BOEM 2012-089

Atlantic Well Folio: Georges Bank Basin

Lydonia Canyon Block 133 No. 1 Well

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1.1. Lydonia Canyon 133-1

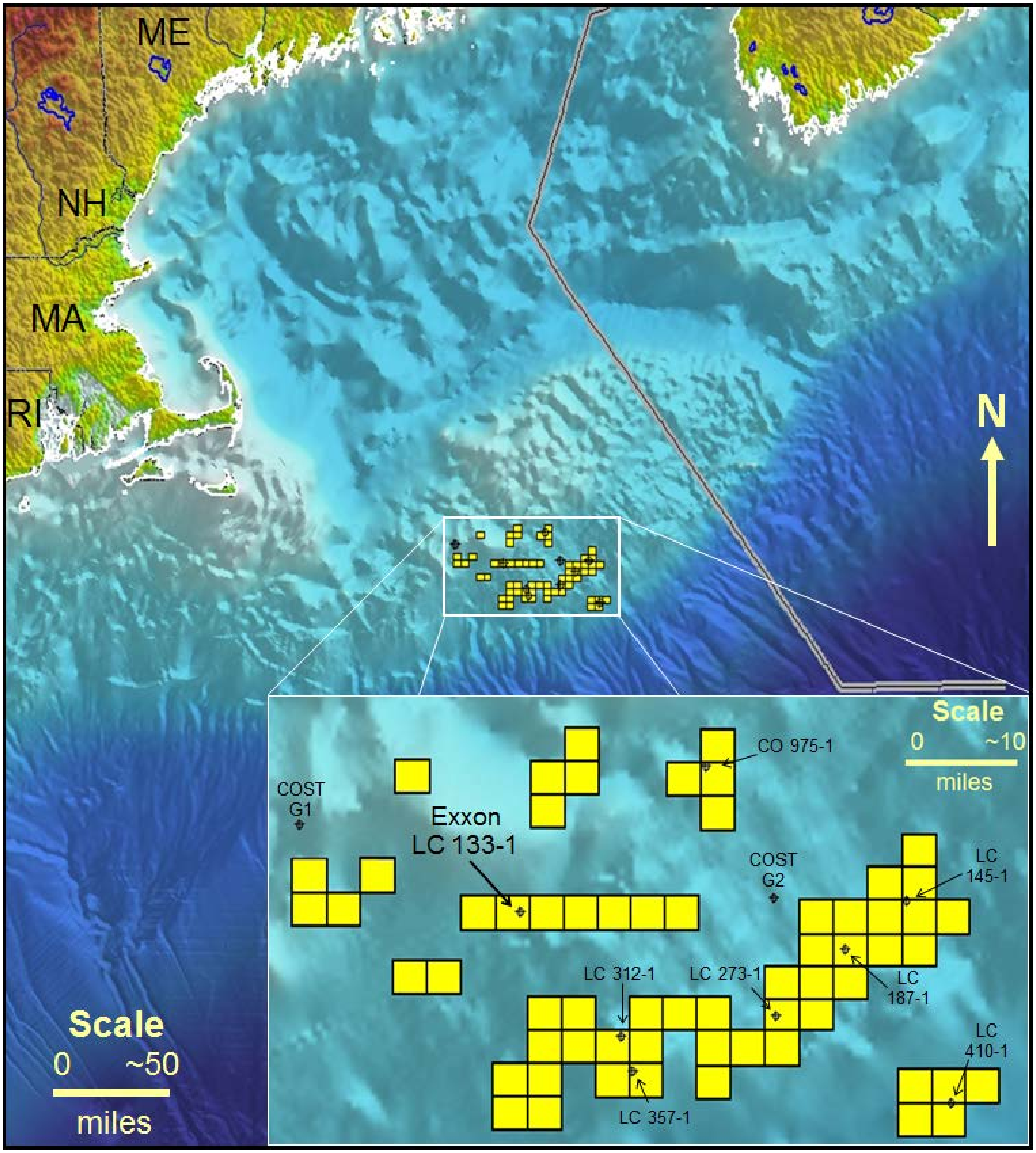

Figure 1. Location map of Georges Bank basin, offshore Massachusetts, USA. Well locations are indicated by the symbol ⌖. Leases previously held in the area are shown in yellow.

