SPERRY-SUN DRILLING SERVICES
LOGGING SYSTEMS
Anchorage, Alaska

CONFIDENTIAL

FINAL ADT WELL SUMMARY REPORT

ARCO Alaska, Inc.
OCS-Y-0866 No. 1
Kuvlum Prospect
Beaufort Sea, Alaska

Final Report Summary
October 1992

PREPARED FOR:
ARCO Alaska, Inc.

PREPARED BY:
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Sperry-Sun Drilling Services
Logging Systems
Anchorage, Alaska

sperry-sun
DRILLING SERVICES

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INTRODUCTION

Drilling operations for OCS-Y-0866 No. 1 on the Kuvlum Prospect were initiated 8-12-92, by ARCO Alaska, Inc. The well was drilled by Beaudril's Kulluk on a location in NR6-4 Block 673 of the Beaufort Sea, offshore Alaska. The OCS-Y-0866 No. 1 was drilled to a total depth of 8,500' on 9-08-92. The total number of operating days that were required to reach 8,500' was 28 days from spud. Due to severe ice conditions, a sidetrack from this well was canceled after testing operations were completed and the well plugged on 10-14-92.

A Sperry-Sun Logging Systems MPT/2000 Unit was in operation from surface to TD providing full mud logging, applied drilling technology, and Mud Pulse-MWD services. The MPT/2000 Unit and crew provided essential assistance in the drilling of OCS-Y-0866 No. #1 by monitoring intrinsic drilling parameters and gas levels. Also provided were real-time Gamma Ray and EWR information, directional surveys, fluid hydraulics information, pore pressure vs. necessary mud weight evaluations, and a wide range of geological interpretations and sampling services.

The following pages of this report are designed to supply concise historical data of the events that occurred on OCS-Y-0866 #1, along with some analysis and recommendations for specific problems that were experienced during different sections of the hole. All of the information compiled in this report was acquired and recorded by the MPT/2000 Unit at the well site.

The sensors incorporated in this unit are independent from the rig sensors and may differ slightly from those reported by the rig contractor. In addition, any evaluations in this report regarding formation evaluations, pore pressure estimates, or other geologic interpretations are made entirely by Sperry-Sun personnel from on site examination of drill cutting samples and pertinent data supplied solely by the MPT/2000 Unit.

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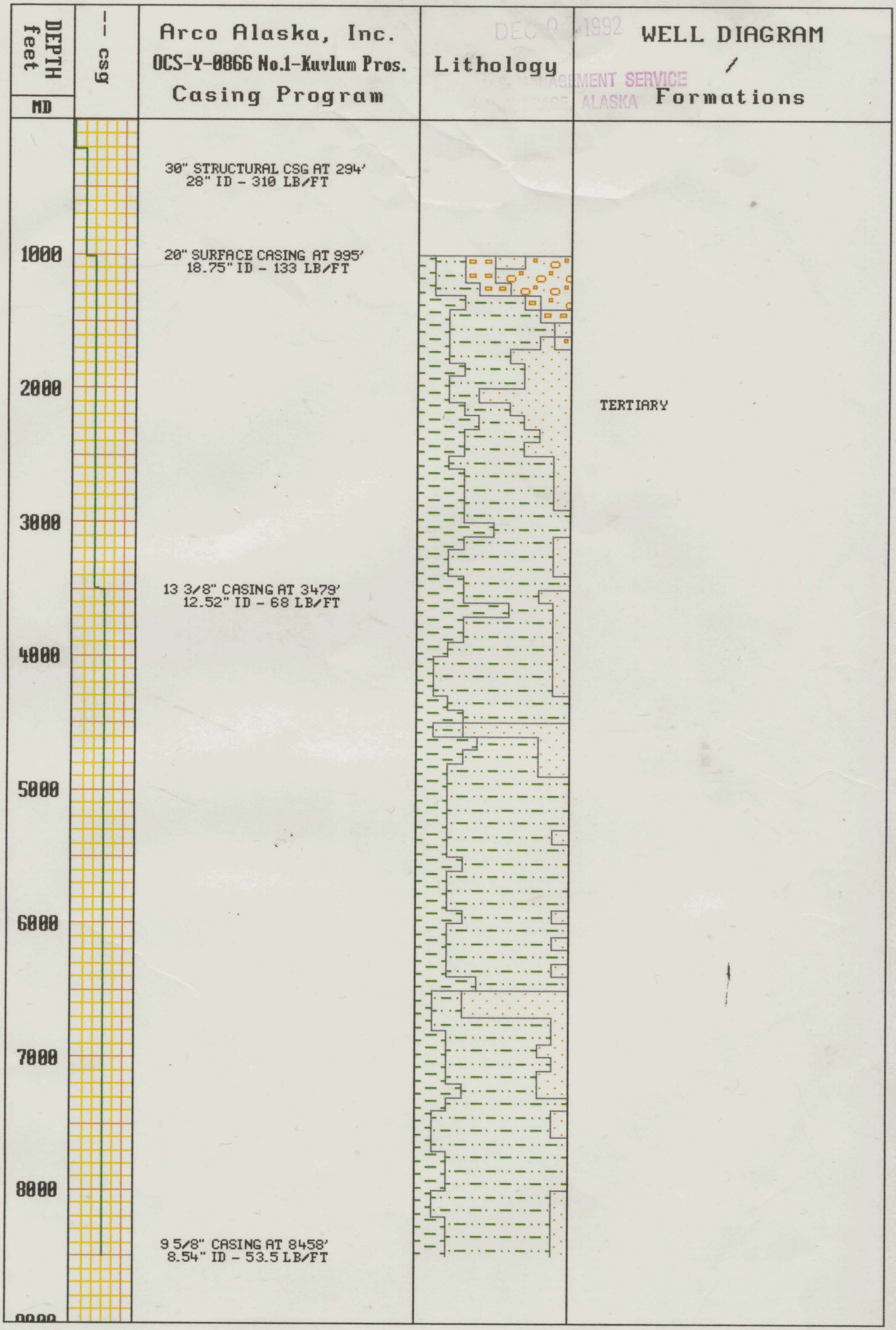
DEPTH feet
MD
-- csg
Arco Alaska, Inc.
OCS-Y-0866 No.1-Kuvlum Pros.
Casing Program
Lithology
WELL DIAGRAM
/
Formations
30" STRUCTURAL CSG AT 294'
28" ID - 310 LB/FT
1000
20" SURFACE CASING AT 995'
18.75" ID - 133 LB/FT
2000
TERTIARY
3000
13 3/8" CASING AT 3479'
12.52" ID - 68 LB/FT
4000
5000
6000
7000
8000
9 5/8" CASING AT 8458'
8.54" ID - 53.5 LB/FT

WELL SUMMARY BY INTERVALS

3

Interval: 294' to 1015'

Days:	14	Average WOB:	0/5 klb
Hole Size:	26"	Average RPM:	83
No. Bits:	1	Average GPM:	1175
Rotating Hours:	30.4	Average SPP:	1350 psi
Deviation:	NA deg	Average ROP:	28 ft/hr
Mud Weight:	8.5 ppg	Mud Type:	Sea Water

Discussion:

The Beaudril Kulluk was positioned on location prior to the spud in date of 8-12-92. Drilling operations were initiated by drilling a large diameter glory hole from the mud line depth of 169' to allow for the positioning of the blow out preventer stack below the ocean floor. Penetration rates for this large diameter hole were slow as the ocean floor at this location appeared to be somewhat compacted and firm. The glory hole was drilled to a depth of 208' on 8-17-92. A 35' diameter caisson then was run to provide a barrier for sediments falling back into the hole.

After landing a temporary guide base and experiencing delays due to ice conditions, 30"- 310 lb/ft casing was jet drilled to 294' in conjunction with Bit No. 1. With the 30" casing landed on the guide base, drilling was continued with Bit No. 1 without returns to surface. The 26" hole was drilled to a depth of 1015' on 8-24-92, occasionally pumping high viscosity sweeps to clean the hole. 20" - 133 lb/ft casing was then run and cemented to a depth of 995'. No hole problems were encountered while drilling this section of the well.

Interval: 1,015' to 3,500'

Days:	8	Average WOB:	10 klb
Hole Size:	12.25/17.5"	Average RPM:	155
No. Bits:	3	Average GPM:	800
Rotating Hours:	33.4	Average SPP:	3200 psi
Deviation:	.52 deg	Average ROP:	93 ft/hr
Mud Weight:	9.8/10.3 ppg	Mud Type:	PHPA

Discussion:

The blow out preventer stack was run on the riser assembly and landed to the well head housing allowing for mud returns to surface. The BOP Stack and the 20" casing were pressure tested prior to drilling ahead with Bit No. 2.

Bit No. 2, a 17.5" bit, was used to drill out the 20" conductor casing along with 11' of new hole to 1,026' on 8-28-92 . The hole was then displaced with 9.8 ppg sea water-PHPA mud. A leak off test was performed at this depth yielding a fracture pressure equivalent of 12.2 ppg. This compares closely to a calculated gradient of 12.0 ppg using the Eaton Method for shales.

Bit No. 2 was then pulled out of the hole and replaced with a 12.25" bit. Bit No. 3 was used to drill ahead through gravel and sand at a controlled drilling rate of $100^{+}/_{-}$ feet per hour to a depth of 1,871' where this bit was pulled after experiencing a loss in overall pump pressure. A new MWD tool was picked up while changing to Bit No. 4.

Bit No. 4 was then used to control drill to the interval depth of 3,500'. Minor problems were experienced during this bit run with slower penetration rates due to this bit balling up while drilling clay at 2,460' and 2,905'. In addition, the mud system was weighted up to 10.1 ppg at 2,500' and 10.3 ppg at 2,985' to counter slight increases in the estimated pore pressure.

The hole was conditioned with a short trip to the shoe that experienced drag on the first trip out that was probably due to swelling clays. While tripping in, the hole was washed and reamed to bottom from 2,200' and additional time was spent circulating to condition the hole for electric logs.

Electric logs were successfully run and operations to open the hole were initiated on 8-31-92. Bit No. 3 was run into the hole ahead of a 17.5" hole opener. Drilling rates were very fast during the hole opening process. The hole was then conditioned with a short trip and additional circulating time in preparation for running casing. $13^3/_8$" - 68 lbs/ft casing, was landed at a total depth of 3,479'. This casing was cemented in place without problems.

Lithologies of this section consisted of gravel, sand, clay, siltstone, traces of limestone, and thin coal beds. Moderate amounts of gravel were recorded in this section. No abnormal gas readings or any indication of gas hydrates were encountered. The pore pressure estimate for this section of the hole ranged from 8.7 to 8.9 ppg, a normal gradient. Hole problems for the interval were slight and were associated with bit balling in clays and minor amounts of fluid loss to the hole while logging and running casing.

Interval: 3,500' to 8,500'

Days:	6	Average WOB:	20/6 klb
Hole Size:	12.25"	Average RPM:	170
No. Bits:	2	Average GPM:	620/700
Rotating Hours:	61.3	Average SPP:	2800 psi
Deviation:	1.32 deg	Average ROP:	81.5 ft/hr
Mud Weight:	10.0/10.6 ppg	Mud Type:	S. Water-PHPA

Discussion:

The blow out preventers were tested prior to running in the hole with Bit No. 5. Bit No. 5 was then used to drill cement, the float collar, and the shoe along with 10' of new formation to 3,510'. The hole was then displaced with fresh 10.0 ppg mud and a leak-off test was performed at this depth. This test yielded a fracture pressure equivalent of 15.0 ppg. This value differs somewhat from a calculated value of 13.9 ppg using the Eaton Method for estimating the fracture gradient in shales.

After completing the leak-off test, Bit No. 5 was used to drill to 4,476' where a short trip to the shoe was performed to condition the hole. Moderate drag was experienced on this trip, probably as a result of swelling clays. A second short trip was made during this bit run at 5,250', also noting drag on the way out of the hole. The trip gas from each of these depths were 471 and 886 units respectively. The mud weight was raised to 10.2 ppg at 4,900' to stabilize higher gas readings recorded at 4,810' and potential drag conditions. Drilling continued with this bit to 6,271' where Bit No. 5 was pulled out of the hole.

Bit No. 6, a PDC type, was run into the hole on the same bottom hole assembly. Drilling continued with this bit using high rotary speeds (170 avg.) and low weight on bit (6,000 lbs-avg.). Very good penetration rates were achieved with this weight and rotary combination. The decision was made to raise the mud weight to 10.5 ppg after noting an increase in background gas and circulating bottoms up at 6,495'.

A significant sand interval was logged during this bit run between 6,510' and 6,665'. Oil shows of fluorescence and cut were recorded in drill cutting samples collected throughout this break. In addition, ratio analysis from gas readings taken in this zone indicated the probable presence of medium gravity oil. A six stand short trip was performed at 6,600' in the middle of this section to verify hole conditions. The maximum gas reading from bottoms up was 2,135 units.

CONCLUSIONS AND RECOMMENDATIONS

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The drilling program for OCS-Y-0866 No. 1 on the Kuvlum Prospect was designed to penetrate to an estimated depth of 8,500' and evaluate Tertiary sands predicted below 4,000'. OCS-Y-0866 No. 1 was drilled to 8,500' in 28 days and was able to reach the predicted TD originally estimated for the hole in an allotted time interval. Preparations to flow test the well were initiated 9/15/92, after cementing the $9^5/_8$" casing string.

Minor hole problems were experienced in the upper intervals of the well which consisted of slower penetration rates in clay formations when the bit balled up and small amounts of fluid lost to the hole while logging and running casing. In the bottom interval of the well, moderate amounts of drag were experienced on trips. The probable causes for the drag were swelling clays and some buildup of cuttings adhering to the bore hole; however, the short trips employed while drilling this section proved to be an effective means to clean and condition the hole.

No significant pore pressure gradient was drilled in any of the intervals of this well. The majority of this well was very near normally pressured. Pore pressure changes were minor and in retrospect, appeared to occur in stages. Using Condensed Pressure Parameter Plots as a reference, we believe small changes in formation pressure occurred around 2,600', 3,800' and 6,200' reaching an estimated value of 9.5 ppg at 6,200'. A continuing trend was noted for the "Dc" exponent and resistivity values below 6,800' possibly indicating a more well defined gradient. A maximum value of 9.8 ppg for formation pressure was estimated for the bottom of the hole.

Shows of fluorescence were noted on the mud logs from depths beginning around 6,400' and extending in sandstones drilled near the total depth of 8,500'. One significant sand formation was drilled that appeared to have reservoir potential from 6,510' to 6,665'. Gas readings indicated the presence of hydrocarbons over this interval. The ratio analysis of these readings also support the premise that this zone is probably predominantly oil bearing. No porosity estimates could be effectively made from the drill cutting samples as the sand came back unconsolidated. A more detailed description of this show is described in the Show Report section of this report.

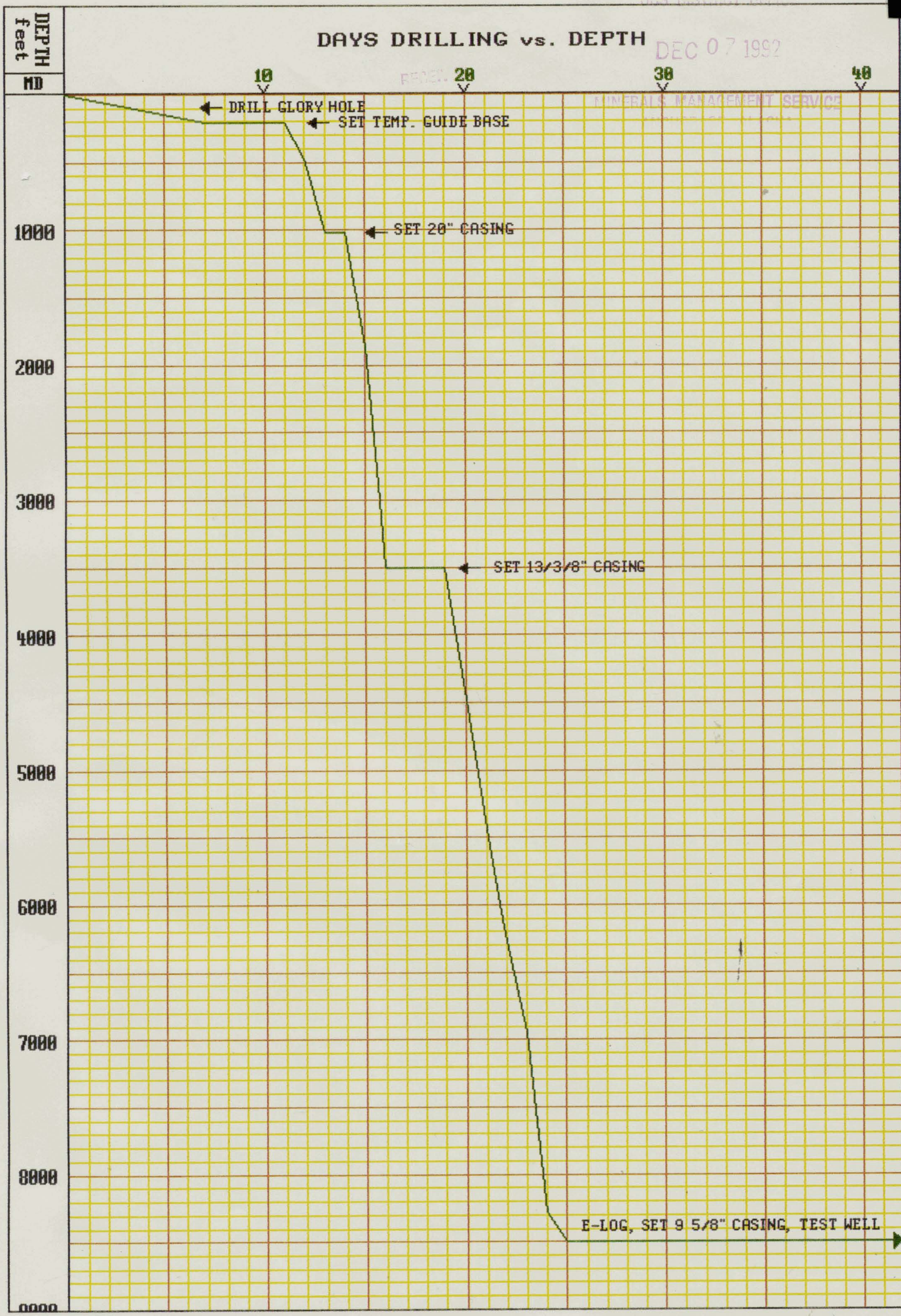
The following hydraulics and mud property recommendations are based on a similar drilling program used on OCS Y 0866-1. The recommendations are made using a similar casing program and include slightly lower recommended mud weights as those used on this well.

