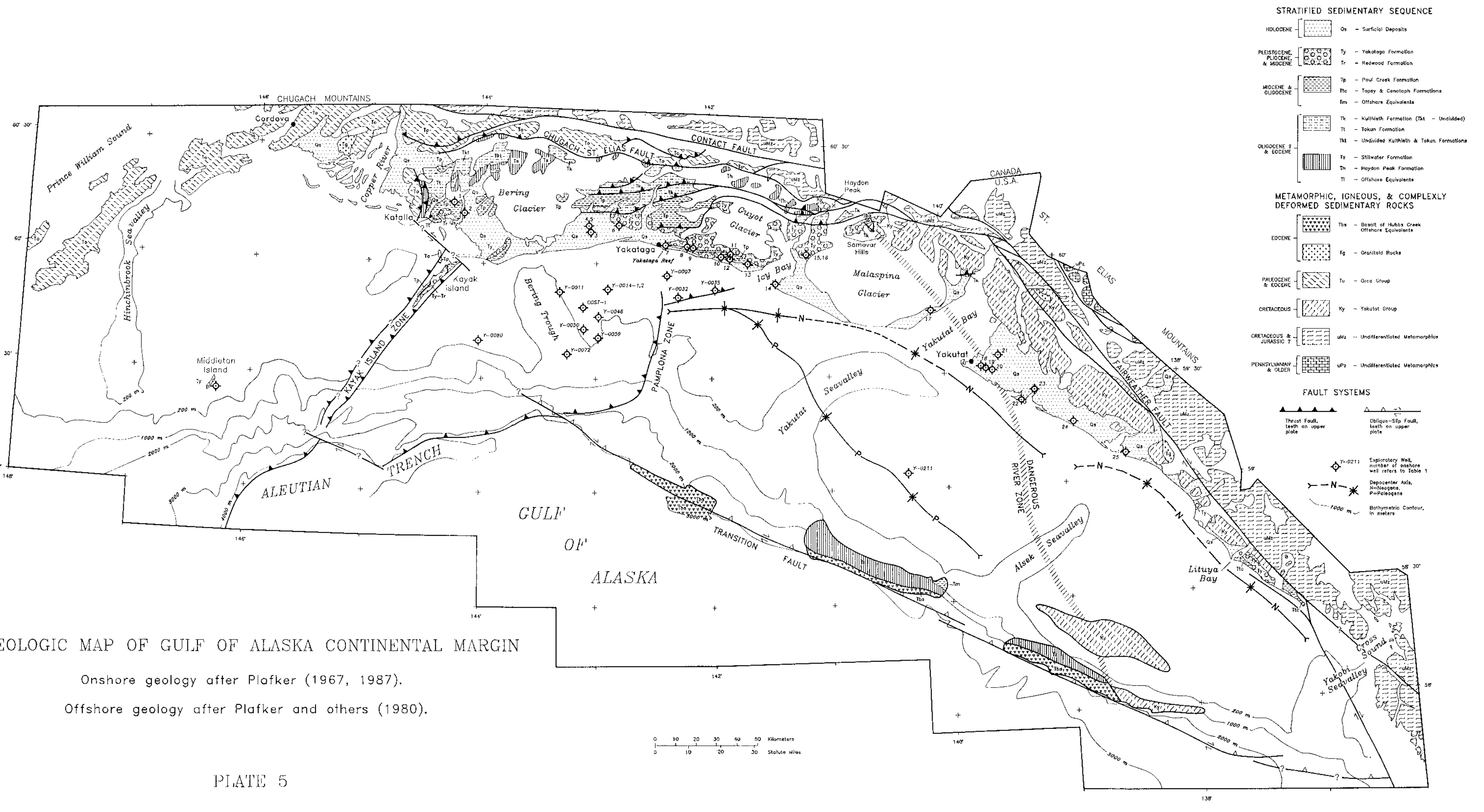


PLATE 4. Multichannel seismic–reflection profiles across the Southeast segment of the Gulf of Alaska continental margin, displaying the stratigraphic framework and structural geology. Seismic profiles SE–1 through SE–6 courtesy of an anonymous donor.