On July 24, 1981, Exxon (100%) spudded Lydonia Canyon (LC) 133-1, the first industry exploration well and third well drilled in Georges Bank basin (GBB) (Figure 1). Two Continental Offshore Stratigraphic Test (COST) wells preceded LC 133-1: COST G-1 in 1976 and COST G-2 in 1977. A listing of wells drilled in GBB and their targets is located in Table 1. Exxon contracted the semi-submersible drilling vessel, *Alaskan Star*, to drill the well. LC 133-1 is located 21 miles southeast of G-1 and 23 miles west-southwest of G-2 in 225 feet (ft) of water. Total Depth (TD) of 14,118 ft was reached October 20, 1981. On November 24, 1981, LC 133-1 was abandoned as a dry hole with no significant hydrocarbon shows.

1.1.1. Objectives and Concepts

The target was an interpreted Middle Jurassic-age Callovian "reef" (Figure 2) at an estimated measured depth (MD) of 12,400 ft.

Included with Exxon's 1981 Application for Permit to Drill and Plan of Exploration submitted to the United States Geological Survey (USGS) were the original pre-drill interpreted seismic lines and structure maps used in this report. These data and post-drill well logs, cores, and test results submitted by the operator and pertinent literature were also used in this report.

Two horizons were shown on Exxon's structure map (Figure 3): the interpreted prospective hydrocarbon-bearing Callovian "reef" and the underlying "pre-reef" Bathonian (Middle Jurassic). The original seismic data, acquired and processed in 1979, shows the objective Callovian "reef" outlined in blue between 2.6 and 2.8 seconds two-way travel time (TWTT) (Figure 4). The smoothly dipping base Bathonian horizon (green) is interpreted to be between 2.7 and 2.9 seconds TWTT. Both oil and gas were anticipated in the objective.

Table 1. Wells drilled in Georges Bank basin

Well	Date	Target	Actual
COST G1	1977	n/a	n/a
COST G2	1976	n/a	n/a
LC 133-1	**1981**	**Callovian Reef**	**Volcanic Sequence**
CO 975-1	1982	Bathonian porous shelf carbonate	Evaporite Lens
LC 410-1	1982	Jurassic Closure	Jurassic Closure poor porosity
LC 312-1	1982	Callovian Reef	"Tite" micritic Limestone
LC 187-1	1982	Jurassic age Limestones and Dolomites	Reservoir of poor quality
LC 145-1	1982	Jurassic Porous Shelf edge Calcarenites and Jurassic Carbonates	"Tite" micritic Limestones
LC 273-1	1982	Four way closure, Jurassic oölitic and bioclastic limestones	"Tite" micritic Limestones
LC 357-1	1982	Simple structural closure in Limestone, Dolomite, and anhydrite	"Tite" micritic Limestones

1.1.2. Results

Drilling

The targeted Callovian "reef" interval was encountered at approximately 13,300 ft. However, instead of the anticipated "reef," cuttings, a conventional core, and sidewall cores indicated that the interval consisted of multiple layers of limestone, pyroclastics, basalt flows, and crystalline igneous diabase overlying diabase dykes (Figure 5) (Jansa and Pe-Piper, 1988).

Conventional cores were cut at the following depths:

- Core #1: 12,250–12,272, recovered 20 ft
  - Interbedded dark gray calcareous shales, micritic limestone, and dark gray shaley limestone
- Core #2: 12,272–12,326, recovered 54 ft
  - Interbedded dark gray to black calcareous shale and shaley limestone, and laminated pyritic dark to light gray shales
- Core #3: 12,392–12,430, no recovery
- Core #4: 13,488–13,491, recovered 3 ft
  - Target Zone
  - Very fine-grained igneous diabase consisting of a dark gray matrix with larger crystals of quartz, olivine, calcite, and opaque minerals

Sidewall cores were taken between 4,685 ft and 14,007 ft (those between 12,180 ft and 13,600 ft are shown in Figure 5) with recoveries ranging from 0.1 to 2 inches.

Using drill cuttings, conventional and sidewall cores provided by Exxon, Jansa and Pe-Piper (1988) sub-divided the volcanic sequence into three distinct units (Figure 5):

- Upper Unit (744 ft thick)
  - Layered pyroclastics and basalt flows
- Middle Unit (124 ft thick)
  - Highly altered volcanic tuff near unit top overlying micritic to biomicritic limestone
- Lower Unit (255 ft thick)
  - Medium dark gray and greenish-gray fine-grained crystalline igneous diabase
  - Interpreted as a feeder dyke system comprising up to 17 dykes of different compositions

Jansa and Pe-Piper (1988) interpreted this volcanic sequence as a remnant of a strombolian-type volcanic cone that most likely formed within a shallow carbonate lagoon.