Recommended Mud Properties

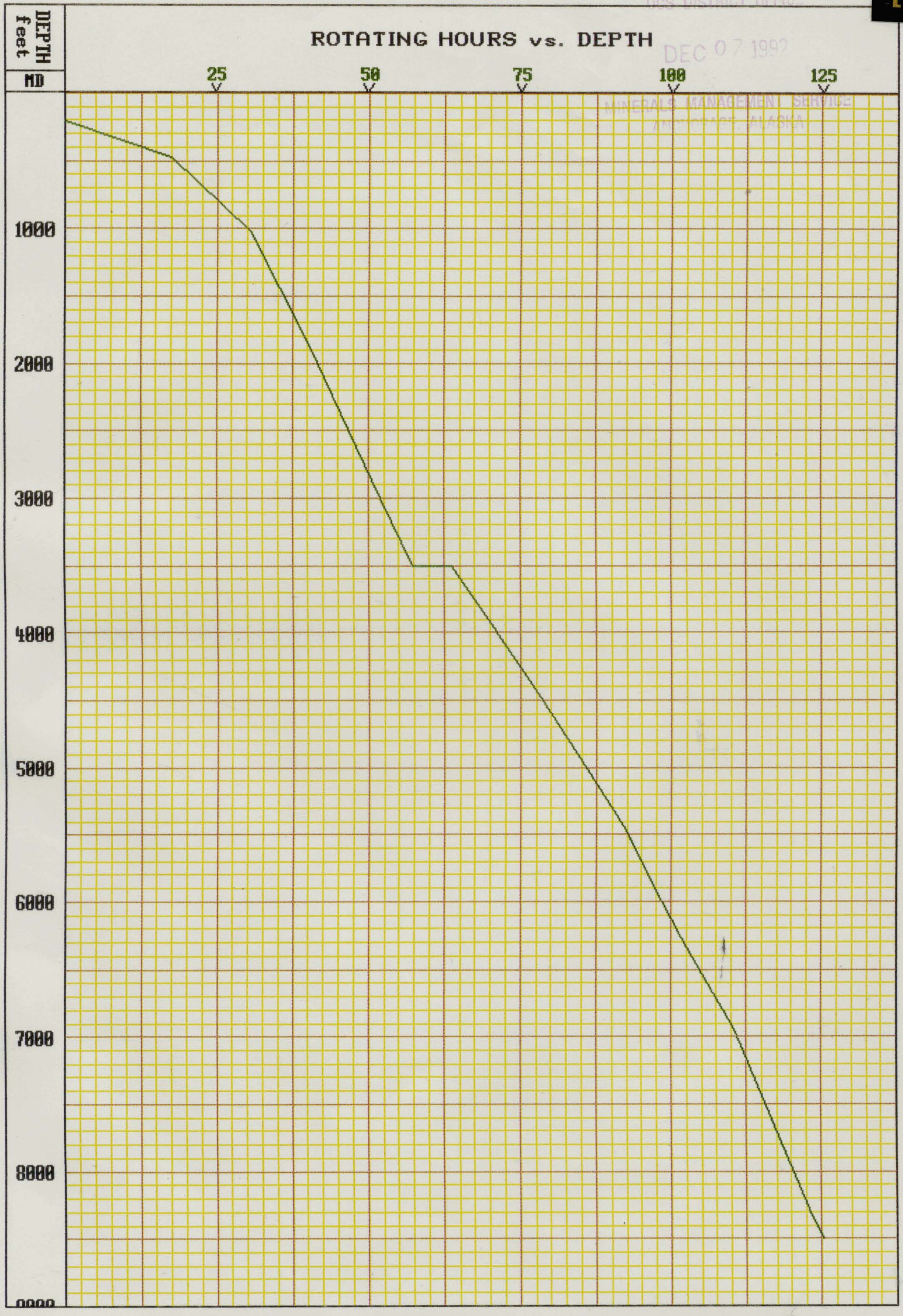
Depth	CSG Seat	Mud Weight	Yield Point	Water Loss
0-1000	20"	Sea water	Sweeps	N/A
-3500	$13^{3}/_{8}$"	9.6	20-25	<6
-6000	$8^{1}/_{2}$" Hole	9.8	20-25	<4
-TD	$8^{1}/_{2}$" Hole	10.0/10.2	20-25	<4

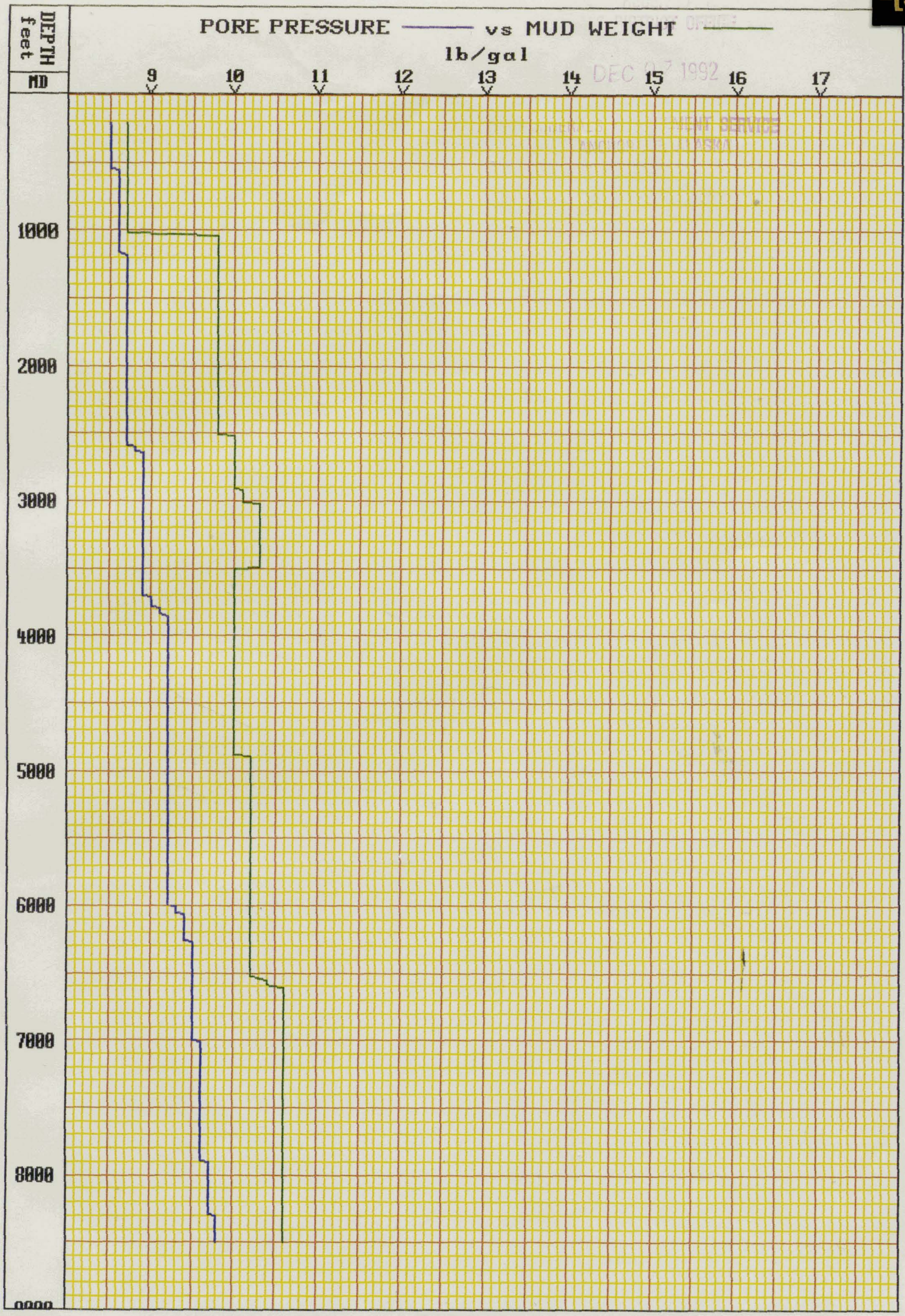
Recommended Hydraulics

Hole Size:	26"	$17^{1}/_{2}$"	12.25"	12.25"
Depth:	800	2500	6000	8200
Gallon per Min:	1100	825	650	600
Nozzle Size:	4-18's	4-14's	4-12's	4-12's
Pump Pressure:	2200	2750	3000	3000

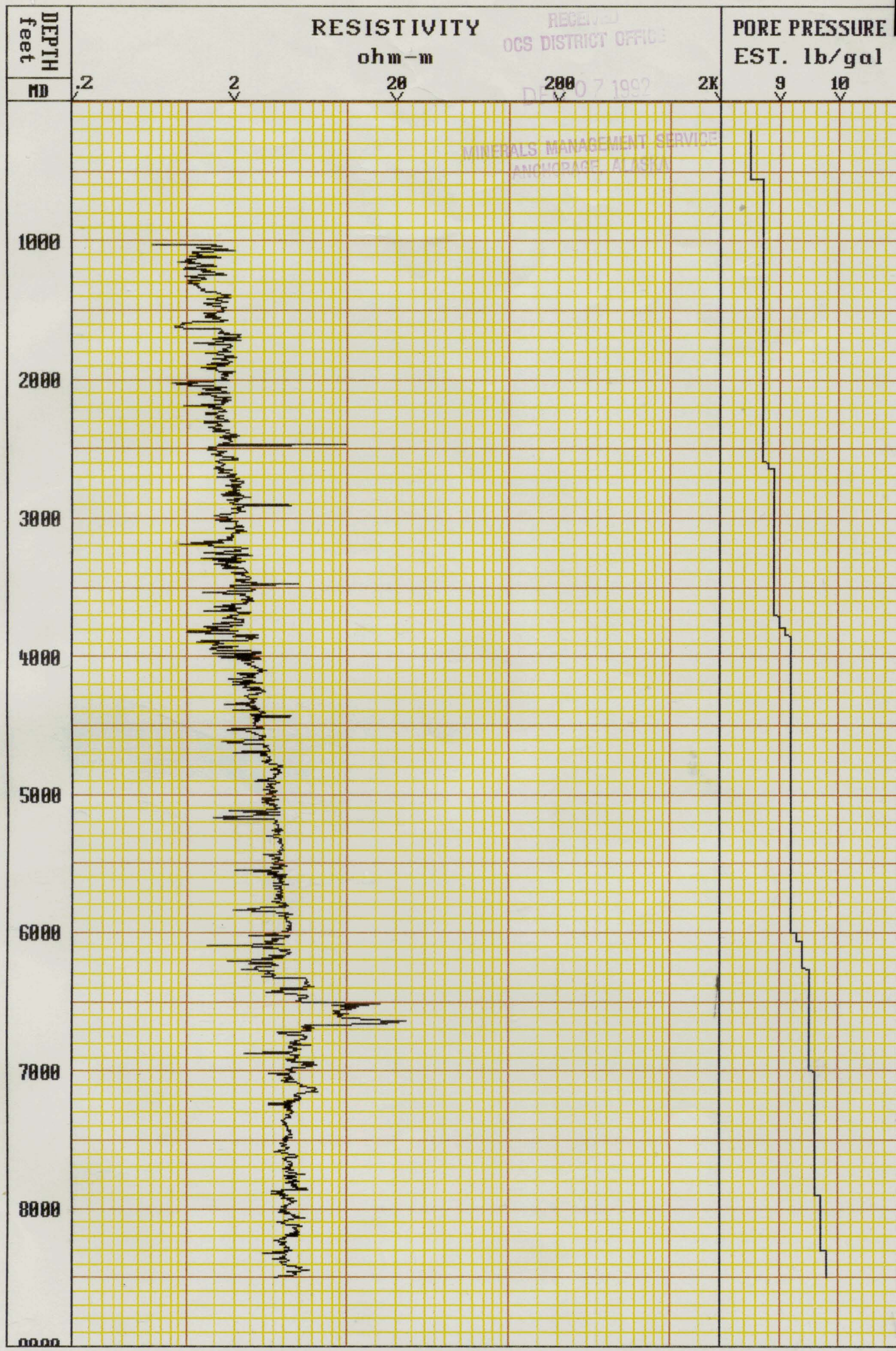

DAYS DRILLING vs. DEPTH
DEPTH feet
MD
10
20
30
40
1000
2000
3000
4000
5000
6000
7000
8000
DRILL GLORY HOLE
SET TEMP. GUIDE BASE
SET 20" CASING
SET 13/3/8" CASING
E-LOG, SET 9 5/8" CASING, TEST WELL

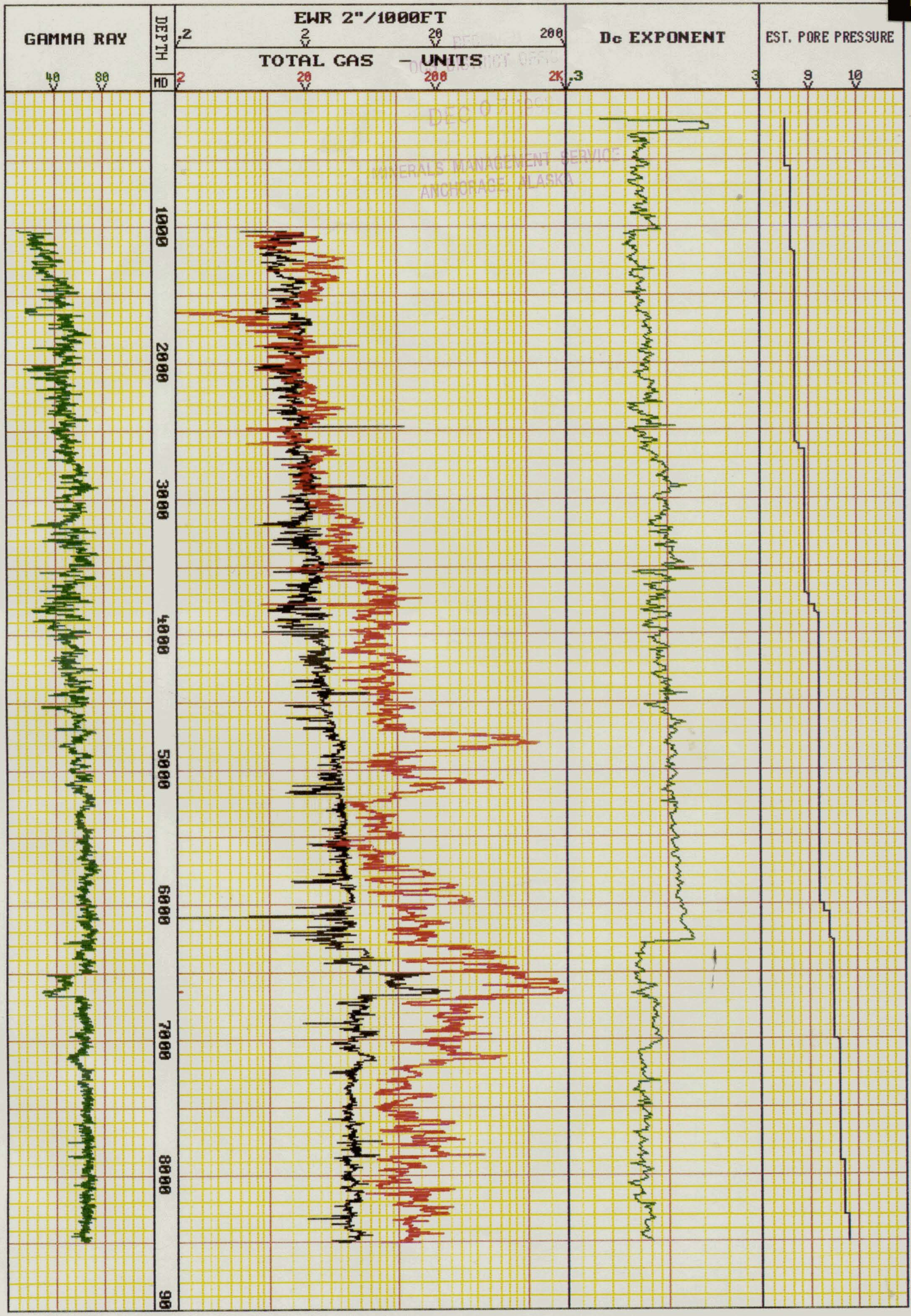
5


ROTATING HOURS vs. DEPTH
DEPTH feet
MD
25
50
75
100
125
1000
2000
3000
4000
5000
6000
7000
8000
9000

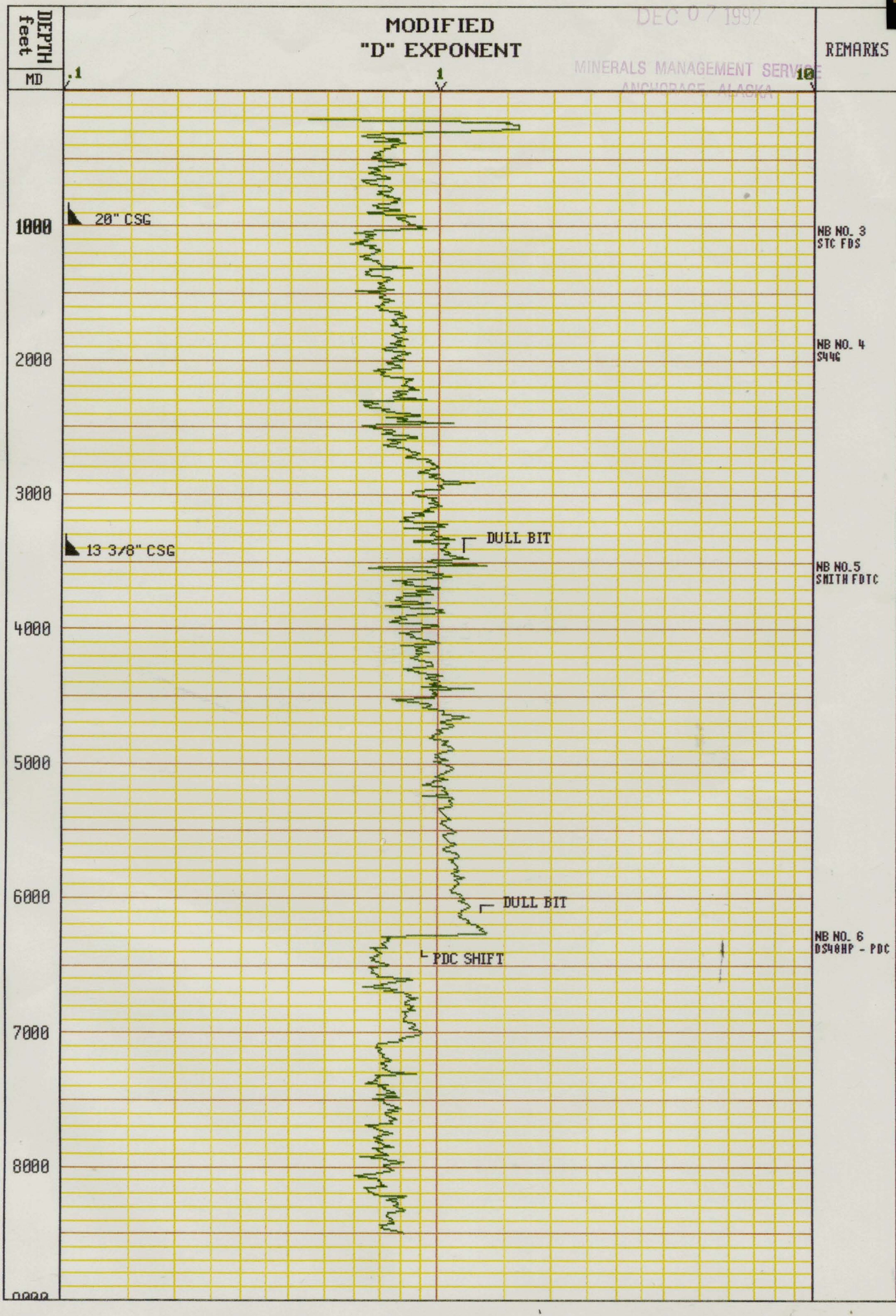

DEPTH feet
MD
PORE PRESSURE vs MUD WEIGHT
lb/gal
9
10
11
12
13
14
15
16
17
1000
2000
3000
4000
5000
6000
7000
8000
9000
DEC 07 1992

-[4]


DEPTH feet
MD
RESISTIVITY
ohm-m
.2
2
20
200
2K
PORE PRESSURE
EST. lb/gal
9
10
1000
2000
3000
4000
5000
6000
7000
8000
9000



GAMMA RAY
40
80
DEPTH
MD
EWR 2"/1000FT
.2
2
20
200
TOTAL GAS - UNITS
2
20
200
2K
Dc EXPONENT
.3
3
EST. PORE PRESSURE
9
10
1000
2000
3000
4000
5000
6000
7000
8000
90


DEPTH feet
MD
MODIFIED
"D" EXPONENT
.1
1
10
REMARKS
1000
2000
3000
4000
5000
6000
7000
8000
20" CSG
13 3/8" CSG
DULL BIT
DULL BIT
PDC SHIFT
NB NO. 3
STC FDS
NB NO. 4
S44G
NB NO.5
SMITH FDTC
NB NO. 6
DS40HP - PDC

SPERRY-SUN DRILLING SERVICES

APPLIED DRILLING TECHNOLOGY

WELL OCS-Y-0866-1 KUVLUM PROSPECT

COMPANY ARCO ALASKA, INC.