GEOLOGIC MAP OF GULF OF ALASKA CONTINENTAL MARGIN

Onshore geology after Plafker (1967, 1987).

Offshore geology after Plafker and others (1980).

PLATE 5

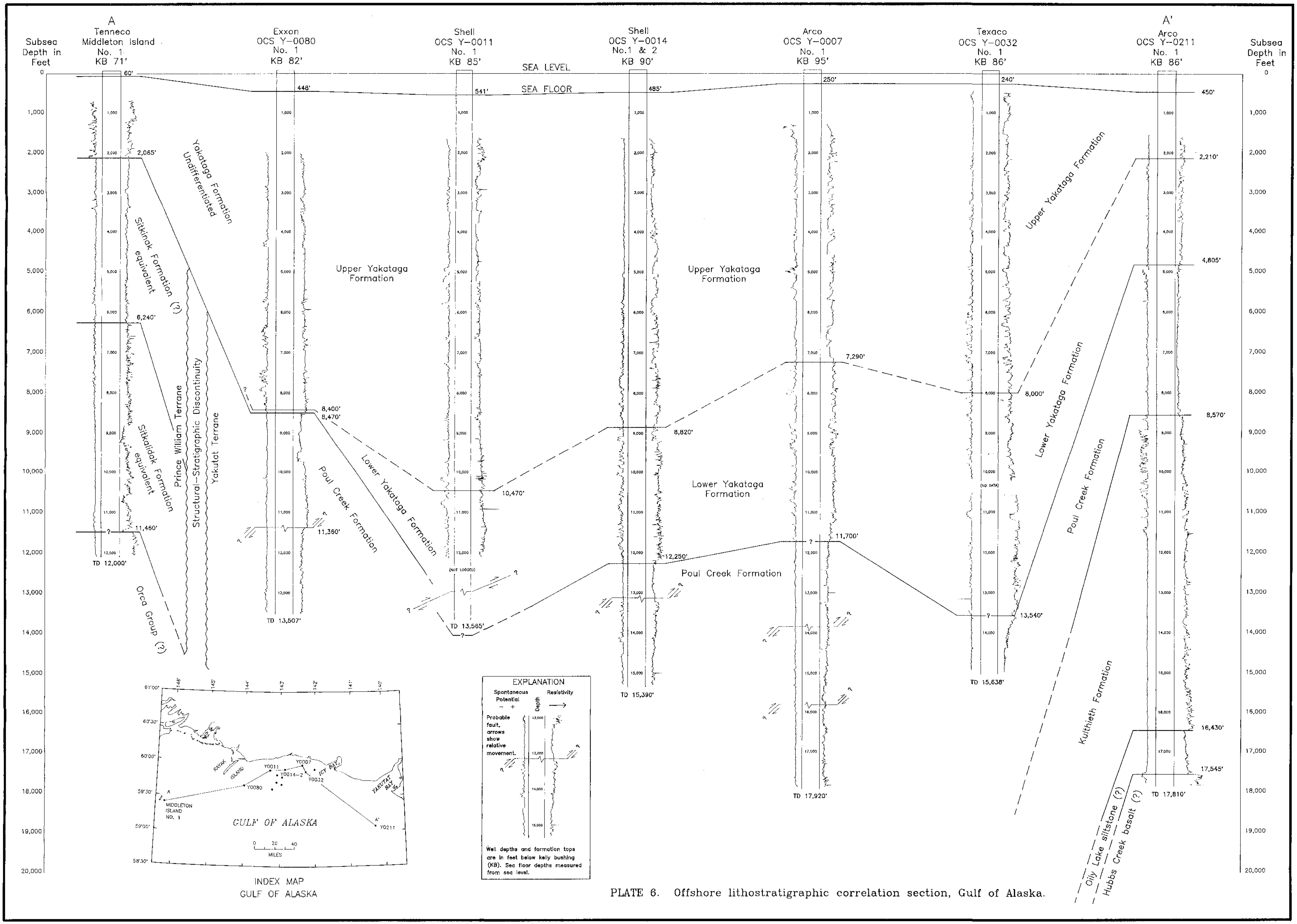


PLATE 6. Offshore lithostratigraphic correlation section, Gulf of Alaska.