Seismic Interpretation

Exxon's pre-drill 2D time-migrated seismic interpretations (Figure 4) were based on the hydrocarbon-bearing Silurian carbonate reefs found in northern Illinois, Indiana, Michigan, Ohio, and Ontario, Canada (Caughlin et al., 1976). On this vintage of seismic data, these reefs generally exhibited a distinct signature composed of a slightly convex upward region representing the reef, stratigraphic thinning above the reef, and a slightly concave sub-reef surface.

Figures 6 and 7 show a 2D seismic line, recently depth-converted and time-migrated (d-c, t-m) by Fugro Robertson (GeoSpec), that intersects the LC 133-1 well. This line traverses the anomaly drilled and two similar anomalies also interpreted to be volcanic cones (red shading, Figure 7) that are inferred to be of similar age. The anomaly tested is at ~12,300 ft MD, where there is a clearly defined pod-like structure approximately 1,000 ft thick. There is stratigraphic thinning above the anomaly, much like the previously mentioned reef analogs. Below the pod-like structure are bright reflectors with low dip (red stippling, Figure 7), which may represent the feeder dyke system interpreted by Jansa and Pe-Piper (1988). These feeder dykes extend below the depths shown on seismic profile. Jansa and Pe-Piper (1988) suggest the dykes are Callovian in age.

A "Map Datum" horizon, interpreted to be intra-Oxfordian in age, (Figures 6 and 7) was chosen to best depict the top of the anomaly tested by LC 133-1. Regional and detailed structure maps were constructed on this horizon (Figures 8 and 9 respectively).

The regional structure map (Figure 8) was created by gridding 28 interpreted 2D d-c, t-m seismic lines. The anomaly drilled by LC 133-1 and two similar anomalies are highlighted in red.

Ten interpreted 2D d-c, t-m lines were gridded to create the detailed structure map of Block 133 (Figure 9) that shows the structural relief of the feature drilled by LC 133-1.

Biostratigraphy and Palaeoenvironment

Biostratigraphic and palaeoenvironment information was compiled from Jansa and Pe-Piper (1988), Ricciardi (1989), and Edson et al. (2000). The reliability of biostratigraphic data is questionable, especially in the Jurassic because of the possible re-deposition of indicator fauna in the shallow environment of deposition (Edson et al., 2000).

Most of the sediments encountered in the LC 133-1 were deposited in an inner shelf environment with some units deposited in a nonmarine or marginal marine environment (Table 2). Water depths were less than 50 ft, averaging approximately 25 ft (Edson et al., 2000).

1.1.3. Operations and Costs

Exxon (100%) leased Block LC 133 in 1979 (Sale 42) for a high bid of $51,797,000.00 (MMS, 1981), ~$172.7 MM in 2012 dollars (HBrothers, 2012). This was a single block prospect, although similar prospects are seen nearby. The total well cost for LC 133-1 was estimated to be $13.5 MM in 1981 (MMS 1981, citing an undated Oil and Gas Journal article), equating to approximately $35.3 MM in 2012 dollars (HBrothers, 2012). No cost breakdown was available. Total drilling time was 124 days (from spud date to completion) including 8 days for blowout preventer repairs (MMS, 1981).

Table 2. Biostratigraphy and probable palaeoenvironment of sediment intervals in LC 133-1

Depth	Age	Lithology	Depositional Environment
730	L. Miocene to Palaeocene	Banquereau Fm: Green silty mudstone	Inner-middle shelf
1220	Maastrichtian to L. Cenomanian	Dawson Canyon Fm.: Gray calcareous siltstone, chalky limestone, unconsolidated sand beds	Shelf
2745	M. Cenomanian to E. Aptian	Logan Canyon Fm.: Limestone unit overlying Gray silty mudstones interbedded sandstones (Naskapi Fm.)	Deltaic
4760	E. Aptian to E. Tithonian*	Mississauga Fm.: Upper: coarse-grained sandstones with interbedded mudstones and limestones; Lower: mudstone containing interbedded sandstone and limestone	Upper: Deltaic Lower: Shelf
7800	E. Tithonian to E. Bathonian (?)*	Mic-Mac-Mohawk Fm.: Silty mudstones and fossiliferous limestone with interbedded sandstone	Mixed clastic and carbonate shelf
12390	Oxfordian (?) to Callovian (?)	Volcanics: Limestones pyroclastics, and basalt flows comprising a volcanic cone and overlying diabase dykes (Jansa and Pe-Piper, 1988).	Shallow carbonate lagoon (Jansa and Pe-Piper, 1988)
13450	Jurassic*	Carbonate consisting of oölitic and peloidal limestone, shales, interbedded sand, and micritic limestones.	Shallow marine