LOCATION BLK 673 BEAUFORT SEA, ALASKA

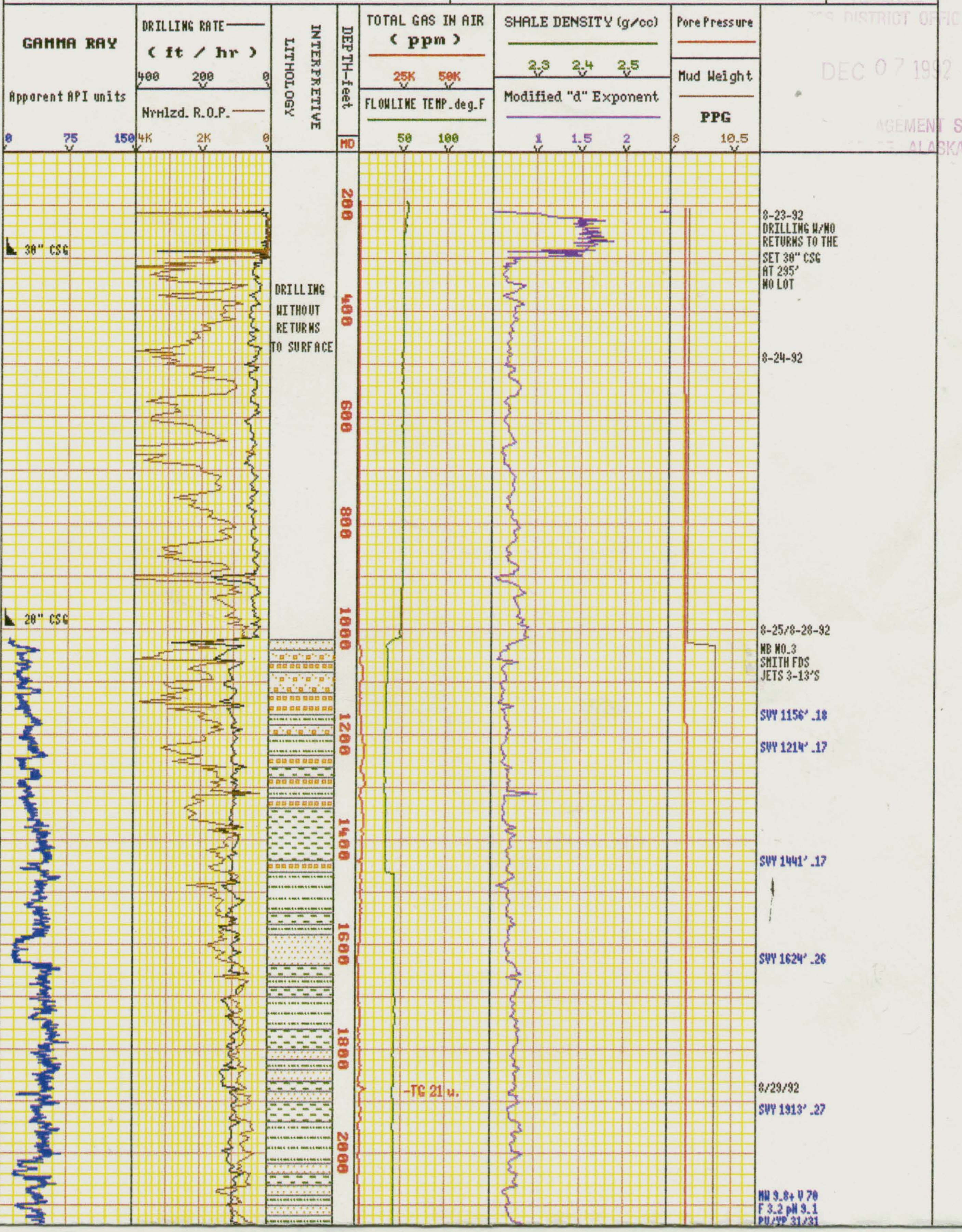
======== LEGEND ========

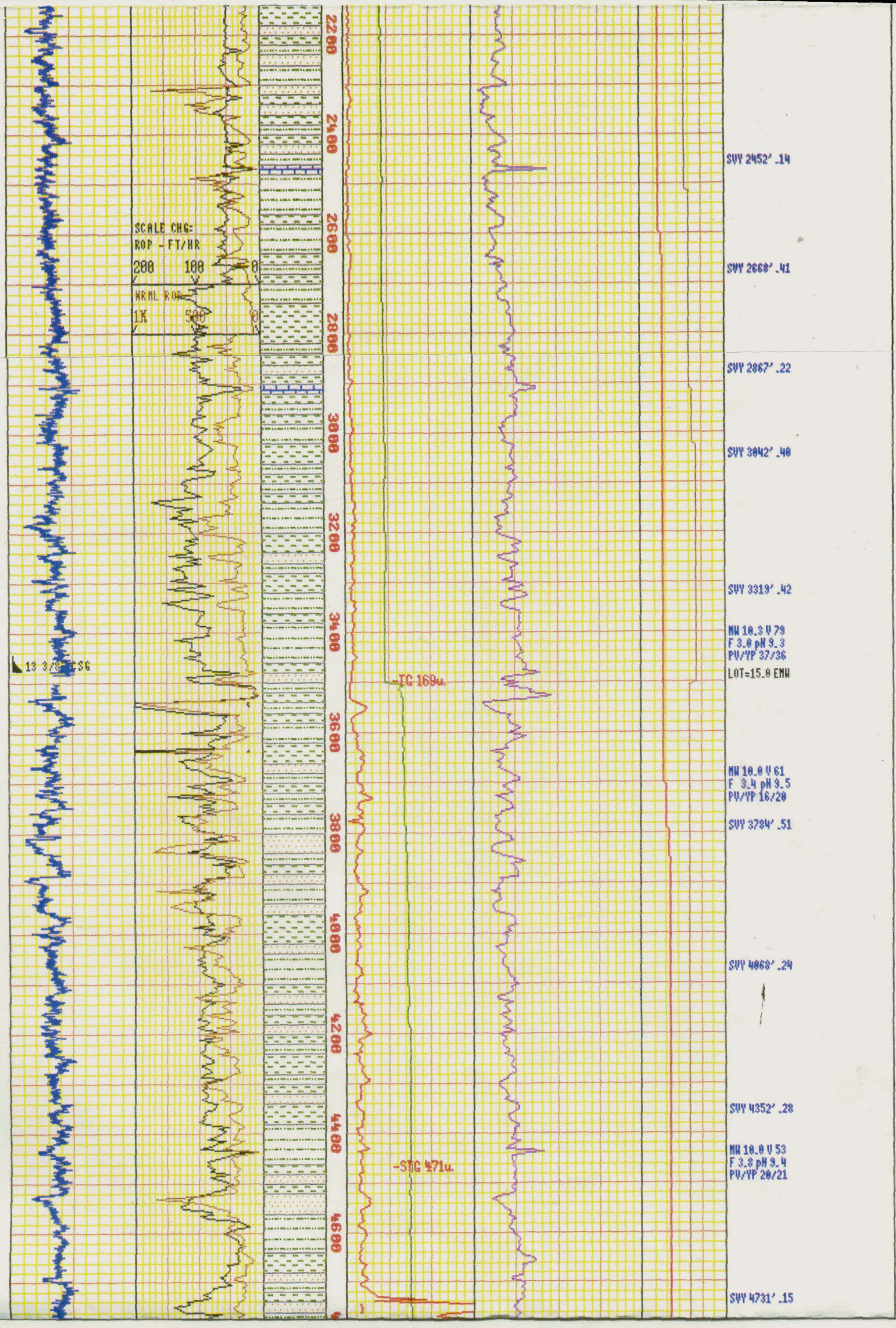
NB New Bit	NCB New Core Bit	CKF Check for Flow
NR No Returns	CO Circulate Out	LAT Log after Trip
TG Trip Gas	TCL Trip Chlorides	SVY Direc Survey

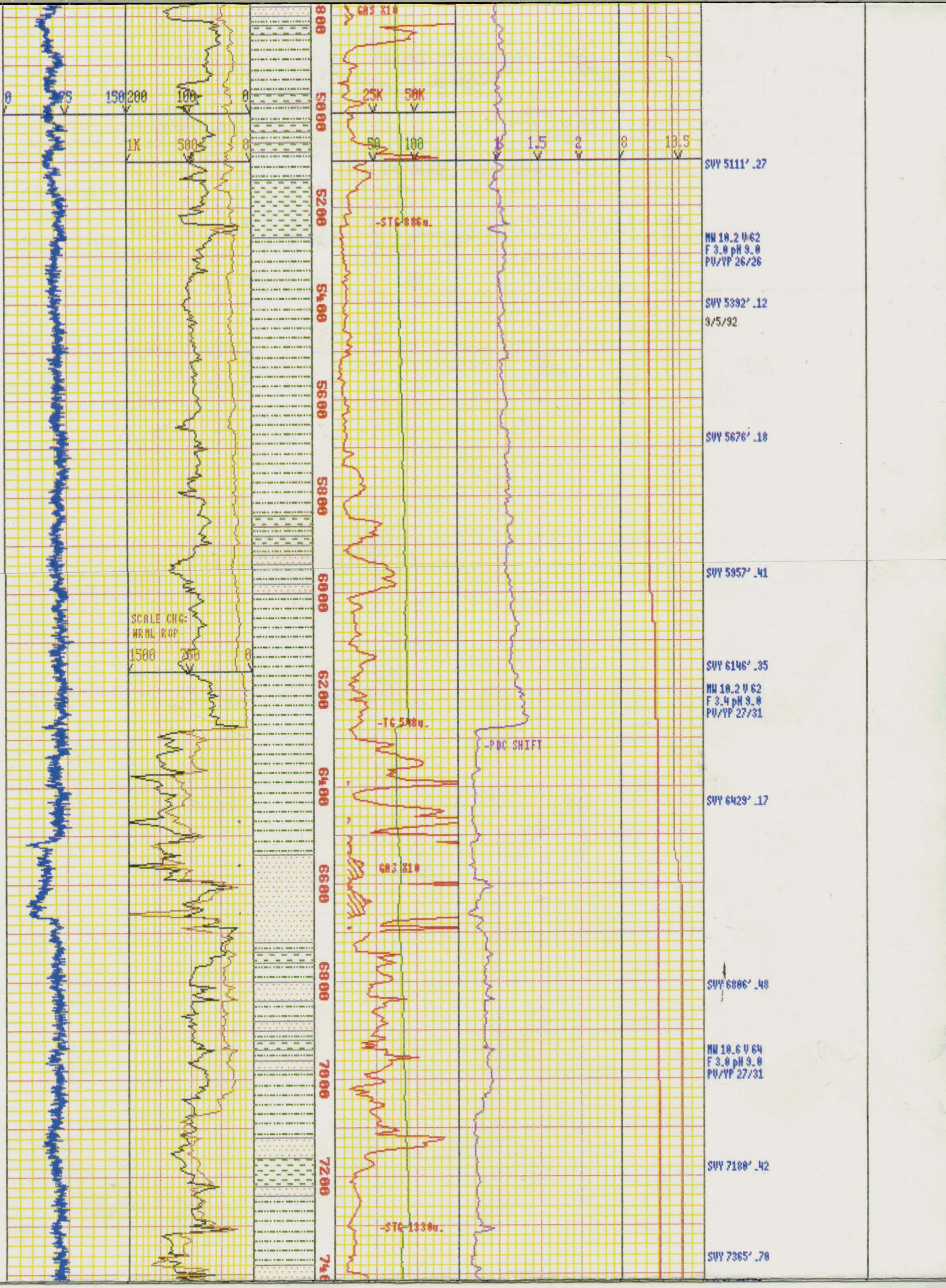
Clay · Shale · Siltstone · Sandstone · Gravel

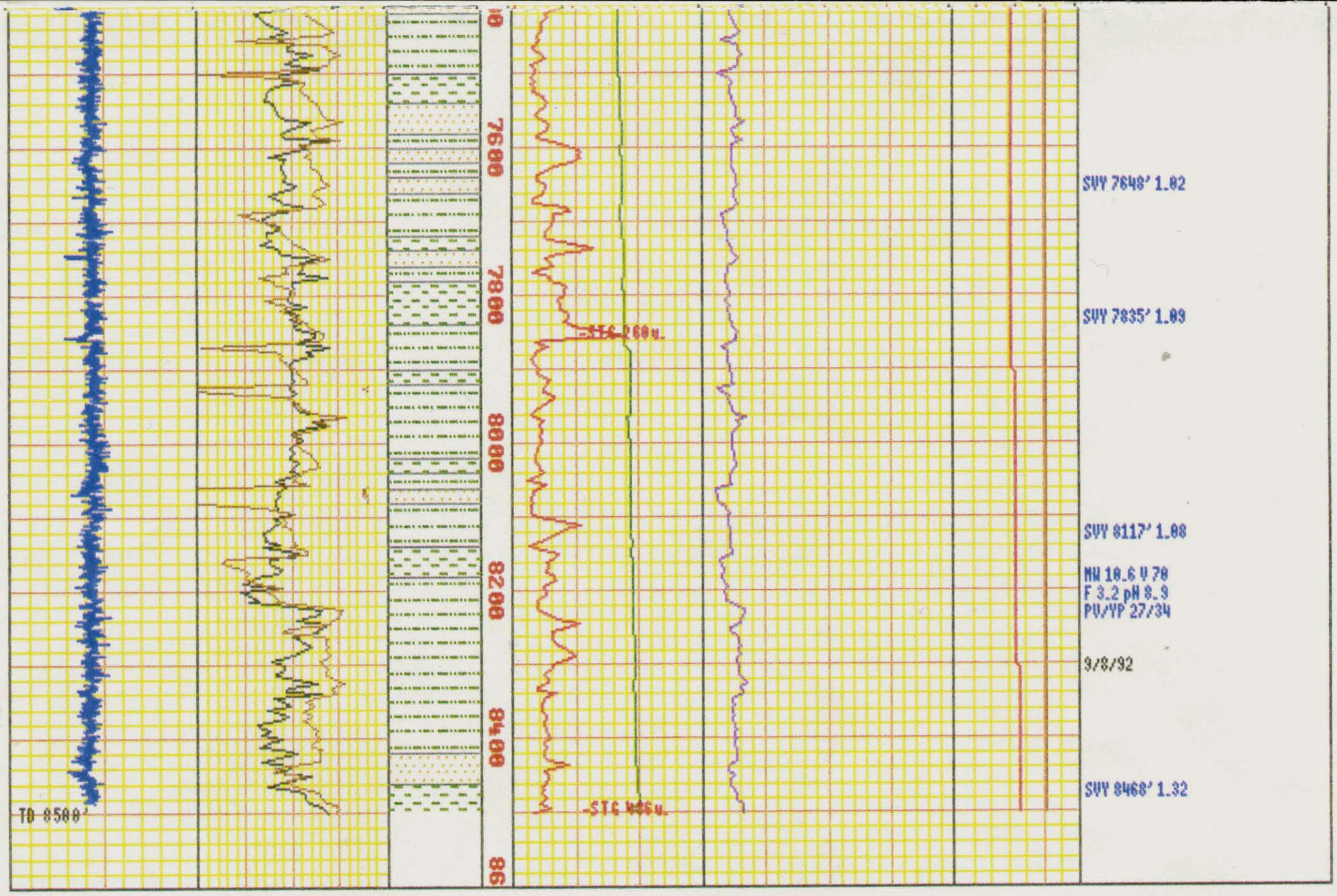
LOGGING SYSTEMS

ADT LOG




2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
SCALE CHG:
ROP - FT/HR
200 100 0
NRML ROP
1K 500 0
13 3/8" CSG
-TG 169u.
-STG 471u.
SVY 2452' .14
SVY 2668' .41
SVY 2867' .22
SVY 3042' .40
SVY 3319' .42
MW 10.3 V 79
F 3.0 pH 9.3
PV/YP 37/36
LOT=15.0 EMW
MW 10.0 V 61
F 3.4 pH 9.5
PV/YP 16/20
SVY 3784' .51
SVY 4068' .24
SVY 4352' .28
MW 10.0 V 53
F 3.8 pH 9.4
PV/YP 20/21
SVY 4731' .15


GAS X10
0
75
150
200
100
0
1K
500
0
25K
50K
50
100
1
1.5
2
8
10.5
SVY 5111' .27
-STG 886u.
MW 10.2 V 62
F 3.0 pH 9.0
PV/YP 26/26
SVY 5392' .12
9/5/92
SVY 5676' .18
SVY 5957' .41
SCALE CHG:
NRML ROP
1500
250
0
SVY 6146' .35
MW 10.2 V 62
F 3.4 pH 9.0
PV/YP 27/31
-TG 548u.
-PDC SHIFT
SVY 6429' .17
GAS X10
SVY 6806' .48
MW 10.6 V 64
F 3.0 pH 9.0
PV/YP 27/31
SVY 7180' .42
-STG 1330u.
SVY 7365' .70
5000
5200
5400
5600
5800
6000
6200
6400
6600
6800
7000
7200


TD 8500'
7600
7800
8000
8200
8400
STG 260u.
STG 486u.
SVY 7648' 1.02
SVY 7835' 1.09
SVY 8117' 1.08
MW 10.6 V 70
F 3.2 pH 8.9
PV/YP 27/34
9/8/92
SVY 8468' 1.32

SPERRY SUN DRILLING SERVICES

LOGGING SYSTEMS A Baroid Company

WELL OCS-Y-0866 KUVLUM NO.1

COMPANY ARCO Alaska Inc.

LOCATION BLOCK 673 Beaufort Sea, Alaska

LEGEND

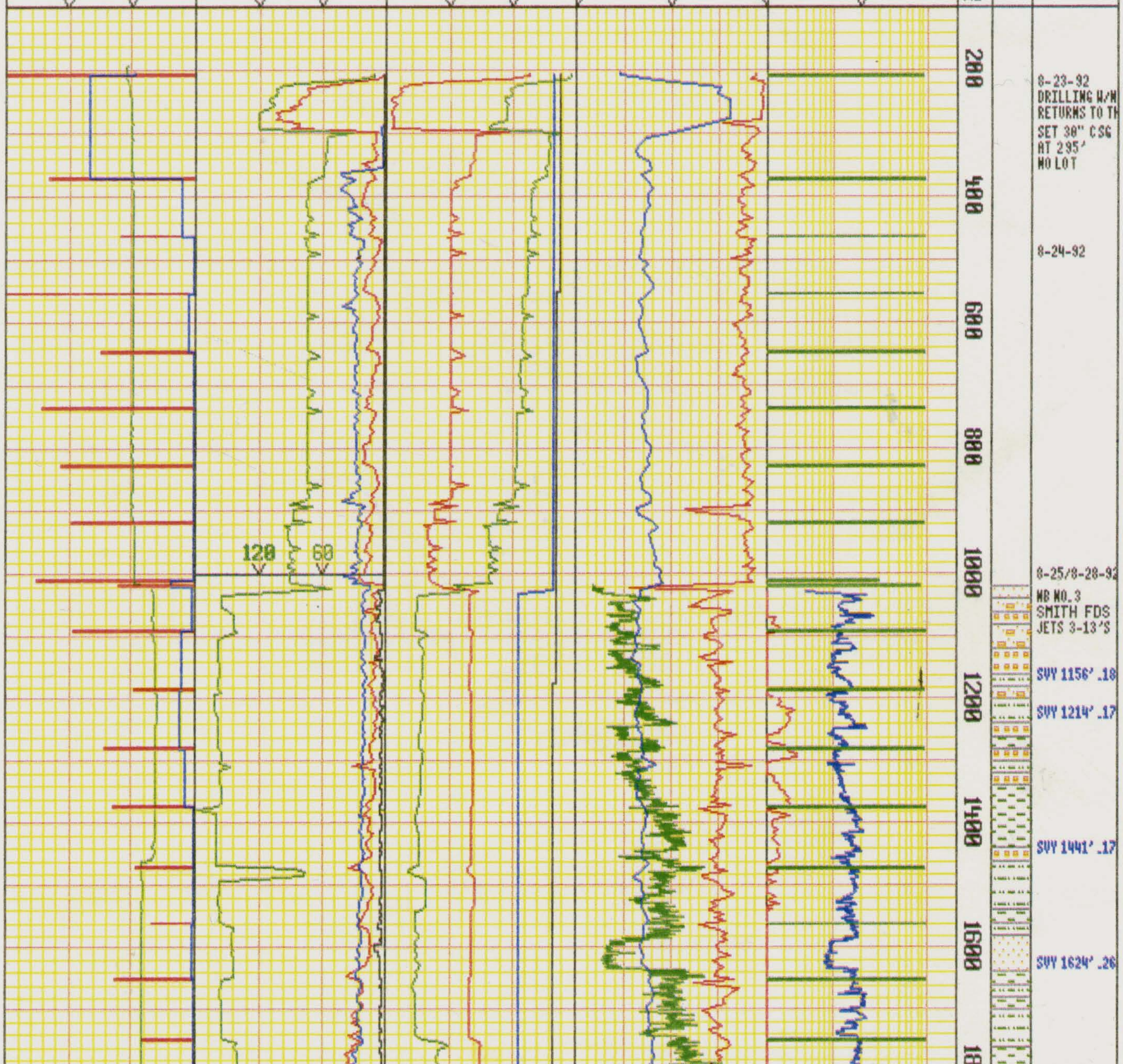
NB New Bit	NCB New Core Bit	CKF Check for Flow
NR No Returns	CO Circulate Out	LAT Log after Trip
TG Trip Gas	CG Connection Gas	DST Drill Stem Test
DC Depth Corr	TCL Trip Chlorides	DS Direc Survey