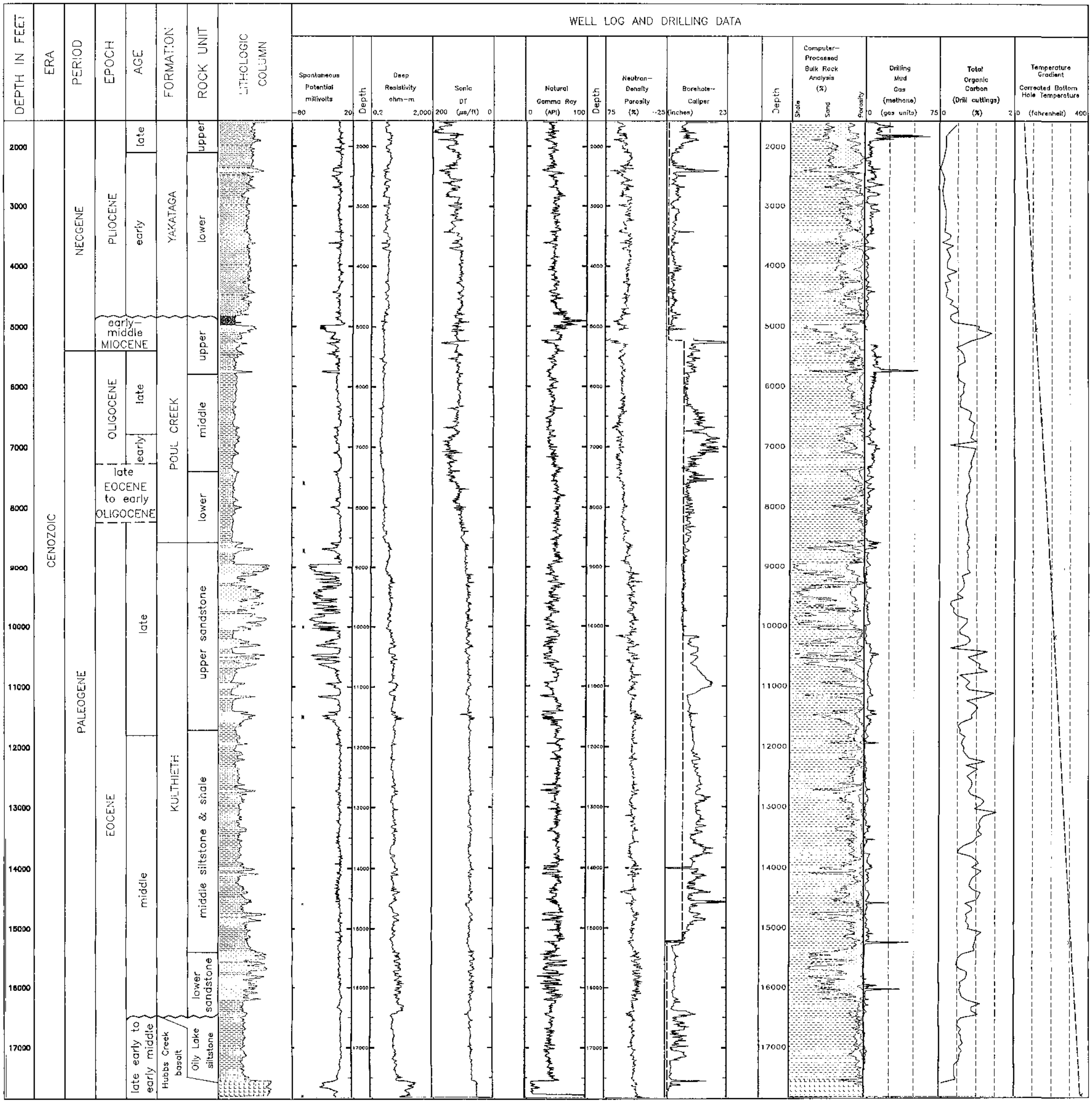
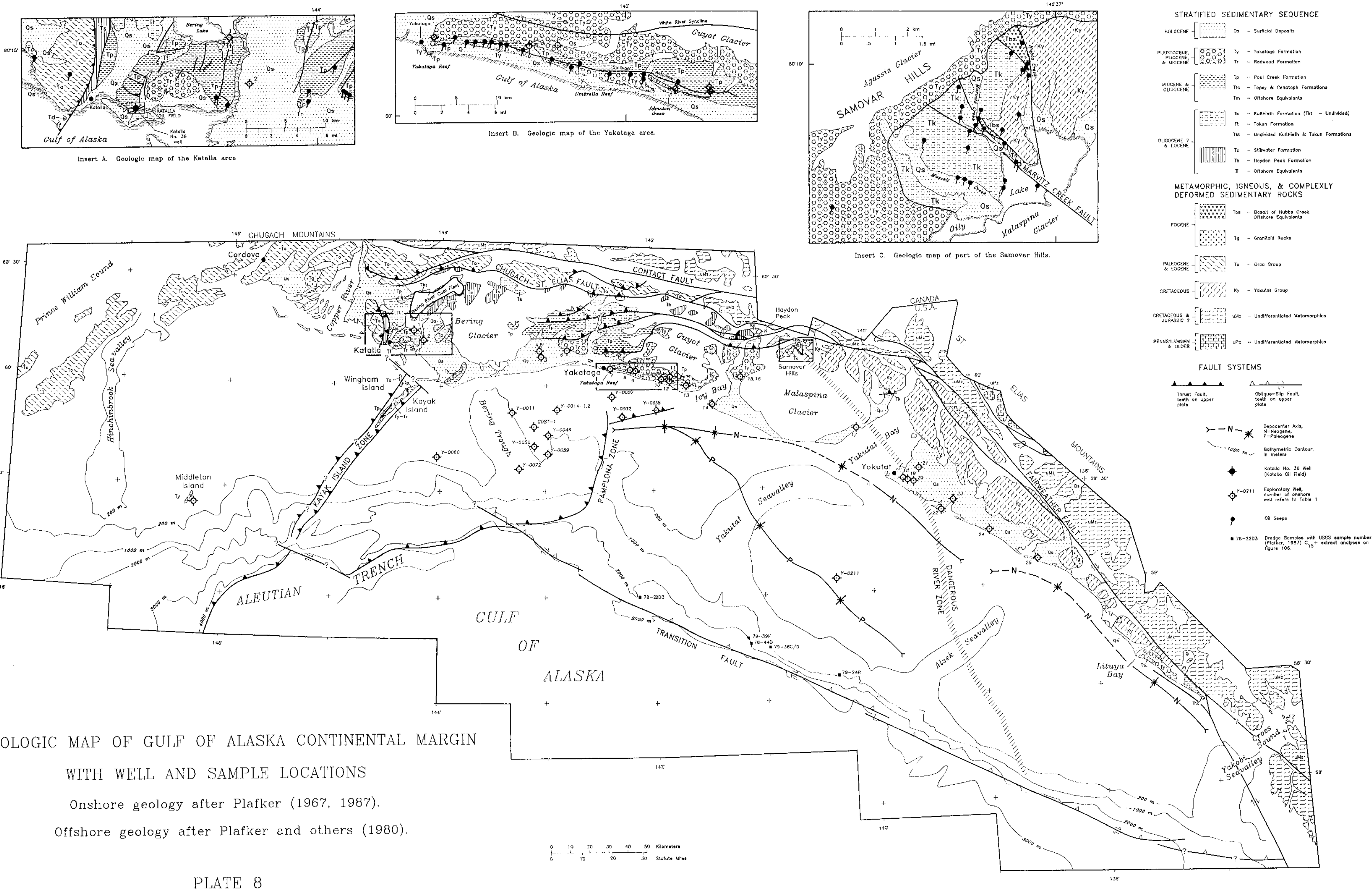


PLATE 7. Stratigraphic column and summary chart of well logs and geologic data, ARCO OCS Y-0211 No.1 well, Gulf of Alaska.



GEOLOGIC MAP OF GULF OF ALASKA CONTINENTAL MARGIN WITH WELL AND SAMPLE LOCATIONS

Onshore geology after Plafker (1967, 1987).

Offshore geology after Plafker and others (1980).

PLATE 8