E. – Early   M. –Middle   L. –Late
*Sediment interpreted as being reworked; therefore, age interpretation considered unreliable.

1.1.4. Petroleum System Analysis

Magoon and Dow (1994) defined a petroleum system as “a natural system that encompasses a pod of active source rock and all related oil and gas and which includes all the geologic elements and processes that are essential if a hydrocarbon accumulation is to exist.” Petroleum is defined as biogenic or thermal gas located in a reservoir or as naturally occurring surficial condensates, asphalts, and crude oils (Magoon and Dow, 1994).

Essential geologic elements are: source rock, reservoir rock, seal rock, and overburden rock (a thick rock column above the source rock interval to generate sufficient temperatures for hydrocarbon generation). Our guidelines for source, reservoir, and seal elements are shown in italics in Table 3.

Table 3. Petroleum System Elements

Element	LC 133-1 Lithology
Source rock *(>1% TOC)*	Shales in the interval ~7800 – ~9700 ft
Reservoir rock *(>10 % ϕ >1 mD k)*	Hauterivian – Albian sandstones (~30% – ~44% of generally mudstone-rich interval).
Seal rock *(10^{-3} mD k)*	Shale
Overburden rock	~9700 ft above deepest source rock interval

Essential processes include trap formation and hydrocarbon generation, as well as hydrocarbon expulsion, migration, accumulation, and preservation (Magoon and Dow, 1994).

The essential processes must act on the geologic elements at specific times such that a reservoir and trap exist, hydrocarbons are generated, expelled from the source rock, migrate into the trap, become entrapped and retained in the trap (Magoon and Dow, 1994). Not all processes will be present in all areas; i.e., when there is no hydrocarbon generation and expulsion, there can be no migration or accumulation.

Geochemistry

Analysis of Exxon's geochemical data shows that some intervals, primarily between ~7800 ft and ~9700 ft MD (Late Jurassic Tithonian–Oxfordian?), contain sufficient TOC (>1%) to generate hydrocarbons (Tables 3 and 4).

BasinMod® *Classic* modeling software was used to define the kerogen type and hydrocarbon generation windows. A hydrogen index versus oxygen index van Krevelan diagram indicated the presence of type II/III and type III kerogens.

Rock-Eval Pyrolysis was used to establish the maturity of organic matter and its petroleum potential. This technique involves heating a sample in a helium atmosphere (Pimmel and Claypool, 2001). The thermal maturation of a sample is determined by T_{max}, "the temperature at which maximum release of hydrocarbons from cracking of kerogen occurs during pyrolysis" (Pimmel and Claypool, 2001). Thermally mature rocks for oil generation are those that reach a T_{max} of ~435 ^{o}C (incipient/early mature for oil generation) and remain at or below 470 ^{o}C (post-mature for oil generation).

Table 4. Petroleum System Processes

Onset hydrocarbon generation	Approximately 10,000 ft MD based on Rock-Eval Pyrolysis T_{max}.
Expulsion	The absence of significant shows indicates a lack of significant thicknesses of mature source rocks (those with TOC >1%) and/or vertical cross–stratal conduits to facilitate hydrocarbon migration or accumulation.
Migration	
Accumulation	

In LC 133-1, rocks are thermally mature below ~10,000 ft MD; however, only a few intervals below this point have TOC values >1%. Therefore, no hydrocarbons were expelled from the source rock. These findings are consistent with MMS (1981).

Consequently, although maturity increases with depth, TOC generally does not.

Rock-Eval Pyrolysis T_{max} data is relatively objective because it is based on kerogen kinetics and is therefore preferable to the more subjective thermal alteration index (TAI) technique, which relies on spore color to estimate the maximum thermal maturity of a sedimentary unit.