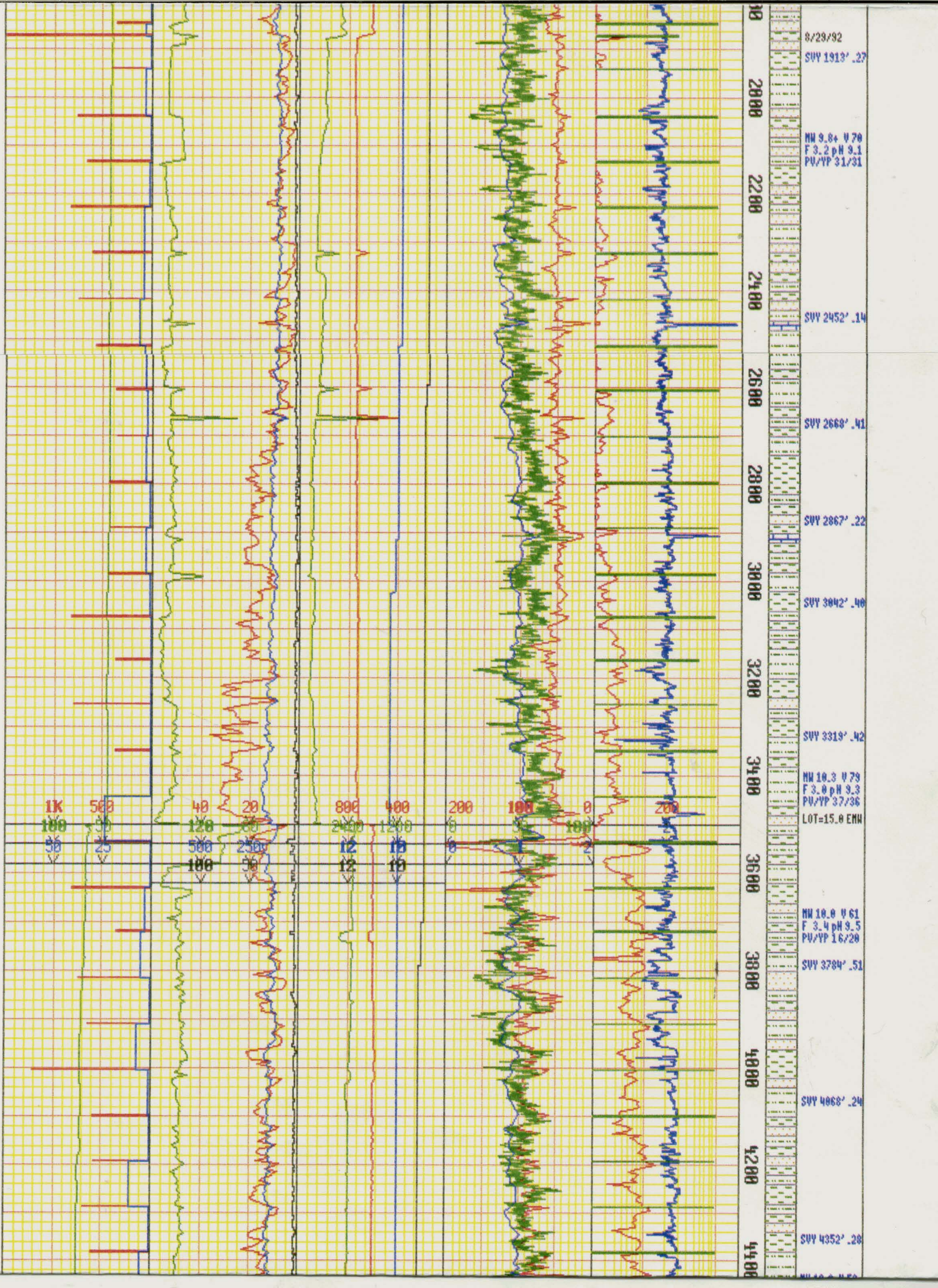
Clay Shale Siltstone Sandstone Gravel

LOGGING SYSTEMS ADT SERVICE

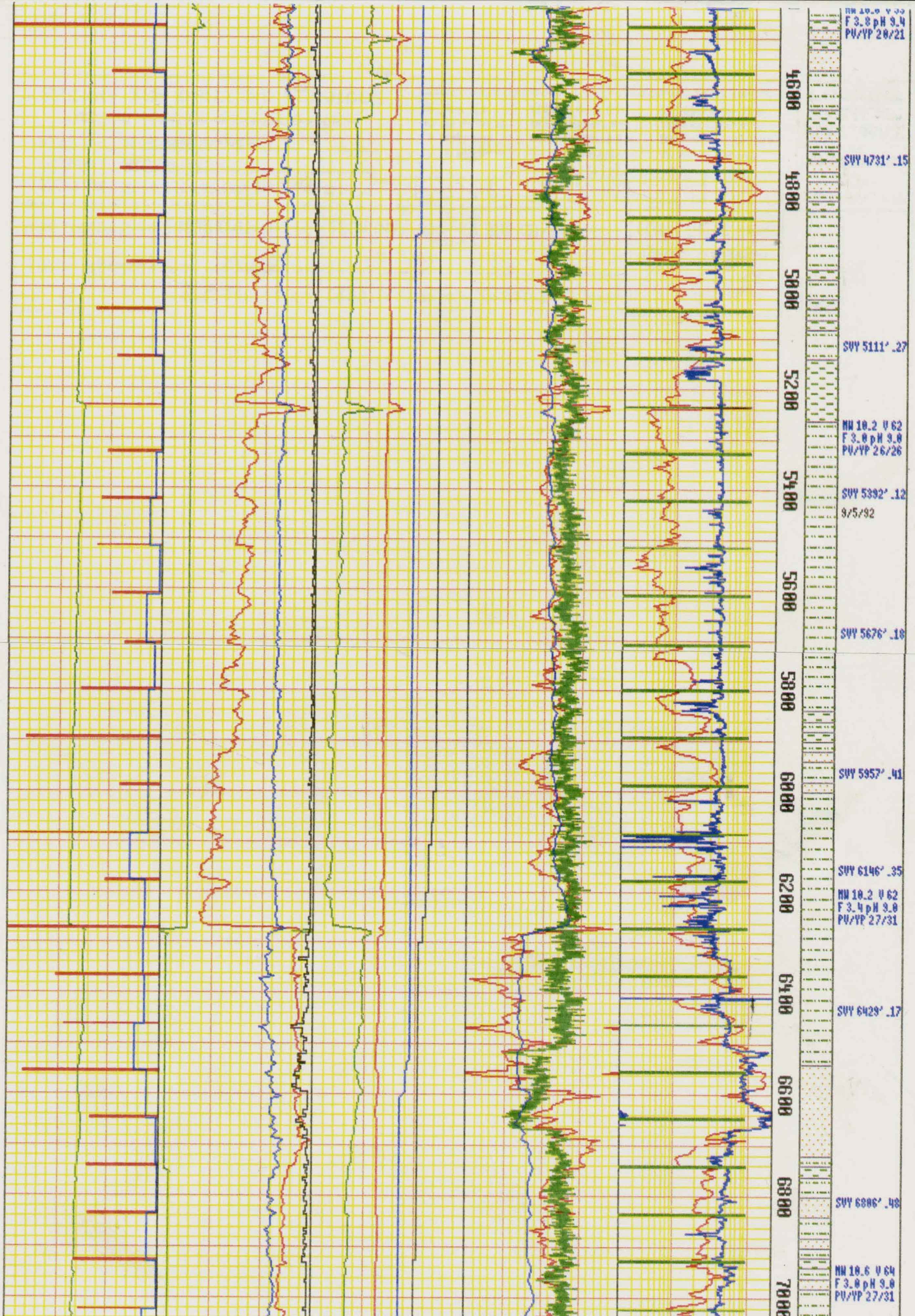
ENGINEERING LOG
50 Feet/Inch

CONN TIME (sec) (bar graph) 1K 500	WOB (klbs) 40 20	FLOW IN (gpm) 800 400	ROP (ft/hr) 400 200 0	CONN LENGTH (bar graph) .2 200 20	DEPTH-feet	LITHOLOGY ANALYSIS	REMARKS
TEMP OUT (f) 100 50	R.P.M. 120 60	STD PIPE (psi) 2400 1200	GAMMA (AAPI) 0 50 100	MAXGAS (units) 2 2K 200			
	TORQ (amps) 500 250	M.W.IN (ppg) 12 10	MOD "dc" EXP 0 1 2	EWR (ohmm) .2 20 2			
CONN DRAG 50 25	TORQ DEV. 100 50	EST PP (ppg) 12 10	SHALE DENS 1.8 2.2 2.6		MD		

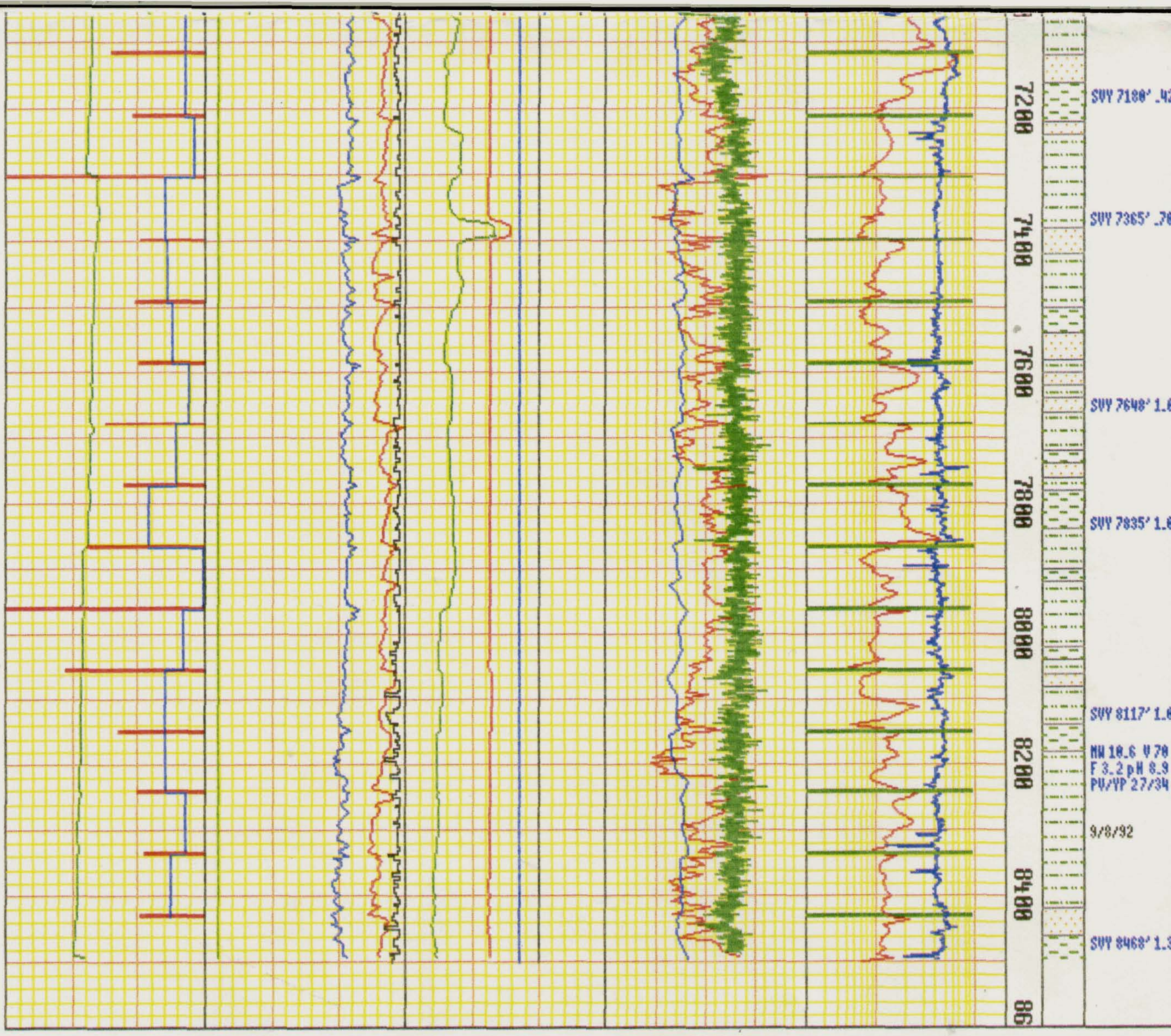




8/29/92
SVY 1913' .27
2000
MW 9.8+ V 70
F 3.2 pH 9.1
PV/YP 31/31
2200
2400
SVY 2452' .14
2600
SVY 2668' .41
2800
SVY 2867' .22
3000
SVY 3042' .40
3200
SVY 3319' .42
3400
MW 10.3 V 79
F 3.0 pH 9.3
PV/YP 37/36
LOT=15.0 EMW
3600
MW 10.0 V 61
F 3.4 pH 9.5
PV/YP 16/20
SVY 3784' .51
3800
4000
SVY 4068' .24
4200
SVY 4352' .28
4400
1K 500
100 50
50 25
40 20
120 60
500 2500
100 50
800 400
2400 1200
12 10
12 10
200 0
100 0
200



4600
4800
5000
5200
5400
5600
5800
6000
6200
6400
6600
6800
7000
F 3.8 pH 9.4
PV/YP 20/21
SVY 4731' .15
SVY 5111' .27
MW 10.2 V 62
F 3.0 pH 9.0
PV/YP 26/26
SVY 5392' .12
9/5/92
SVY 5676' .18
SVY 5957' .41
SVY 6146' .35
MW 10.2 V 62
F 3.4 pH 9.0
PV/YP 27/31
SVY 6429' .17
SVY 6806' .48
MW 10.6 V 64
F 3.0 pH 9.0
PV/YP 27/31


7200
7400
7600
7800
8000
8200
8400
86
SVY 7180' .42
SVY 7365' .70
SVY 7648' 1.0
SVY 7835' 1.0
SVY 8117' 1.0
MW 10.6 V 70
F 3.2 pH 8.9
PV/YP 27/34
9/8/92
SVY 8468' 1.3

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DRILLING SERVICES
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LOGGING SYSTEMS

BIT RECORD

CASING PROGRAM				
30	inch at	294	ft
20	inch at	995	ft
13 3/8	inch at	3479	ft
9 5/8	inch at	8458	ft
	inch at		ft

COMPANY	ARCO Alaska Inc.	FIELD/BLOCK	Beaufort Sea Block 673
WELL	OCS-Y-0866 Kuvlum No.1	LOCATION	North Slope
CONTRACTOR	Beaudril-Global	STATE	Alaska
MUD COMPANY	M-I Drilling Fluids	SPUD DATE	12 August 1992

DATE	BIT NO	TYPE	SIZE inches	JETS 1/32	DEPTH OUT	FEET drlg	ROP ft/hr	HRS	TOT HRS	CST $/ft	WOB klbs	RPM	FLOW gpm	SSP psi	MW ppg	GRADE			REMARKS
																B	T	G	
08-22-92	1	HTC OSC3A	26	24-24-24	1015	809	26.5	30.4	30.4	129	13.6	83	883	1069	8.7	1	2	1	Jetted 30" csg, drill hole f/20" csg
08-27-92	2	SEC S3SJ4	17.5	16-16-16-10	1026	11	32.5	1.2	31.6	NA	2	64	890	2325	9.8	1	1	I	DRILL OUT 20"
08-28-92	3	STC FDS	12.25	13-13-13	1861	845	98.2	8.6	40.2	49	6	153	842	3250	9.8	1	1	I	POOH FOR NEW MWD TOOL
08-30-92	4	SEC S44G	12.25	13-13-13-10	3500	1629	95.5	17.0	57.2	47	13	157	740	3175	10.3	2	2	I	POOH AT CSG POINT
09-01-92	RR3	STC FDS	12.25/17.5	13-13-13	3500	2474	372	6.6	63.8	NA	17	159	1022	2925	10.5	2	2	I	OPEN HOLE WITH 17.5 H.O.
09-03-92	5	STC FDTC	12.25	14-14-14	6271	2771	73.3	37.8	101.6	56	19	135	617	2650	10.2	2	2	1	
09-06-92	6	DS40 HP	12.25	TFA=.6496	8500	2229	94.9	23.5	125.1	51	6	170	700	2900	10.6	I	N	C	PDC - POOH AT TD

sperry-sun DRILLING SERVICES A Baroid Company **LOGGING SYSTEMS**

CASING PROGRAM				
30	inch at	294	ft
20	inch at	995	ft
13 3/8	inch at	3479	ft
9 5/8	inch at	8458	ft
	inch at		ft

DRILLLING MUD RECORD

COMPANY: ARCO Alaska Inc.
WELL: OCS-Y-0866 Kuvlum No.1
CONTRACTOR: Beaudril-Global
MUD COMPANY: M-I Drilling Fluids

FIELD/BLOCK: Beaufort Sea Block 673
LOCATION: North Slope
STATE: Alaska
SPUD DATE: 12 August 1992

DATE	DEPTH ft	WEIGHT lb/gal	VIS sec	PV cp	YP lb/hf2	GELS 10 sec/ 10 min	FLTR ml/30m	HTHP /deg F	CAKE 1/32	SOL %	OIL %	WATER %	SD %	CEC meq/hg	pH	PM	Pf/Mf	Cl- ppm	CA ppm
08-25-92	1015	9.5	135	29	41	25/55	11.0	na	2	6	0	94	na	27.5	9.5	.40	.20/.40	5000	40
08-27-92	1015	9.8	38	11	14	4/8	10.4	na	2	3	0	97	na	5.0	8.7	.20	.10/.70	13500	1440
08-28-92	1026	9.8	48	23	18	3/5	3.2	na	2	3	0	97	na	5.0	9.1	.20	.15/.90	13500	1360
08-29-92	2132	9.8+	70	31	31	5/10	3.2	na	1	7	0	93	2.5	5.0	9.1	.50	.20/.80	15000	1240
08-30-92	3500	10.3	79	37	36	6/11	2.6	na	1	9	0	91	2.0	6.25	9.0	.40	.30/1.0	17000	1240
08-03-92	3500	10.3+	64	30	31	5/9	3.0	na	1	8.5	tr	91.5	2.0	5.0	9.3	.50	.30/1.0	17000	1320
09-01-92	3500	10.5	88	41	40	5/15	2.6	na	1	10	tr	90	2.0	5.0	9.0	.40	.30/1.1	17000	1400
09-02-92	3500	10.2	51	24	14	2/7	3.8	na	1	9	tr	91	2.0	3.75	8.8	.30	.20/.90	17000	1600
09-03-92	3510	10.0	61	16	20	3/5	3.4	20.8/200	2	7	0	93	0	4.0	9.5	.35	.25/.50	7300	360
09-04-92	4440	10.0	53	20	21	3/5	3.8	13.4/200	2	7.5	0	92.5	.75	3.75	9.4	.30	.15/.50	7300	240
09-05-92	5250	10.2	62	26	26	4/12	3.0	14.4/200	2	8.5	0	91.5	.75	5.0	9.0	.30	.15/.50	6800	180
09-06-92	6270	10.2	73	27	31	4/10	3.4	14.0/200	<2	8	tr	92	.75	5.0	9.0	.30	.15/.05	6200	160
09-07-92	6925	10.6	64	27	31	4/12	3.0	13.0/200	<2	9.5	.5	90	.6	4.5	9.0	.30	.10/.60	7800	300
09-08-92	8250	10.6	70	27	34	4/12	3.2	12.4/200	<2	9.5	.5	90	.5	5.5	8.9	.30	.10/.50	10100	440
09-09-92	8500	10.6+	74	27	33	4/11	2.8	11.2/200	1	10	tr	90	.5	5.0	8.9	.30	.15/.70	11100	500
09-10-92	8500	10.6	74	15	40	5/10	3.0	11.6/200	1	10	tr	90	.5	5.0	8.8	.30	.15/.75	11000	500
09-11-92	8500	10.6	82	28	29	5/11	3.8	13.0/200	1	10	tr	90	.5	5.0	8.8	.20	.05/.80	12500	600
09-12-92	8500	10.6	82	28	35	5/12	3.2	13.0/200	1	10	tr	90	.5	5.0	8.8	.20	.05/.75	12500	600
09-13-92	8500	10.6	82	28	34	3/11	3.2	13.0/200	1	10	tr	90	.5	5.0	8.8	.20	.05/.75	12500	600
09-14-92	8500	10.6+	72	24	28	4/13	3.6	13.2/200	1	10	tr	90	.5	5.0	8.6	.1	.05/.75	12500	750
09-15-92	8500	10.8	72	24	29	4/12	3.6	13.4/200	1	10.5	tr	89.5	.5	5.0	8.6	.1	.05/.75	12500	750
09-16-92	8500	10.8	67	25	16	3/13	5.0	18.0/200	1	10.5	tr	89.5	.5	5.0	8.5	.1	.05/.95	12500	800

sperry-sun
DRILLING SERVICES

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ARCO ALASKA, INC.
WILDCAT
AKMF920617:55-171-00008
AUGUST 1992