Exploration Implications

The main exploration implication derived from LC 133-1 is that the structure seismically identified as a "reef" is a volcanic cone consisting of basalt flows, pyroclastics, and limestone overlying numerous diabase dykes. The drilled anomaly is one of a group of similar seismic anomalies in the area. The sedimentary section below ~10,000 ft MD in LC 133-1 is thermally mature; however, that interval contains only a few zones with TOC values >1% and is therefore non-source. There were no noteworthy hydrocarbon shows in the well (Table 5).

Table 5. LC 133-1 Target Summary

Pre-Drill Interpretation	
Target	~12,400 ft MD Interpreted Callovian "reef"
Trap Type	Stratigraphic
Hydrocarbon Expected	Oil or gas
Post-Drill Results	
Target Interval	At ~12,300 ft MD the interval consisted of multiple layers of limestone, pyroclastics, basalt flows, and crystalline igneous diabase overlying diabase dykes interpreted as a volcanic cone formed in a shallow carbonate lagoon (Jansa and Pe-Piper, 1988)
Hydrocarbon Shows	No significant shows of either oil or gas.
DST	In drilling break in upper volcanic section recovered water

Acknowledgements

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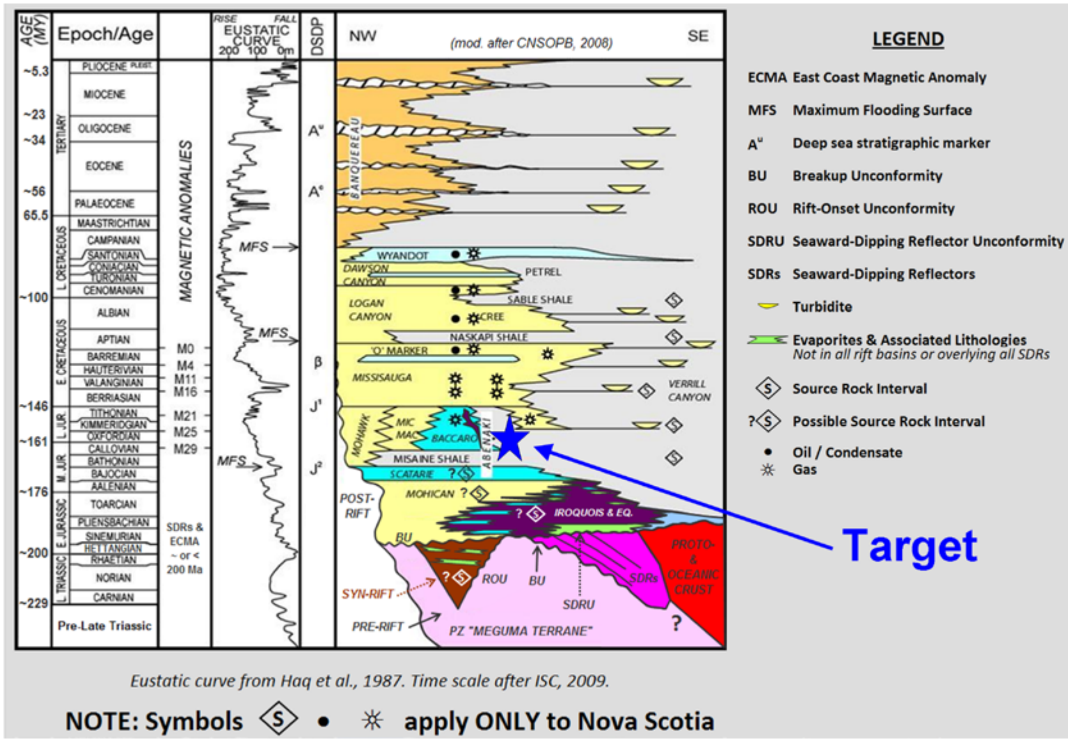

Figure 2. Stratigraphic chart and target interval for Exxon Lydonia Canyon (LC) Well 133-1.