KUVLUM #1
KULLUK
NORTH REFERENCE : TRUE NORTH
SHORT COLLAR METHOD
MAG. FIELD STRENGTH (NT) : 57609
DIP ANGLE : 81.03
TOTAL CORRECTION : 32.04

MEASURED DEPTH	ANGLE DEGREE	DIRECTION DEGREE	VERTICAL DEPTH	LATITUDE FEET	DEPARTURE FEET	VERTICAL SECTION	DOG LEG SEVERITY
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1156.23	0.18	68.10	1156.23	0.68	1.69	1.13	0.02
1214.15	0.17	286.60	1214.15	0.74	1.69	1.18	0.57
1441.25	0.17	333.40	1441.25	1.13	1.21	1.43	0.06
1531.29	0.48	306.20	1531.28	1.48	0.85	1.66	0.37
1624.45	0.26	339.70	1624.44	1.90	0.46	1.96	0.32
1913.34	0.27	291.33	1913.33	2.76	-0.40	2.54	0.07
2104.02	0.08	0.21	2104.01	3.06	-0.81	2.70	0.13
2297.74	0.14	255.87	2297.72	2.97	-1.16	2.52	0.03
2389.50	0.34	275.59	2389.48	2.97	-1.54	2.41	0.24
2452.02	0.14	301.63	2451.99	3.02	-1.79	2.39	0.36
2482.06	0.26	271.99	2482.03	3.05	-1.89	2.39	0.50
2575.36	0.36	232.60	2575.33	2.88	-2.33	2.10	0.24
2668.65	0.41	183.16	2668.62	2.37	-2.58	1.54	0.35
2761.32	0.49	165.37	2761.29	1.65	-2.50	0.88	0.17
2859.78	0.21	150.04	2859.75	1.09	-2.30	0.40	0.29
2867.09	0.22	95.51	2867.06	1.08	-2.28	0.39	2.66
2954.56	0.16	93.67	2954.53	1.06	-1.99	0.45	0.06
3042.78	0.40	2.16	3042.75	1.35	-1.86	0.77	0.49
3132.28	0.50	327.34	3132.25	1.99	-2.05	1.33	0.32
3319.86	0.42	358.68	3319.82	3.37	-2.51	2.52	0.14
3415.06	0.38	338.17	3415.02	4.01	-2.64	3.10	0.16
3468.28	0.53	7.89	3468.24	4.42	-2.67	3.49	0.52
3501.85	0.52	354.85	3501.81	4.73	-2.66	3.78	0.34
3600.81	0.78	356.68	3600.76	5.85	-2.74	4.83	0.27
3689.69	0.76	347.02	3689.63	7.03	-2.91	5.92	0.15
3784.70	0.51	340.08	3784.63	8.05	-3.20	6.82	0.27
3878.75	0.58	335.66	3878.67	8.88	-3.53	7.51	0.07
3971.54	0.22	323.77	3971.46	9.44	-3.83	7.97	0.39
4068.95	0.24	358.24	4068.87	9.80	-3.95	8.28	0.14
4165.53	0.30	54.11	4165.45	10.15	-3.75	8.68	0.27
4256.36	0.26	40.67	4256.28	10.45	-3.42	9.05	0.09
4352.54	0.28	83.15	4352.46	10.64	-3.04	9.35	0.21
4446.86	0.25	105.56	4446.77	10.62	-2.61	9.44	0.11

sperry-sun
DRILLING SERVICES

ARCO ALASKA, INC.
WILDCAT
AKMF920617:55-171-00008
AUGUST 1992

KUVLUM #1
KULLUK
NORTH REFERENCE : TRUE NORTH
SHORT COLLAR METHOD
MAG. FIELD STRENGTH (NT) : 57609
DIP ANGLE : 81.03
TOTAL CORRECTION : 32.04

MEASURED DEPTH	ANGLE DEGREE	DIRECTION DEGREE	VERTICAL DEPTH	LATITUDE FEET	DEPARTURE FEET	VERTICAL SECTION	DOG LEG SEVERITY
4539.15	0.45	14.07	4539.06	10.91	-2.33	9.81	0.56
4731.71	0.15	327.24	4731.62	11.86	-2.28	10.73	0.19
4919.83	0.30	4.69	4919.74	12.56	-2.38	11.37	0.11
5111.17	0.27	40.71	5111.08	13.40	-2.04	12.27	0.09
5203.67	0.19	24.84	5203.58	13.70	-1.84	12.62	0.10
5392.84	0.12	20.97	5392.75	14.16	-1.64	13.12	0.03
5582.62	0.05	20.58	5582.53	14.42	-1.54	13.39	0.04
5676.92	0.18	118.44	5676.83	14.33	-1.38	13.36	0.14
5768.47	0.32	9.71	5768.38	14.52	-1.21	13.58	0.45
5864.03	0.42	340.66	5863.93	15.11	-1.28	14.13	0.22
5957.02	0.41	340.89	5956.92	15.75	-1.50	14.68	0.00
6052.22	0.33	357.56	6052.12	16.35	-1.62	15.22	0.14
6146.04	0.35	322.68	6145.94	16.85	-1.81	15.65	0.22
6240.87	0.44	326.29	6240.77	17.38	-2.19	16.05	0.09
6429.65	0.17	312.00	6429.54	18.17	-2.80	16.64	0.15
6523.16	0.12	39.49	6523.06	18.34	-2.84	16.78	0.22
6617.92	0.36	6.59	6617.81	18.71	-2.75	17.16	0.28
6806.50	0.48	46.06	6806.39	19.84	-2.11	18.43	0.16
6899.14	0.57	28.57	6899.03	20.51	-1.62	19.21	0.19
7180.65	0.42	3.40	7180.53	22.76	-0.89	21.58	0.09
7272.90	0.67	10.43	7272.77	23.62	-0.77	22.44	0.27
7365.11	0.70	33.50	7364.98	24.62	-0.37	23.51	0.30
7648.01	1.02	47.56	7647.84	27.75	2.44	27.30	0.14
7835.67	1.09	29.91	7835.47	30.42	4.56	30.47	0.18
8117.60	1.08	35.24	8117.35	34.91	7.42	35.58	0.03
8211.54	1.09	33.40	8211.28	36.37	8.43	37.27	0.04
8305.31	1.38	36.50	8305.02	38.03	9.59	39.19	0.31
8400.03	1.31	44.42	8399.72	39.72	11.03	41.22	0.21
8468.80	1.32	38.63	8468.47	40.90	12.07	42.65	0.19

CALCULATIONS BASED ON THE MINIMUM CURVATURE METHOD
HORIZONTAL DISPLACEMENT AT A DEPTH OF 8468.8 FEET
IS 42.6 FEET ALONG N 16 DEG 27 MIN E
RELATIVE TO WELL HEAD
VERTICAL SECTION RELATIVE TO WELL HEAD
VERTICAL SECTION COMPUTED ALONG 16.45 DEG
A DECLINATION OF 32.04 HAS BEEN APPLIED

SHOW REPORTS

This section of the report contains copies of show evaluation reports for OCS-Y-0866 #1. These reports are based on chromatography evaluations of gases retrieved from mud samples injected into Sperry-Sun's Steam Still apparatus; consequently, interpretations made on each report reflect this procedure. Show reports are not always included in the well report analysis because of restricted information requirements placed on some wildcat wells. They do offer some insight of fluid content on potential producing zones of good permeability; however, they are often inadequate on tight zones or when gas samples are taken while coring.

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See attachment regarding SPE-AIME, B.O. Pixler referencing hydrocarbon ratio evaluations.

sperry-sun DRILLING SERVICES
A Baroid Company
LOGGING SYSTEMS

Show Report 1 Part B
Depth Interval 6510 to 6550
True Vert. Depth 6510 to 6550
Prepared by A. Provant / J. Patton
Delivered to McGrath / Decker
Date 9-7-92 Time 22:00

Operator ARCO ALASKA, INC.
Well Name OCS-Y-0866 - KUVLUM NO.1
Location BLOCK 673 BEAUFORT SEA, ALASKA

ZONE PRODUCTION	[X] GAS	[X] OIL		[ ] WATER		[ ] NON-PRODUCIBLE HYDROCARBONS	
CONTACT DEPTH	Gas/Oil	ft.	Gas/Water	ft.	Oil/Water	ft.	

5 DEPTH 6520 ft. GAS [ ] % [X] units 880 MUD CHLORIDES (ppm) 6200

(Steam Still ppm's in 1000's)

	FLOWLINE ppm	-	SUCTION ppm	=	SHOW ppm
C_1	22,800	-	550	=	22,250
C_2	1,470	-	25	=	1,445
C_3	1,390	-	30	=	1,360
C_4	1,430	-	44	=	1,386
C_5	1,078	-	46	=	1,032

HYDROCARBON RATIOS

C_1/C_2 =	15
C_1/C_3 =	16
C_1/C_4 =	16
C_1/C_5 =	22

PRODUCTION ANALYSIS [X] GAS [X] OIL [ ] WATER [ ] NON-PRODUCIBLE HYDROCARBONS

6 DEPTH 6550 ft. GAS [ ] % [X] units 1100 MUD CHLORIDES (ppm) 6200

(Steam Still ppm's in 1000's)

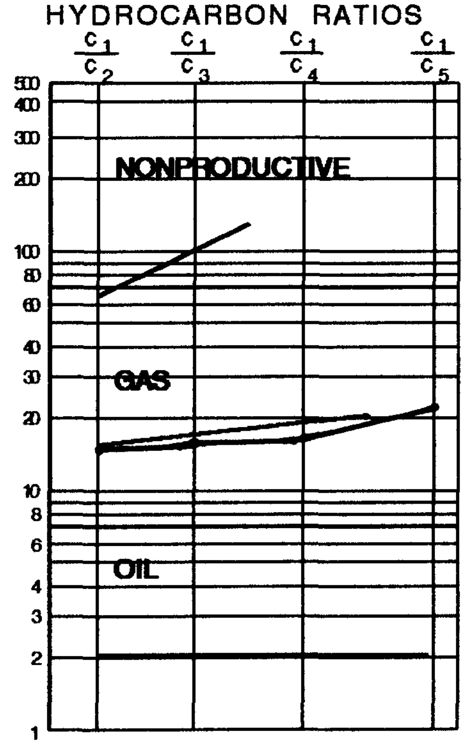
	FLOWLINE ppm	-	SUCTION ppm	=	SHOW ppm
C_1	23,800	-	550	=	23,250
C_2	2,060	-	25	=	2,035
C_3	1,730	-	30	=	1,700
C_4	1,530	-	44	=	1,486
C_5	1,359	-	46	=	1,313

HYDROCARBON RATIOS

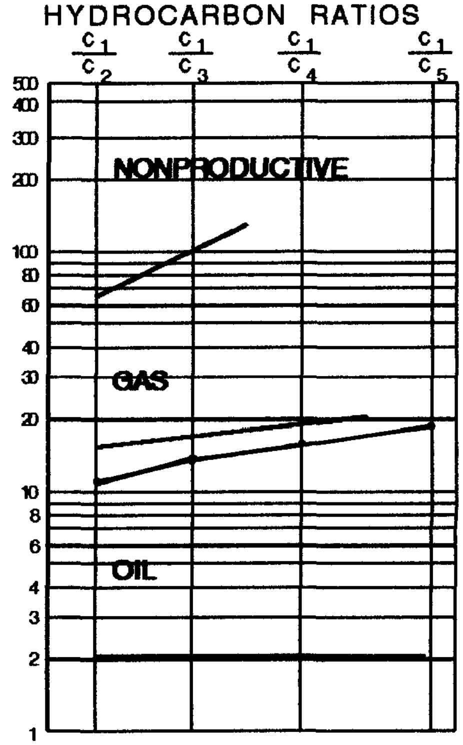
C_1/C_2 =	11
C_1/C_3 =	14
C_1/C_4 =	16
C_1/C_5 =	18

PRODUCTION ANALYSIS [ ] GAS [X] OIL [ ] WATER [ ] NON-PRODUCIBLE HYDROCARBONS

HYDROCARBON RATIOS



HYDROCARBON RATIOS



LITHOLOGY

SD-CLR,GRY,BLK,S&P,VF-FGR,PRED FGR,ANG-SBRND,FSRT,ARG,SLTY, GRADING TO SILT IP,MOSTLY UNCONS,POSS SILT & CLY MTRX,60% QTZ,40% LITH FRAGS.TR TN STAIN IP,NO VIS POR WITH UNCONS SD.

SHOW EVALUATION

20-30% DUL WH-GRN FLOR IN SMPL,POOR SLO DIFF YEL CUT FLOR, SHORT DURATION-STRONG OIL ODOR,NOTABLE BRI YEL-GRN FLOR IN FLOWLINE DRILLING MUD SAMPLE. VERY GOOD OVERALL SHOW RATING..

REMARKS

RATIO ANALYSIS INDICATE THE PRESENCE OF HIGHER GRAVITY HYDROCARBONS OR GAS IN THE VERY TOP OF THIS ZONE. GOOD FLOURESCENCE FOUND IN DRILLING MUD SAMPLES INDICATES GOOD POROSITY AND PERMEABILITY.

sperry-sun DRILLING SERVICES **LOGGING SYSTEMS**
A Baroid Company

Show Report 2 Part B
Depth Interval 6550 to 6610
True Vert.Depth 6550 to 6610
Prepared by A. Provant / J. Patton
Delivered to McGrath / Decker
Date 9-7-92 Time 23:00

Operator ARCO ALASKA, INC.
Well Name OCS-Y-0866 - KUVLUM NO.1
Location BLOCK 673 BEAUFORT SEA, ALASKA

ZONE PRODUCTION	[ ] GAS	[X] OIL	[ ] WATER	[ ] NON-PRODUCIBLE HYDROCARBONS
CONTACT DEPTH	Gas/Oil ____ ft.	Gas/Water ____ ft.	Oil/Water ____ ft.	

5 DEPTH 6580 ft. GAS [ ] % [X] units 1300 MUD CHLORIDES (ppm) 6200

	FLOWLINE ppm	-	SUCTION ppm	=	SHOW ppm	HYDROCARBON RATIOS	
	(Steam Still ppm's in 1000's)						
C_1	7,500	-	550	=	6,950	C_1/C_2 =	10
C_2	735	-	25	=	710	C_1/C_3 =	9
C_3	775	-	30	=	745	C_1/C_4 =	10
C_4	765	-	44	=	721	C_1/C_5 =	10
C_5	731	-	46	=	685		

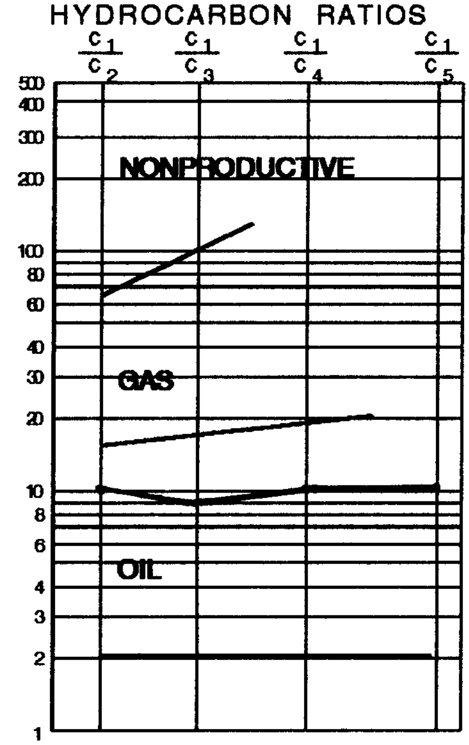
PRODUCTION ANALYSIS [ ] GAS [X] OIL [ ] WATER [ ] NON-PRODUCIBLE HYDROCARBONS

6 DEPTH 6610 ft. GAS [ ] % [X] units 755 MUD CHLORIDES (ppm) 6200

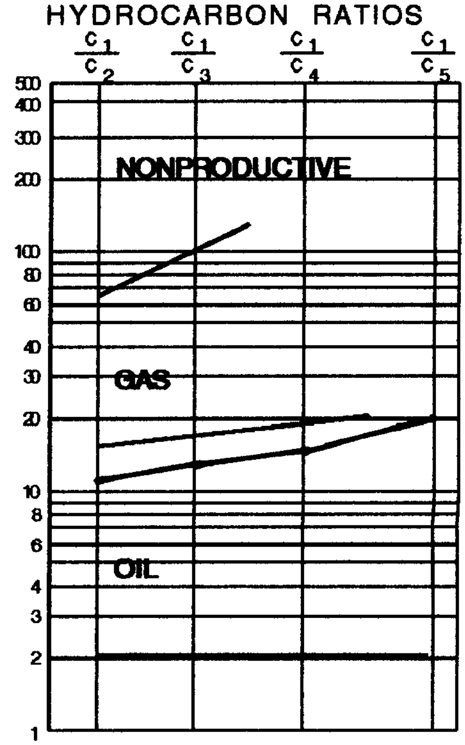
	FLOWLINE ppm	-	SUCTION ppm	=	SHOW ppm	HYDROCARBON RATIOS	
	(Steam Still ppm's in 1000's)						
C_1	5,600	-	550	=	5,050	C_1/C_2 =	11
C_2	480	-	25	=	455	C_1/C_3 =	13
C_3	430	-	30	=	400	C_1/C_4 =	14
C_4	395	-	44	=	351	C_1/C_5 =	20
C_5	301	-	46	=	255		

PRODUCTION ANALYSIS [ ] GAS [X] OIL [ ] WATER [ ] NON-PRODUCIBLE HYDROCARBONS

HYDROCARBON RATIOS



HYDROCARBON RATIOS



LITHOLOGY

SD-CLR,GRY,BLK,S&P,VF-FGR,PRED FGR,ANG-SBRND,MSRT,ARG,SLTY, GRADING TO SILT IP,UNCONS,POSS SILT & CLY MTRX,60% QTZ, 40% LITH FRAGS.NO VIS POR WITH UNCONS SD.

SHOW EVALUATION

40-50% DUL WH-YEL/GRN FLOR IN SMPL, DIFF MILKY/YEL BATCH CUT, SHORT DURATION-STRONG OIL ODOR,NOTABLE BRI YEL-GRN FLOR IN FLOWLINE DRILLING MUD SAMPLE. VERY GOOD OVERALL SHOW RATING..

REMARKS

RATIO ANALYSIS INDICATE THE PRESENCE OIL IN THIS ZONE. RATIO PLOT AT 6610 AND SLOWER DRILL RATES LOGGED FROM 6600-6610' INDICATE THAT THIS PART OF ZONE MAY BE TIGHT.

sperry-sun DRILLING SERVICES
A Baroid Company
LOGGING SYSTEMS

Show Report 3 Part B
Depth Interval 6610 to 6665
True Vert.Depth 6610 to 6665
Prepared by A. Provant / J. Patton
Delivered to McGrath / Decker
Date 9-7-92 Time 23:30

Operator ARCO ALASKA, INC.
Well Name OCS-Y-0866 - KUVLUM NO.1
Location BLOCK 673 BEAUFORT SEA, ALASKA

ZONE PRODUCTION	☐ GAS	☒ OIL	☐ WATER	☐ NON-PRODUCIBLE HYDROCARBONS
CONTACT DEPTH	Gas/Oil ____ ft.	Gas/Water ____ ft.	Oil/Water ____ ft.	