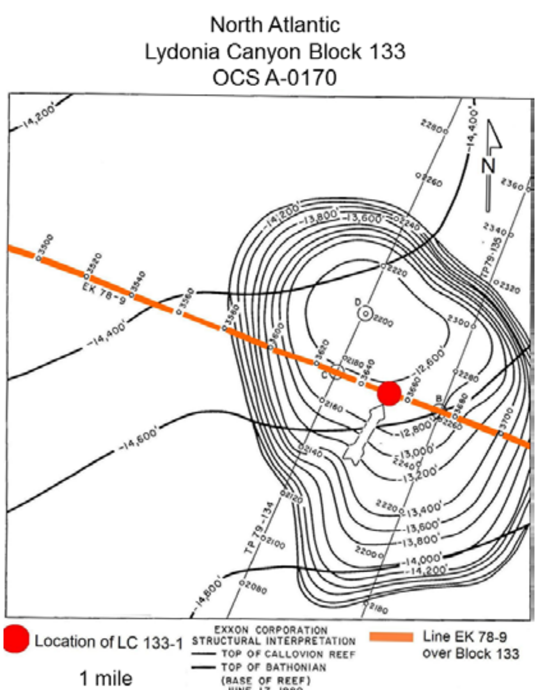

Figure 3. Structure map (after Exxon, 1981) showing the top of the targeted Callovian Reef (thin black lines) and the top of the Bathonian (thick black lines).

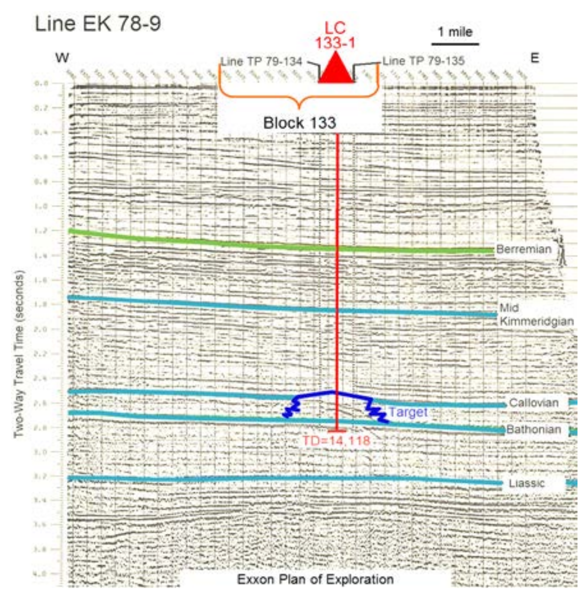

Figure 4. Interpreted seismic showing the targeted Callovian "reef" (after Exxon, 1981).