5 DEPTH 6630 ft. GAS ☐ % ☒ units 1550 MUD CHLORIDES (ppm) 6400

(Steam Still ppm's in 1000's)

	FLOWLINE ppm	-	SUCTION ppm	=	SHOW ppm	HYDROCARBON RATIOS	
C_1	11,200	-	475	=	10,725	C_1/C_2 =	12
C_2	960	-	31	=	929	C_1/C_3 =	13
C_3	865	-	65	=	800	C_1/C_4 =	13
C_4	890	-	94	=	796	C_1/C_5 =	22
C_5	600	-	114	=	486		

PRODUCTION ANALYSIS ☐ GAS ☒ OIL ☐ WATER ☐ NON-PRODUCIBLE HYDROCARBONS

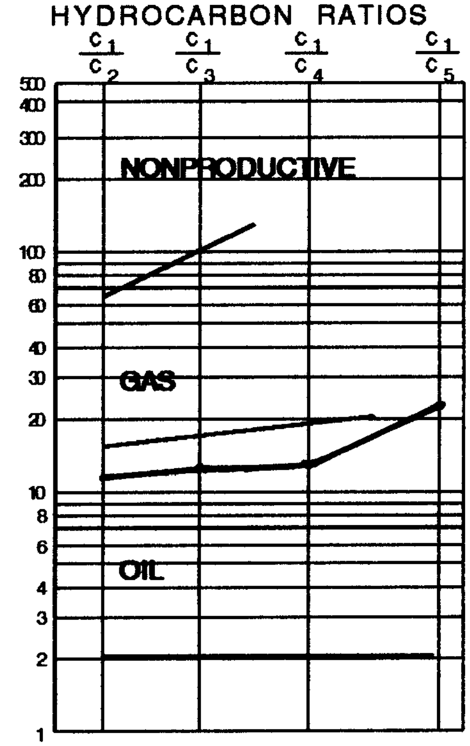
6 DEPTH 6665 ft. GAS ☐ % ☒ units 1100 MUD CHLORIDES (ppm) 6400

(Steam Still ppm's in 1000's)

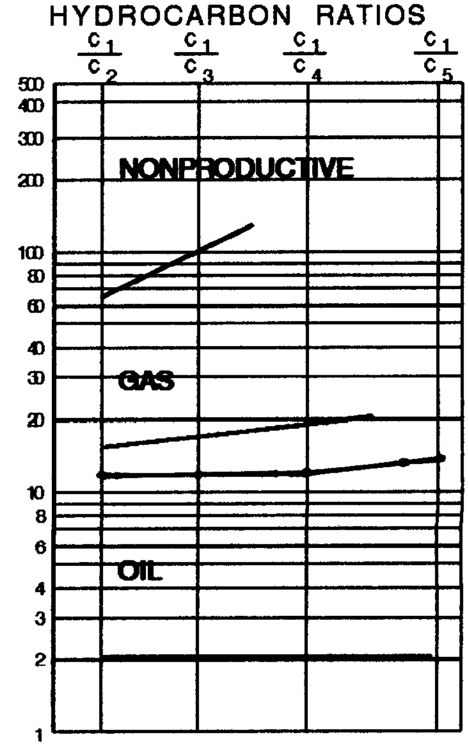
	FLOWLINE ppm	-	SUCTION ppm	=	SHOW ppm	HYDROCARBON RATIOS	
C_1	8,100	-	450	=	7,650	C_1/C_2 =	12
C_2	685	-	31	=	654	C_1/C_3 =	12
C_3	705	-	65	=	640	C_1/C_4 =	12
C_4	710	-	94	=	616	C_1/C_5 =	13
C_5	713	-	114	=	599		

PRODUCTION ANALYSIS ☐ GAS ☒ OIL ☐ WATER ☐ NON-PRODUCIBLE HYDROCARBONS

HYDROCARBON RATIOS



HYDROCARBON RATIOS



LITHOLOGY

SD-CLR,TRAN,BRN,BLK,S&P,VF-FGR,PRED FGR,ANG-SBRND,M-WSRT,
ARG,SLTY, POSS SILT & CLY MTRX,60% QTZ,40% LITH FRAGS,
NO VIS POR WITH UNCONS SD.

SHOW EVALUATION

50-60% DUL WH-YEL/GRN FLOR IN SMPL, DIFF MILKY/YEL BATCH CUT,
NOTABLE BRI YEL-GRN FLOR IN FLOWLINE MUD SAMPLES,
VERY GOOD OVERALL SHOW RATING.

REMARKS

RATIO ANALYSIS INDICATE THE PRESENCE OIL IN THIS ZONE.
GAMMA RAY AND RESISTIVITY DATA INDICATE A COARSER OR CLEANER
SECTION FROM 6630-6660'.

2254

Formation Evaluation by Analysis of Hydrocarbon Ratios

B. O. Pixler, SPE-AIME, Baroid Div. National Lead Co.

Introduction

Mud logging was first offered commercially in Aug., 1939. This logging method quickly gained favor among many operators because the type of fluid in the formation could be determined within minutes after the formation was drilled. The presence and magnitude of the methane show was and is the most important factor in mud log interpretation. However this magnitude in some instances was improperly understood, and as a consequence some operators still do not use mud logging, even though the early technique frequently made the difference between a successful well and an abandoned hole. Both the "hot wire" log of gas combustibles in the sample and the percent-of-gas log obtained with the conventional gas trap and the gas chromatograph indicate only that the reservoir in question contains hydrocarbons. These methods do not necessarily indicate the quantitative amounts of the various hydrocarbons in the mud.

The addition of a new Steam Still-Reflux gas sampling system to gas chromatography enables accurate determination of the composition of the mud gas sample. A knowledge of gas composition makes it possible to establish the relationship of methane to the heavier hydrocarbon shows. An awareness of this relationship led to a new, additional mud log interpretative technique that permits relating the quantitative amounts of methane (C_1), ethane (C_2), propane (C_3), butane (C_4), and pentane (C_5) to in-place reservoir fluid content.

A long-accepted premise is that as formations are drilled, the drilling mud filtrate partially flushes the formation fluid ahead of the bit. It was generally thought that the formations were flushed to an irreducible minimum — generally considered to be about 30 percent of in-place fluid. Experience in mud logging, however, has shown that this rarely happens. This partial flushing does not prevent mud logging from successfully determining productive or nonproductive formations. Experienced logging engineers, in possession of quantitative gas analyses, make interpretations that take into account the flushing that results in rocks of various permeabilities, the effect of overbalanced mud weight and the effect of initial filtrate loss.

Method

Ordinarily, when formation cuttings are drilled they retain much of the formation pore fluid. This fluid is released to the mud column as the cuttings travel up the annulus. Most of the formation fluid in the cuttings will be "produced" into the drilling mud during the top 500 ft of hole travel. Conventionally, a mud sample is diverted to a mechanically operated gas trap to obtain a sample of the gas in the mud. The efficiency of this trap is from 15 to 70 percent, depending upon the gel strength of the mud, the amount of mud flowing through the trap and the rotation speed of the trap impeller. The magnitude of the conventional

The ratio of methane to the heavier hydrocarbon components — ethane, propane, butane, and pentane — is indicative of gas, oil and water productive potential. The Steam Still-Reflux Unit, used in conjunction with mud logs and gas chromatographs yields a quantitative analysis from which this ratio can be plotted.

gas show is, therefore, quantitative only to the air-gas sample obtained. The sample is accurately analyzed by the gas chromatograph; but, because the sample furnished by the conventional gas trap represents only a fraction of the gas present in the mud, and because that fraction is not representative of the total gases in the mud, the results are still only qualitative.

When the Steam Still-Reflux Unit is used to obtain the gas sample, the gas sample will represent almost 100 percent of the hydrocarbon fractions C_1 through C_5 that were in the mud sample. This enables the chromatograph analysis to be related quantitatively to the mud, and the readings to be reported as parts per million of each hydrocarbon vapor (C_1 through C_5) to mud volume.

Because the cuttings from a particular formation "produce" the gas they contain into the drilling mud, it was reasonable to assume that this same formation, if completed, would produce gases of a similar composition. This assumption led to a comparison of ppm Logs of hydrocarbon vapors with similar data from producing wells. Plots were made of the ratio of methane to each of the heavier hydrocarbons from many analyses of wellhead samples. These plots were compared with plots, made from ppm Logs, of gas in mud. Both groups of plots showed definite patterns between (1) the magnitude of the ratios of methane to each of the heavier hydrocarbons, and (2) the slope of the lines of the plotted ratios. These, in turn, indicate productive potential and reservoir permeability.

The Steam Still-Reflux Unit consists of a small steam boiler, mud-injection port, mud-steam mixing chamber, Reflux-Condensing Unit and a gas-extraction port. Five ml of mud are injected into the purged mud-steam mixing chamber. The mud is rolled with 2,000 to 4,000 volumes of steam. The hydrocarbons (C_1 through C_5) extracted from the mud are collected at the Reflux-Condensing Unit, withdrawn with a syringe, diluted to the standard chromatograph sample size and injected into the chromatograph for analysis. The Reflux-Condensing Unit removes only the lighter paraffin series hydrocarbons from the mud sample tested. For example, if the mud contains diesel oil, the more complex hydrocarbons — C_6 and above — condense and drop back into the mud-steam mixing chamber. Therefore, regardless of whether the fluid phase of the mud is oil or water, the gas sample analyzed contains only the light fractions through C_5, and the analysis is representative of the formation gas.

The full importance of determining formation gas composition has not always been apparent. At first it was observed that if the magnitude of butane in the mud was greater than the magnitude of either propane or ethane, the zone in question would produce water and hydrocarbons. Later, the ratios of methane to each of the heavier hydrocarbon components were plotted on semilog paper. Hydrocarbon ratio plots obtained from ppm Logs and available data from wellhead gas sample analyses were compared. The comparison of the plots from ppm Logs and wellhead gas analysis data showed a striking correlation. The correlation demonstrated that ppm Logs made with Steam Still-Reflux samples could be interpreted in terms of in-place formation content.

The magnitude of the methane-to-ethane ratio determines if the reservoir contains gas or oil or if it is nonproductive. The slope of the line of the ratio plot of C_1/C_2, C_1/C_3, C_1/C_4, and C_1/C_5 indicates whether the reservoir will produce hydrocarbons or hydrocarbons and water. Positive line slopes indicate production; negative slopes indicate water-bearing formations. An undersaturated reservoir may show a negative slope, but such occurrences are rare. The ratio plots may not be definitive for low permeability zones, but unusually steep plots indicate tight zones.

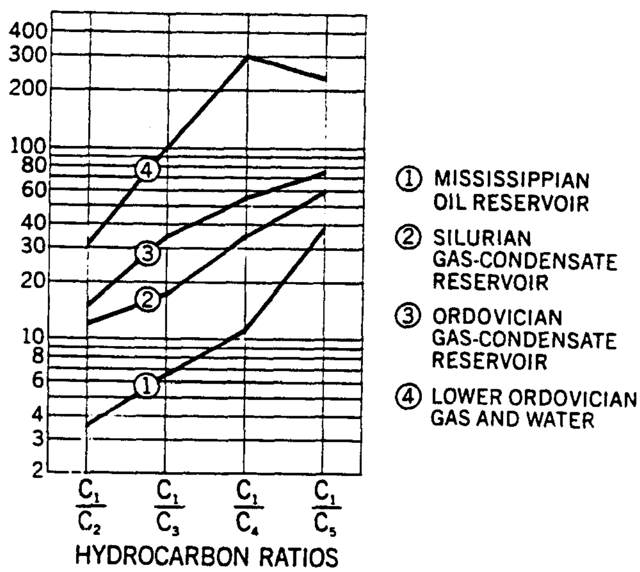


Fig. 1—Hydrocarbon ratio plots obtained from wellhead sample analyses data, limestone reservoirs, Rocky Mountain area.

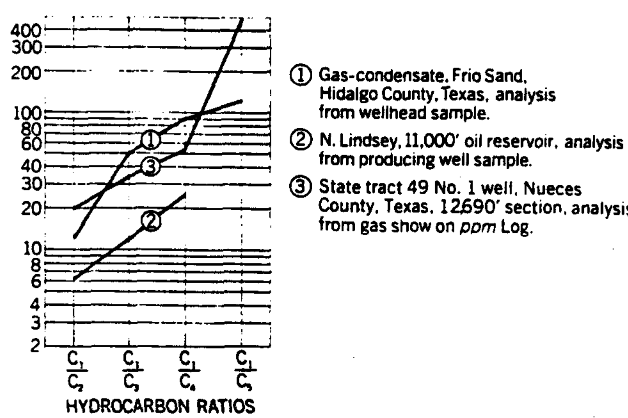


Fig. 2—Hydrocarbon ratio plots, productive reservoirs, South Texas.

A ratio of C_1/C_2 between 2 and 15 indicates oil. A ratio of C_1/C_2 between 15 and 65 indicates gas. The lower the C_1/C_2 ratio, the richer the gas or the lower the oil gravity. If the ratio of C_1/C_2 is below about 2 or above about 65 the zone is nonproductive.

Field Examples

Fig. 1 shows average hydrocarbon ratio plots from limestone reservoirs in the Rocky Mountain area. Plot 1 is derived from analyses of gases from Mississippian oil-producing reservoirs. The C_1/C_2 ratio is 3.5. The slope of the line is positive and not steep. Plot 2 was obtained from analyses of gases from wells producing gas-condensate from the Silurian. The C_1/C_2 ratio is 12; the line slope is again positive and not steep. Plot 3 is from gas-condensate wells producing from the Ordovician. The C_1/C_2 ratio is 15 and, again, the slope of the line is not steep; all three plots show slopes favorable for production. Plot 4 shows ratios obtained from an analysis of gas from the Lower Ordovician, which produced gas and water. The plot shows a negative slope of the section from the C_1/C_4 ratio to the C_1/C_5 ratio. Many tests have verified the fact that if a ratio plot shows a negative slope, the zone in question is water-bearing.

Fig. 2 shows plotted hydrocarbon ratios for productive reservoirs in South Texas. Plot 1 was made from an analysis of a wellhead sample of gas-condensate produced from a Frio sand, Hidalgo County. The production is rich in liquid hydrocarbons as indicated by the low C_1/C_2 ratio. Plot 2 is from an analysis of a wellhead gas sample from an 11,000-ft oil reservoir, North Lindsey field. The pentane was not reported, but the low C_1/C_2 ratio indicates oil production. Plot 3 was obtained from a gas show at 12,690 ft on the ppm Log of the State Tract 49 No. 1 Well, Nueces County, Tex. Formation tests resulted in gas production.

Experience shows that if the C_1/C_2 ratio is above 65 the zone is too tight for commercial production. Fig. 3 shows the ratio plots obtained from ppm Logs on Texas Gulf Coast wells that were nonproductive in the zones of interest. Plot 1 is from the ppm Log of the R. A. Tally No. 1 Well, Victoria County, Tex. The C_1/C_2 ratio was 470. The zone was tested extensively but it was a low permeability reservoir that could not be commercially completed. Plots 2 and 3 are from the State Tract 49 No. 1 Well, Nueces County, Tex. Plot 2 was from a sand encountered at about 8,060 ft. The relatively high ratios of C_1/C_2, C_1/C_3, C_1/C_4, and C_1/C_5 indicated that the zone was nonproductive because of the low permeability. This was subsequently verified by testing. Plot 3 was obtained from a sand at 9,130 ft. The negative slope of the ratio plot, C_1/C_2 to C_1/C_3, indicated that the zone was water-bearing. Subsequent formation tests showed water and non-commercial amounts of gas.

Plot 4 was obtained from the ppm Log of the Kovar No. 1 Well, Victoria County, Tex. The sand encountered from which the plot was made is at 10,120 ft. The gas show appeared to be good, but a negative slope of the C_1/C_3 ratio to the C_1/C_4 ratio was positive identification of a water-bearing formation.

Evaluation Technique

It is apparent that with this evaluation system, potential production can be accurately predicted. The only significant time lapse between penetration of the formation and evaluation of its productive possibilities is the time required to pump the mud from the bottom of the hole to the surface and analyze it by the Steam Still-Reflux and Chromatograph method. Fig. 4 shows the evaluation technique, which may be described as follows.

First, record the net increase of each gas component over the background gas; next, plot the ratios

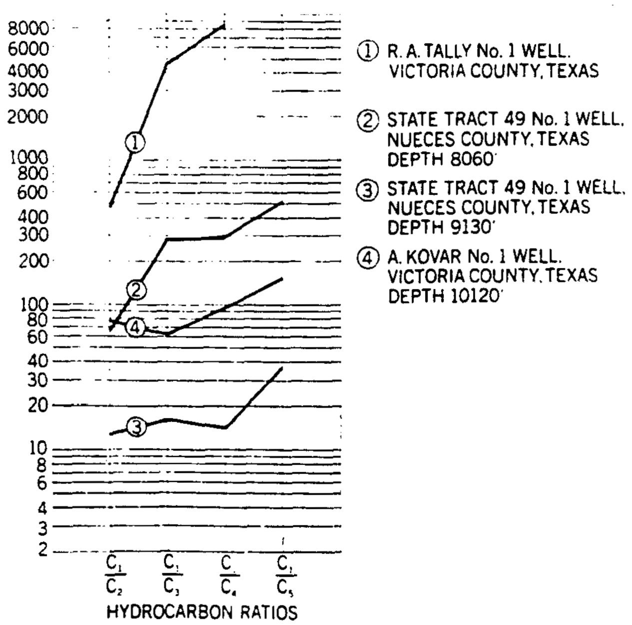


Fig. 3—Hydrocarbon ratio plots, nonproductive reservoirs, South Texas—analyses from gas shows on ppm Logs.

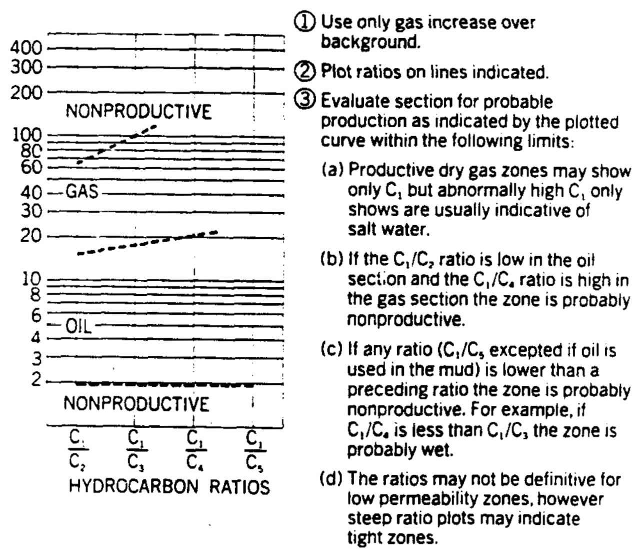


Fig. 4—ppm Log and report form for evaluation of show.

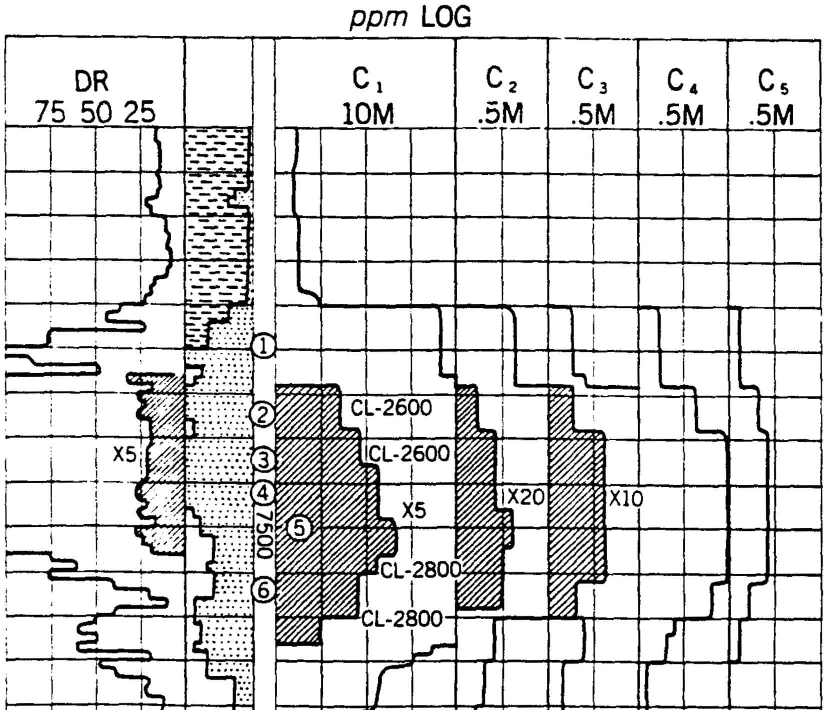
C_1/C_2, C_1/C_3, C_1/C_4, C_1/C_5 on the ratio lines as indicated. Then evaluate, within the following limits, the section in question for probable production as indicated by the plotted curve:

1. Productive dry gas zones may show only C_1, but abnormally high shows of C_1 only are usually indicative of salt water.
2. If the C_1/C_2 ratio is low in the oil section and the C_1/C_4 ratio is high in the gas section the zone is probably nonproductive.
3. If any ratio (C_1/C_5 excepted if oil is used in the mud) is lower than a preceding ratio, the zone is probably nonproductive. For example, if C_1/C_4 is less than C_1/C_3, the zone is probably water-bearing.
4. The ratios may not be definitive for low permeability zones; however, steep ratio plots may indicate tight zones.