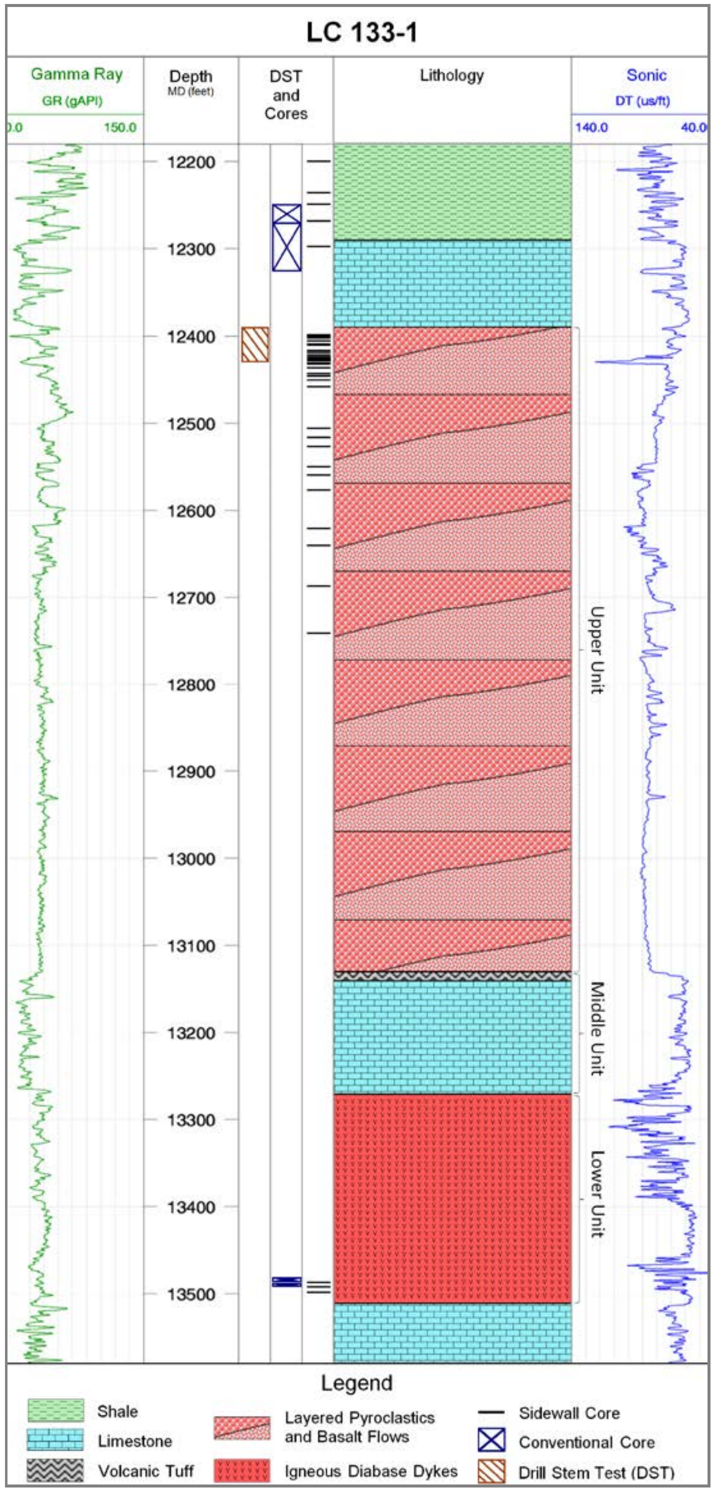

Figure 5. Well LC 133-1 target interval lithology is based on gamma ray and sonic logs, conventional and sidewall cores, and drill cuttings.

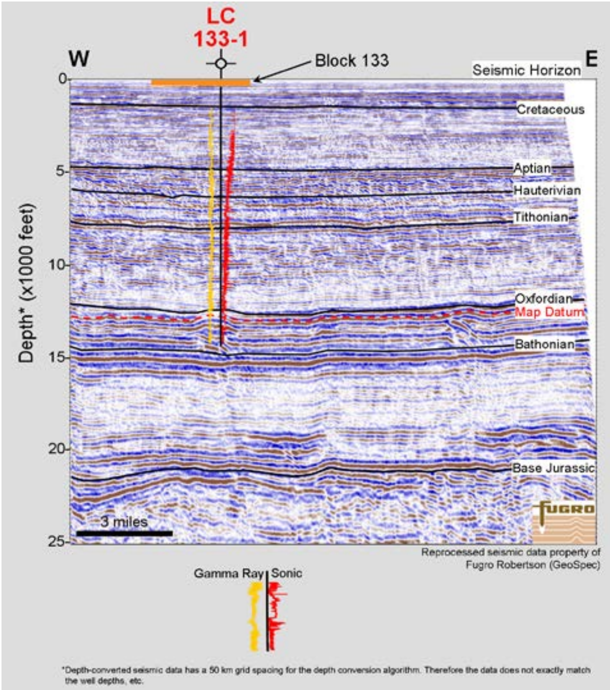

Figure 6. Depth-converted, time-migrated seismic profile through LC 133-1 showing interpreted horizons and "Map Datum" used for Figures 8 and 9.

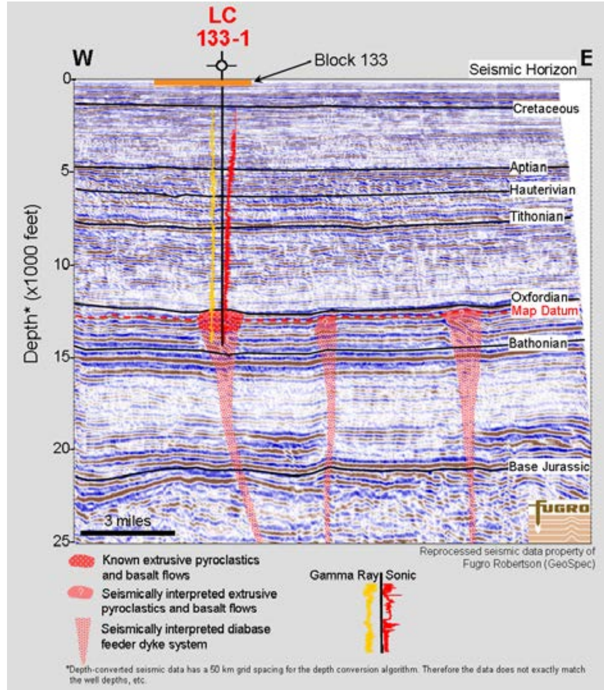

Figure 7. Depth-converted, time-migrated seismic profile through LC 133-1 showing previously drilled and interpreted extrusive pyroclastics, basalt flows, and underlying diabase dykes.