Application

The ppm Log is only one of many tools that are ordinarily used for formation evaluation. But in many instances, the ppm Log has furnished the vital information necessary to make the final decision on a well. One well drilled in inland waters of Louisiana had what appeared on the ppm Log to be a good sand body, but the ppm Log showed only a nominal increase in gas. After the sand was penetrated and the well deepened, hole trouble was encountered. No other information of interest was available on the sand. The cost of the side-tracking to investigate the sand was sizable. Tight hole conditions and the low magnitude of the gas show indicated that the sand had good permeability and that possibly formation hydrocarbons had been flushed ahead of the bit. A plot of the hydrocarbon ratios indicated oil production. Therefore, at considerable expense, the sand was investigated and a new oil field was found.

An interesting well recently drilled in St. Martin Parish, La., was the No. 1 St. Martin Bank and Trust located on the southeast flank of the Anse La Butte Dome. A good sand encountered at about 8,000 ft showed oil, but the negative slope of the ratio plot indicated that the sand was water-bearing. The well was deepened to approximately 9,600 ft. One of the partners, a successful independent with a talent for finding oil by "feel" and by prudent use of the latest technology, decided that the formations in which the well was being drilled were tilted to almost vertical.



HYDROCARBON RATIOS

PLOT	C_1/C_2	C_1/C_3	C_1/C_4	C_1/C_5
1	26	62	78	155
2	8.6	14	59	118
3	5.6	7.4	46	106
4	6.8	9.1	56	130
5	5.4	11	70	193
6	4.5	15	54	254

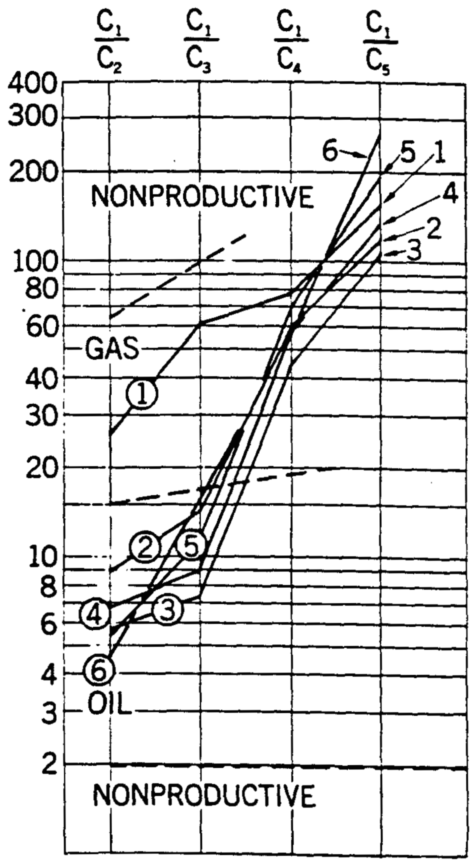


Fig. 5—ppm Log and hydrocarbon ratio plots, No. 1 St. Martin Bank and Trust Well, St. Martin Parish, La.

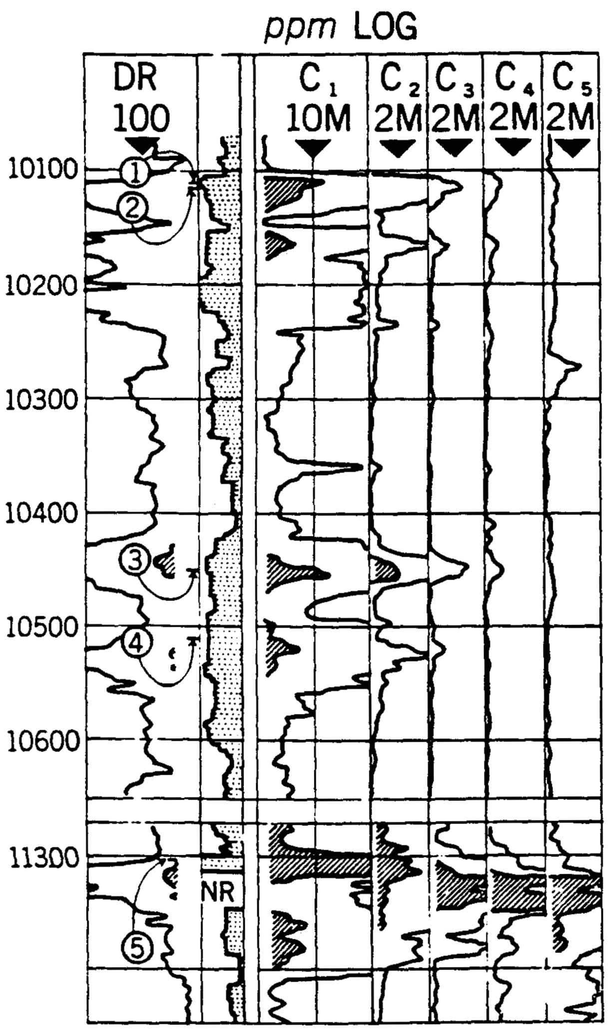
On his recommendaion the well was plugged back to about 7,000 ft and sidetracked. The sand that was drilled at 8,000 ft in the first hole was encountered in the directional hole at approximately 7,400 ft and the entire sand was hydrocarbon saturated.

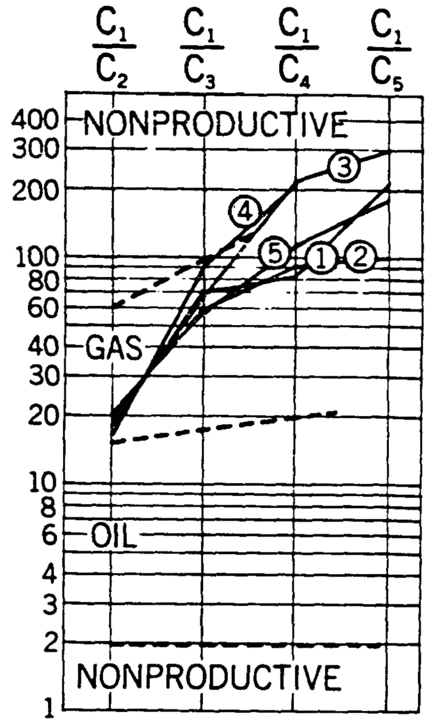
The ppm Log and the ratio plots from the sand in the sidetrack hole are shown in Fig. 5. Table 1 shows the mud gas components related to percent of total gas. In actual practice the ppm gas shows obtained from the ppm Log are not converted to percent of total gas; but note the general decrease in percent methane in the lower section of the sand compared with that in the upper section. The magnitude of the gas show in the straight hole and in the sidetrack hole was significant. An accurate determination, however, of the composition of the gas in both cases led to correct conclusions on the potential productivity of the sand at the different depths in each hole. Note that the ratio Plot 1 at the top of the sand indicates a gas cap. As shown in Table 1, the gas was 93.1 percent methane. Subsequent plots indicated that production would be oil. In each of these cases the C_1/C_2 ratio was less than 9. The lowest ratio, 4.5, is shown in Plot 6, which was made from the show at the bottom of the sand.

TABLE 1—MUD GAS COMPONENTS, PERCENT OF TOTAL GAS

Depth (ft)	C_1	C_2	C_3	C_4	C_5
7,460	93.1	3.6	1.5	1.2	0.6
7,475	82.4	9.6	5.9	1.4	0.7
7,485	74.4	13.3	10.0	1.6	0.7
7,490	78.0	11.4	8.6	1.4	0.6
7,500	77.0	14.3	7.2	1.1	0.4
7,515	76.1	17.1	5.1	1.4	0.3

Another example of the application of the ppm Log is No. 1 State Tract 198 Well, Aransas County, Tex. Many sands were encountered showing the presence of hydrocarbons. The logging crew submitted more than 60 ratio plots to the operator during the drilling of the well. In almost all instances subsequent information verified the logging engineers' predictions of probable productivity based on the ratio plots. Fig. 6 shows a section of the ppm Log and the ratio plots for this well. The gas composition relating the percent of each gas component to the total gas is shown in Table 2. Gas condensate production is indi-





HYDROCARBON RATIOS

PLOT	$\frac{C_1}{C_2}$	$\frac{C_1}{C_3}$	$\frac{C_1}{C_4}$	$\frac{C_1}{C_5}$
1	18	71	84	230
2	20	61	92	102
3	19.5	78	233	310
4	16	93	232	∞
5	19.3	58	115	185

Fig. 6—ppm Log and hydrocarbon ratio plots, No. 1 State Tract 198 Well, Aransas County, Tex.

TABLE 2—MUD GAS COMPOSITION, PERCENT OF TOTAL GAS

Depth (ft)	C_1	C_2	C_3	C_4	C_5
10,110	92.0	5.2	1.3	1.1	0.4
10,115	92.0	4.6	1.5	1.0	0.9
10,450	93.3	4.8	1.2	0.4	0.3
10,520	92.8	5.8	1.0	0.4	0.0
11,305	92.3	4.8	1.6	0.8	0.5

cated by the ppm Log and ratio plots as shown. The zones are tight marine deposits — especially the 10,520-ft zone. Plot 4 has the steepest line slope; pentane was not present. The slope of Plot 3 is steep. Plots 2 and 5 show more favorable (less steep) line slopes. The electric log and subsequent formation tests made of each zone indicated probable production. The well was completed as a gas condensate producer in the 11,300-ft section, which is the section plotted as No. 5.

Conclusions

Only qualitative shows of hydrocarbons in the mud can be derived from conventional mud logs. If chromatography is used, only a general indication of in-place gas composition is obtainable. Such hydrocarbon shows may be reported as units of gas or percent hydrocarbons or parts per million of gas in the air-gas mixture tested. Only the presence in relative amounts, not the actual quantity, of hydrocarbons in mud is indicated, and other supplemental information may be necessary to evaluate the formation in terms of potential productivity. However, if the composition of the gas sample obtained from the mud is representative of the in-place formation gas, then the gas analysis is accurate. The use of the Steam Still-Reflux Unit makes possible a report of formation gas composition on the ppm Log. Meaningful ratio plots of gas composition can then be made. Even though many factors affect the amount of reservoir fluid released to the drilling mud, reservoir potential productive capabilities can be determined by a study of the ratio of methane to each of the heavier hydrocarbon components. The hydrocarbon ratio plot is a unique technique and provides the operator with new information for evaluating productive possibilities of exploratory wells.

Computer programs involving percent gas in mud (ppm Log) and gas composition are being used in special cases to determine reservoir potential production. The use of computers in mud log interpretation, although new, will contribute significantly towards a better application of the data shown on the ppm Log.

JPT

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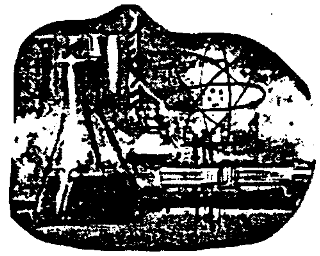
WELL LOG ANALYSIS



Mud Analysis Logging

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Abstract

Mud analysis logging is a direct method of detecting oil and gas in formations drilled. The factors that determine the hydrocarbon content of the drilling mud are discussed. The advantages and disadvantages of the various techniques for separation of gas from the mud and for gas detection are considered.

Examples included show field results of the latest mud logging development — the quantitative analysis of drilling mud for volatile hydrocarbons. Mud analysis provides the means for obtaining valuable formation information not otherwise available. Now, the system furnishes even greater diagonstic data for interpretation.

Introduction

Mud analysis well logging is not a recent development. Even before the introduction of rotary drilling, cable tool drillers logged their hole with bailings. The early rotary drillers kept a watchful eye on the mud returns for telltale gas bubbles. They continued to examine formation fragments — this time bit cuttings — removed from the mud by screens or by settling. The "feel" of the bit told them whether they were drilling in sand or shale, and changes in rates of penetration indicated changes in subsurface rock strata. Tops and thicknesses of formations were logged on the rotary drilling reports.

Mud logging technology has come a long way since 1939 when it was first introduced commercially. While all mud logging techniques have been continually improved, the greatest strides in development have been made in mud gas separators and mud gas detectors.

Release of Hydrocarbons to Mud Flow

The most important diagnostic in mud analysis logging is the record of gas detected in the mud. Hydrocarbons in the formation drilled are released to the mud flow, first, at the instant the section is drilled and, second, by gas expansion in cuttings as the mud pressure decreases while the cuttings are carried to the surface. The relative concentration in mud of hydrocarbons released from the reservoir rock during drilling depends on the extent to which the rock is flushed by the mud filtrate and on the rate of mud circulation. The following three factors influence the amount of flushing.

1. The physical characteristics of the formation — porosity, permeability and type of pore distribution.
2. Properties of the drilling mud — weight, viscosity, water loss and gel strength.
3. Rate of drilling.

Also, it is evident that the greater the rate of penetration, the greater is the concentration of hydrocarbons per unit volume of drilling mud. On the other hand, coring increases the ratio of mud circulated to volume of formation drilled, resulting in a reduction of hydrocarbon concentration.

Hydrocarbons are released to the mud from the formation bit cuttings as they are transported up the annulus. At atmospheric pressure, the bit cuttings are completely "depleted". The formation fluid has been "produced" into the mud stream. Mud analysis well logging depends upon an accurate analysis of the mud at the surface for gas. It is equally important to have both an efficient gas separator and a reliable gas detector.

Mud Gas Separators

Until recently, all gas samples were obtained from mud by means of mechanical separators. The objective of mechanical separation is to expose a maximum amount of mud surface to air for the release of gas. The efficiency of the mechanical separator is not constant. Mud properties and the area of the mud surface exposed vary under normal operating conditions. Efficiency also varies with mud temperature and atmosperic air temperature and humidity.

Fig. 1 shows three conventional types of gas separators in general use today. Type A is a baffle separator. As mud flows from one baffle to another, the area of the mud surface exposed to a counter flow of air is increased. The efficiency of this separator is good if the mud has a comparatively low weight, viscosity, solid content and gel strength. However, an increase of these mud properties tends to hold gas in the mud, and the efficiency of the separator decreases rapidly. Type B separator is a blendor. Agitation is thorough, and a maximum area of mud is exposed to the air in the closed system. The blendor is highly efficient, but it is a batch operation. Type C is a continuous, self-pumping aeration separator. The efficiency of this trap is excellent, particularly with the low-molecular-weight hydrocarbon gases. A continuous flow of air is whipped through the mud where the maximum mud surface is exposed. The efficiency for methane separation from

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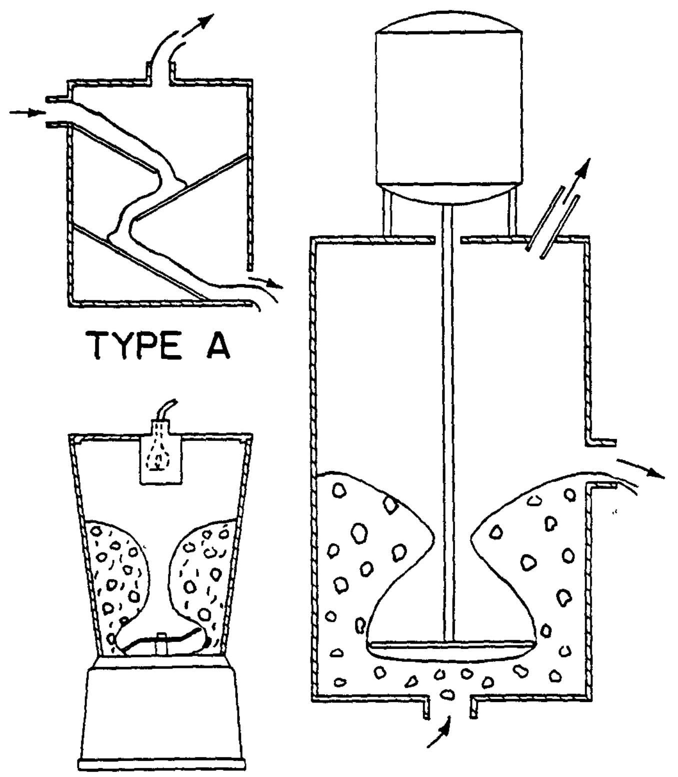

Fig. 1—Three conventional types of mud gas separators. Type A is a baffle separator, Type B is a blendor and Type C is a continuous self-pumping aeration separator.

the mud is not seriously affected by normal changes in mud properties.

Gas Detection Instruments

Instrumentation for the determination of gas separated from the mud must be reliable and accurate. A continuous "hot-wire" analyzer has been the most widely used gas-detector instrument. This instrument has been developed to a high degree of accuracy and sensitivity for methane detection and reliability of operation. Special sensing elements enable the hot-wire analyzer to respond linearly to changes in methane concentration from zero to about 10 per cent. Special equipment makes possible the separation of methane from other gases so that the hot-wire detector can be used regardless of the type drilling mud — even those containing crude oil.

As the use of crude oil in mud increased, some mud loggers looked to more elaborate instrumentation to enable them to detect methane and other hydrocarbon components in the mud. Two fine laboratory instruments — the mass spectrometer and infra-red absorption equipment — were applied to well logging and were investigated extensively. The mass spectrometer monitors the gas for predetermined masses (molecular weights) by ionization of the sample gas. Sensitivity is excellent — about 50 ppm for most gases. The fragmentation of the hydrocarbon molecules in the mass spectrometer makes calculation of results quite complex and time-consuming. Under field operating conditions, difficulties were encountered in sampling, in variations of voltage and the frequency of the power source. Infra-red analysis is based on the amount of the infra-red energy absorbed by various hydrocarbons at predetermined frequencies. The gas components are determined through the use of comparison cells. Neither the mass spectrometer nor the infra-red equipment gained wide acceptance, although the infra-red logging technique is used to a limited extent.

The most popular of the new gas analyzers is the gas chromatograph. In comparison to the other analyzers, it is simple in construction, reliable in operation and readily adapted to field use. Chromatography resolves the components of the gas easily, quickly and accurately. Although it is not a continuous monitor, batch analyses of gas samples can be made frequently. The time required to run a complete chromatogram depends upon the resolution desired of the component hydrocarbons and upon the number of components to be determined.

The chromatograph can be used to analyze both gases and volatile liquids. The sample to be analyzed is injected into a stream of carrier gas which is moved through a chromatograph column. The hydrocarbon components in a mixture of gases are separated due to their individual affinity to the special columnar packing. For example, a gas mixture composed of the paraffin-series hydrocarbons would be separated roughly in accordance with their boiling points. Methane, the lightest gas, has only a slight affinity to the columnar material and would emerge from the column first. As the boiling points of the gases progressively increase, their affinity to the columnar material increases and their emergence time from the column is increasingly longer.

The chromatograph column provides an unusual and simple means of separating a volatile mixture into its individual components. Catalytic or thermal sensing elements, depending on the instrumentation, are used to detect the various gases as they are carried out of the column. Response to the gases is recorded by electronic strip-chart recorders. Identification of each gas as it emerges from the column is made by time. Calibration of the instrument with known concentrations of pure gases makes possible a quantitative determination of these gases in various gas mixtures.