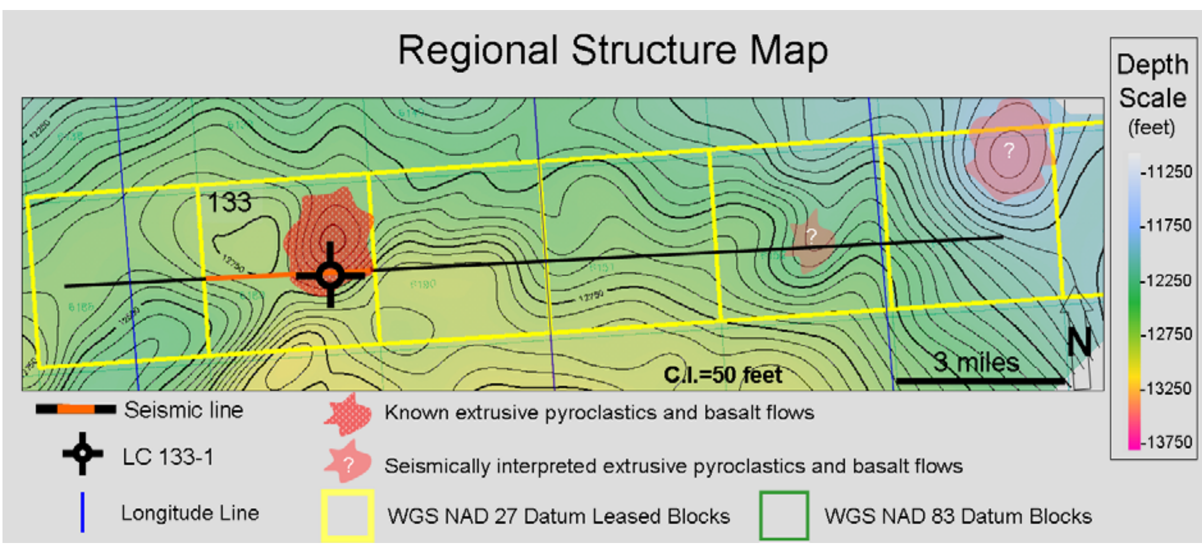

Figure 8. Regional depth structure map on "Map Datum" from Figures 6 and 7.

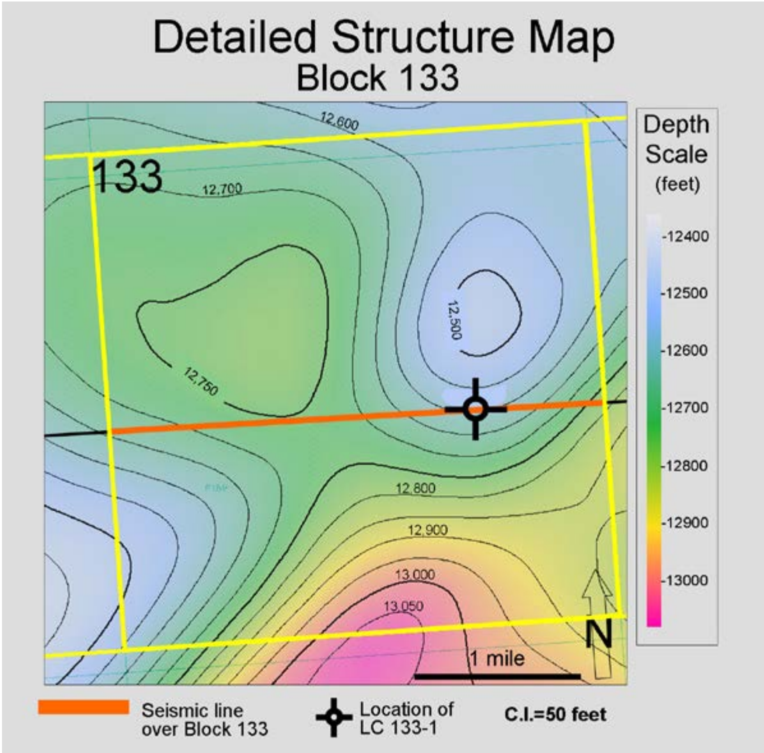

Figure 9. Block 133 detailed depth structure map of the "Map Datum" (Figures 6 and 7).

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