One peculiarity of chromatography is the fact that it is difficult to separate methane and hydrogen. Hydrogen may be present due to a reaction of water with iron in the low-pH muds. One particularly successful chromatograph makes use of special equipment to remove the hydrogen contamination before the test sample is introduced into the column. Air is the carrier gas, and a catalytic sensing element is used which gives a more accurate response curve to hydrocarbons.

The hydrogen flame detector, still another type of gas analyzer, has been given extensive field trials. It has higher sensitivity than does the hot-wire gas detector, but the increased sensitivity usually is not helpful. The much simpler hot-wire detector usually is operated at less than maximum sensitivity. The hydrogen flame detector, therefore, does not appear to have any particular advantage over the hot-wire for field application. One definite disadvantage is the fact that it cannot be used where the detection of helium is an important consideration.

Quantitative Measurements of Volatile Hydrocarbons in Mud

With chromatography developed to its present stage, it follows that mud sampling techniques would be improved. Instrumentation for gas analysis had far out-stripped mud sampling techniques. Intensive development work resulted in the development of the Steam Still — a revolutionary tool that strips volatile hydrocarbons from a sample of drilling mud.* By teaming the chromatograph with the

*The Steam Still is the subject of a pending patent application.

Steam Still, an acurate quantitative analysis of mud is made for volatile hydrocarbons — methane, ethane, propane, butane and pentane plus heavier molecular-weight hydrocarbons. These hydrocarbon vapors may be reported in parts per million of mud volume.

Fig. 2 is a perspective drawing of the Steam Still. The essential parts include (1) the boiler, (2) the mud and steam mixing chamber, and (3) the condenser. Small samples — usually 5 ml — of drilling mud are injected with a syringe into the Steam Still through a check valve at the base of the mixing chamber. The sample of mud is swept by steam vapor about 1,000 times its own volume. Concentrated hydrocarbon vapor is collected in a syringe through a port located at the top center of the condenser. The gas sample is then introduced into the chromatograph where the various components are accurately measured.

The efficiency of the Steam Still does not fluctuate (which is an inherent disadvantage with the mechanical separators). Gas readings are not influenced by changes in drilling-mud properties. The Steam Still makes possible a log of the true concentration of the hydrocarbon components. The ratios of the heavier molecular-weight components to methane are accurately determined.

Fig. 3 shows a comparison of two chromatograms obtained by different mud sampling techniques. The lower chromatograph was run on a gas sample collected from the Steam Still; the upper chromatogram reflects what the same mud showed using a conventional mud-gas separator. It is interesting to note that the lighter hydrocarbons shown on both chromatograms are about the same magnitude. However, the Steam Still chromatogram reflects a much higher ratio of the heavier molecular-weight gases to methane. On both chromatograms, the gas sample was introduced at Position 1. After methane, ethane, propane, isobutane and normal butane had emerged from the column, the columnar flow was reversed at Position 2. The pentanes, hexanes and other heavier hydrocarbons remaining in the column were back-flushed. These hydrocarbons moved out of the column at the same respective speed that they had moved forward. Consequently, they emerged from the column at virtually the same time in the reverse flow. The pentane-plus peak represents a composite of these gases. It is possible to reverse the columnar flow at any time and obtain a single peak reading for any combination of gases still in the column. Position 3 indicated on both chromatograms shows when the direction of the column flow was again changed preparatory to injection of a new gas sample.

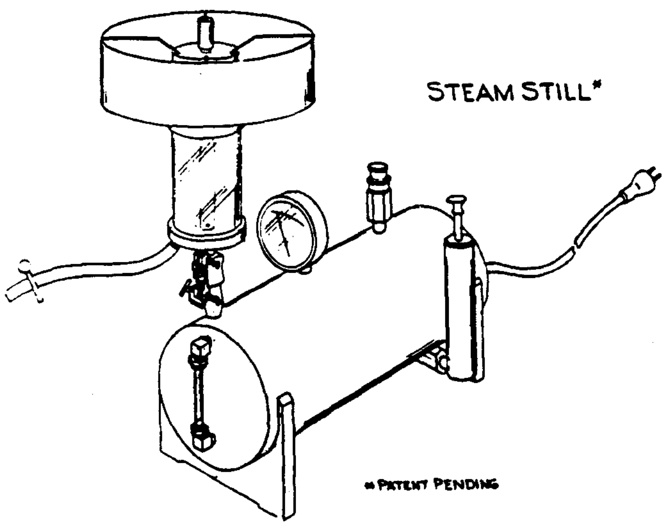

Fig. 2—Perspective drawing of the Steam Still—a revolutionary tool that removes the volatile hydrocarbons from a sample of drilling mud.

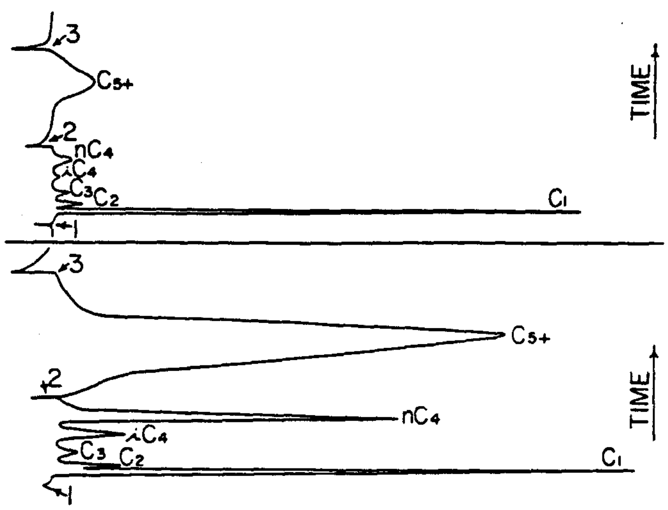

Fig. 3—A comparison of chromatograms obtained from different gas separators. The lower chromatogram is an analysis of a gas sample obtained from the Steam Still. The upper chromatogram reflects the analysis of a gas sample obtained from the same mud using a conventional gas separator.

The Steam Still makes possible an accurate record of the volatile hydrocarbon content of the mud, whether the analysis is made on location or later in the laboratory using bottled mud samples. Also, the feature of bottling small mud samples is useful with on-location analysis. A complete chromatogram of volatile hydrocarbons in the drilling mud can be obtained in four minutes. All critical zones can be checked at frequent and regular intervals, even when the drilling rate is fast.

Application

Mud logging generally is used on wildcat or exploratory wells. In some cases, it is used on field development wells where complicated stratigraphy occurs or specific problems are involved. In some areas, the electric log is difficult to interpret where there is low saline concentration in formation waters, where muds have high saline content, or where the formations are carbonate rocks. The mud log provides positive, direct identification of formation hydrocarbons. It is used as a correlative tool to enable operators to change their daily well programs so that possible productive formations can be evaluated immediately.

Gas indications may warn of impending blowouts and, thereby, allow provision to be made for the control of high-pressure zones. Wells can be drilled more economically by minimizing hazards and reducing down-time.

In general, three programs may be followed when using mud analysis logging. When a drilling break is obtained, further drilling is stopped until the mud has been circulated to the surface. If the mud analysis indicates the presence of hydrocarbons, a core may be taken or the interval may be drill-stem tested. This procedure may be particularly suitable in areas where productive formations are rather thin or where a water column is present.

If during normal drilling an oil or gas show is encountered, further penetration may be stopped and mud circulation continued until the returns from the bottom of the hole have reached the surface. If these returns still indicate the presence of hydrocarbons, a core may be taken or the

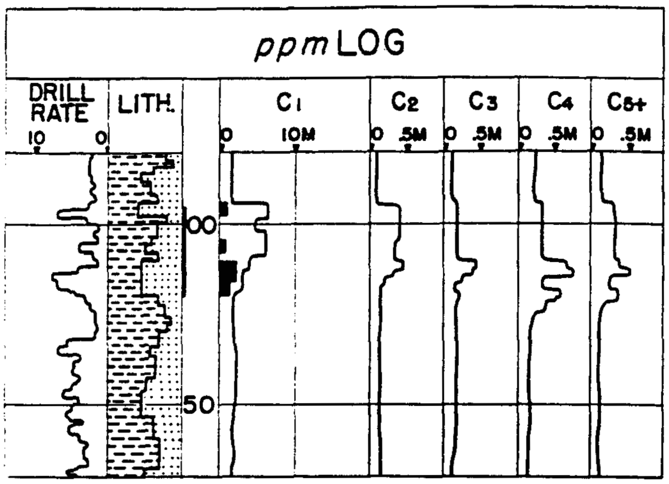

Fig. 4—A section of the ppm Log from an exploratory well, Lafourche Parish, La.

interval drill-stem tested. A reduction in the show of hydrocarbons may indicate that the formation has been penetrated completely. In this case, drilling can be resumed and the section further evaluated by sidewall sampling at the next electric-log run.

In some areas, wells may be drilled to total depth without taking conventional cores or testing. The results of the mud analysis log, in conjunction with the electric log, sidewall core samples and other available information, may be used to determine the productive capabilities of the various formations.

Presentation of the Mud Log

A complete mud analysis log includes: (1) shows of hydrocarbons detected in the drilling mud and cuttings; (2) detailed rate-of-penetration curve; (3) lithologic log and formation description; (4) drilling-mud properties; and (5) data pertinent to the well's operation such as coring points, trips for new bit, drill-stem tests, etc.

All shows of hydrocarbons are related on the log to their proper depth of origin. The usual mud-logging unit includes equipment for measurements of the drilling-mud properties — weight, viscosity, water loss, cake thickness, pH, salinity, alkalinity and mud resistivity.

Some mud loggers provide on-location core-analysis equipment for quick measurements of conventional or sidewall cores for porosity, permeability, oil and water saturation, and the ratio of measured gas volume to bulk volume of the core. This last measurement permits a quick evaluation of the formation potential so that drilling operations will not be delayed unnecessarily.

Fig. 4 is a section of the ppm Log from an exploratory well in Lafourche Parish, La. A 25-ft section was perforated below 15,000 ft. as indicated. During an initial completion test, the well flowed at the rate of over 200 B/D of 47° gravity oil through 14/64-in. choke, with a tubing pressure in excess of 2,300 psi and a gas-oil ratio of 14,000:1. Basic sediment and water showed 11 per cent. The significant increase of methane on the log was accompanied by a show of the heavier molecular-weight gases.

Fig. 5 is a comparison of a section of the ppm Log with the electric log from a field development well in Lafourche Parish. Although the section was not tested, this sand in an adjacent updip well produces oil and water. Here, the section is considered a depleted residual-oil sand. The electric log indicates that the sand probably is wet. This zone

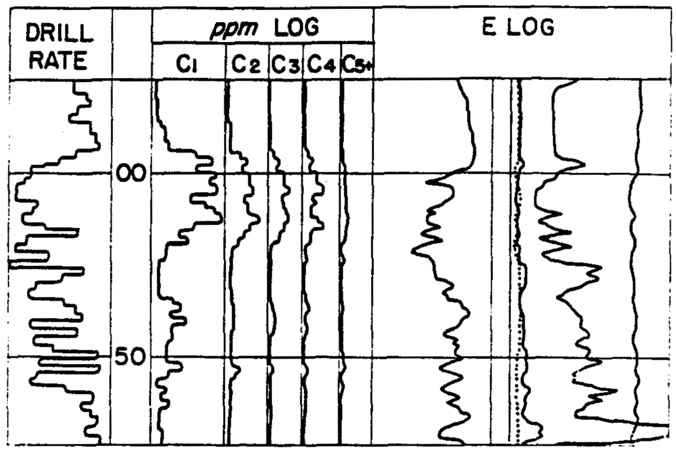

Fig. 5—A comparison of a section of the ppm Log and the electric log from a field development well, Lafourche Parish, La.

is a well known old reservoir. Oil is present in this new hole, but the original formation pressure has been reduced and the water level has risen. Without the established background history, the ppm Log would require that the sand be evaluated further. Incidentally, the ppm Log was based on an off-location analysis service. During the drilling of the well, 1-oz mud samples were accumulated and subsequently sent to the laboratory for analysis.

Mud Log Evaluation

Formation evaluation from the mud log is based on the significant increases of hydrocarbons in the mud as related to the drill-time curve and the lithology. Good gas shows often are logged that, according to the drill time and lithology, originate in tight sands with low permeability or in thin, nonproductive sections. In other cases, less-significant anomalies of gas shows may originate in permeable zones of considerable thickness and may be indicative of commercial production. If highly permeable hydrocarbon reservoirs are drilled slowly, flushing may occur and reduce the show of gas in the mud. Coring reduces the volume of formation drilled with respect to a unit volume of mud and, thus, may reduce the intensity of the gas show.

The most important recent advancement to aid in the interpretation of the mud log was the development of the Steam Still. As the volatile hydrocarbons are removed from the mud, potentially productive formations are indicated. These hydrocarbons — methane, ethane, propane, butane and pentane-plus — are indicative of the hydrocarbons that may be produced. Sometimes, significant shows of methane are difficult to evaluate; the ppm Log aids in eliminating the unimportant shows. Although productive dry-gas horizons have been encountered, gas shows comprised only of methane usually are indicative of lignite or salt-water sands.

Conclusion

The combination of the new Steam-Still technique and the chromatograph is a significant development in mud analysis logging. It offers more diagnostic information to determine the probable production of formations encountered in exploratory drilling and in many field development wells. ★★★

EDITOR'S NOTE: A PICTURE AND BIOGRAPHICAL SKETCH OF B. O. PIXLER APPEAR ON PAGE 363.

FORMATION EVALUATION BY ANALYSIS OF HYDROCARBON RATIOS

The following information is of critical interest from the Pixler paper:

1. Formation cuttings retain in excess of 30% of their original fluids after flushing occurs. (Pg. 665)

2. The fluids these cuttings "produce" into the mud as they travel up the annulus will be representative of fluids the well would ultimately give up if put on production. (Pg. 666)

3. The magnitude of the methane to ethane ratio determines if the zone contains GAS or OIL or if the hydrocarbons are NON-PRODUCIBLE (tight formation). (Pg. 666)

4. Line slope indicates productions of HYDROCARBONS ONLY or HYDROCARBONS AND WATER. (Pg. 666-667)

5. Steep plots may be un-definitive but usually indicate tight (low permeability) zones. (Pg. 666)

6. If the methane to ethane ratio is above 65 or below 2, the zone is too tight for commercial production. (Pg. 667)

7. Statement 3 on page 68 should read "water bearing" rather than "non-productive".

8. The "evaluation technique" outlined on pages 667 and 668 states that "the net increase of each gas component over the background gas" is to be recorded. Background gas must be considered from two perspectives. First, if the well is being drilled in an overbalanced condition, the background reading can be determined by processing a sample from the suction pit through the steam-still and chromatograph. Secondly, if the well is being drilled in an underbalanced condition, and formation hydrocarbons are bleeding into the annulus, the background reading must be determined from a flowline sample. Since the condition of balance is oftentimes difficult to determine, a foolproof method of determining background gas has been proposed.

    a. After securing permission from the operator, have the driller pick the bit up off bottom and cease drilling but continue circulating. Ten minutes of circulation without drilling should be adequate.

    b. After the last drilled cuttings have arrived at the surface, capture a syringe full of mud from the flowline and process it through the steam-still and chromatograph. (You might wait an additional couple of minutes after bottoms-up to insure that all drilled cuttings have been circulated to the surface.) This can be determined by monitoring the shale shaker for cuttings. If cuttings continue to come across the shaker through the entire ten minute time period of non-drilling, this indicates that either the well is underbalanced and cuttings are "popping" off the wall into the annulus OR the formation is water-sensitive and cuttings are caving or sloughing into the annulus. In either case, these cuttings will usually generate gas readings at the surface that must be considered as "background".

c. The individual gas ppm's that are measured from the mud when no drilled cuttings are present should be subtracted from all flowline ppm gas readings. This reading will include gases that were circulated back down the hole from the suction pit.

There are at least three reasons why the operator may not want to afford you the "luxury" of determining an accurate background gas reading using these procedures:

* "Time is money and this procedure is too expensive."

* "The well is not being drilled in an underbalanced condition."

* "The mud properties are such that the formation is not sloughing into the hole."

All of these are valid and worthwhile reasons to not perform the background procedure. However, the accuracy of our ration analysis to determine probable production is jeopardized.

Some ammunition for our side of the argument could be:

* "The background reading would only need to be taken once per tour and when a change in mud or formation properties occurs." (This would include when an increased pore pressure regime has been encountered.)

* "The whole purpose in drilling the well is to look for production, so give us the opportunity to help you find it." (Be careful how you present this argument.)

* "At least allow us to determine a proper background reading before drilling zones of interest or shows."

If this doesn't persuade the operator to see things your way, realize you are performing a service for him and he calls the shots. Also, a reading taken from the suction pit at regular intervals will probably, but not always, give you an accurate background reading.

Background readings should be of major concern if:

A. There is inadequate mud degassing equipment on the rig.
B. After a hydrocarbon bearing zone has been penetrated.

GUIDELINES FOR USING PPM RATIO PLOTS TO EVALUATE HYRDROCARBON SHOWS

(REVISED 9/27/89 TO COVER "METHANE ONLY" SHOWS)

1. A show that has only methane or primarily methane CAN be indicative of a productive zone. Many wells in the Gulf of Mexico produce only methane or methane and saltwater. (The commercial productivity of a GAS/SALTWATER well is based on the relative proportions of gas versus saltwater saturations determined by resistivity measurements.)

    a) Fill out a SHOW REPORT in a zone that meets the requirements of a show based on the definition <u>even if it contains methane only.</u>

    b) State in the LOGGER'S OPINION that this is a "methane only" show.

    c) Also state that C1 only CAN be indicative of dry-gas production BUT usually has saltwater associated with it.

    d) After making the ppm plot and observing for a <u>negative slope,</u> checking for a <u>chloride increase</u> (by titration or conductivity) OR observing a <u>resistivity decrease</u> on an MWD log, appropriately "X" the <u>GAS</u> or <u>GAS and WATER</u> indication in the ZONE PRODUCTION ANALYSIS paragraph on page 1, including the depth of the water contact if detectable and the footage of the show.

2. C1/C2 between 2 and 15 indicates OIL. You should see some fluorescence in the mud or cuttings but <u>not necessarily.</u>

    a) Values in the range of 2 - 4 indicate low gravity oil (10 - 15 on the API gravity comparison scale.) A low gravity oil can have a bronze, brown or dull orange <u>fluorescence</u> and be very dark brown to black in <u>color.</u>

    b) Values in the range of 4 - 8 indicate medium gravity oil (15 - 35 on the API gravity comparison scale.) A medium gravity oil will have a cream to bright yellow <u>fluorescence</u> and be light to medium brown in color.

    c) Values in the range of 8 - 15 indicate high gravity oil (35+ on the APT gravity comparison scale.) A high gravity oil will have bright blue to blue-white <u>fluorescence</u> and be clear in <u>color</u>. SEE NOTE BELOW.

3. C1/C2 ratios in the 15 to 65 range indicate GAS. Any fluorescence associated with a GAS zone indicates the presence of condensate. SEE NOTE BELOW.

    a) Values in the 15 - 20 range indicates gas rich in heavies, C4 and C5 ppms, and would most likely be associated with condensate.

    b) Values in the 20 - 50 range indicates gas rich in mid ranged hydrocarbons, C2 and C3 ppms.

3. c) Values in the 50 - 65 range indicates gas rich in the lighter fraction, C1 ppms.

NOTE: C1/C2 ratios in the 10 - 20 range can indicate the presence of CONDENSATE or DISTILLATE. Indications would be the presence of bright yellow or blue white fluorescence OR cut. (Condensate is a hydrocarbon that is a GAS under the temperatures and pressures of the reservoir but "condenses" to a LIQUID when it reaches the surface. It would compare to gasoline in appearance and physical characteristics and was in fact called "drip gas" in the early oilfield.

4. C1/C2 ratios less than 2 and greater than 65 indicate NON-PRODUCIBLE HYDROCARBONS.

   a) A hydrocarbon with a value less than 2 indicates an OIL with a gravity so low (the oil is very thick) that it can't be produced.

   b) A hydrocarbon with a value greater than 65 indicates a light GAS, mostly C1, but the low permeability nature of the formation makes it non-producible.

5. The slope of the line of all plotted ratios indicates if the zone will produce hydrocarbons only OR hydrocarbons and water. Line slope also provides some indication as to the formation permeability.

   a) An all positive slope, up and to the right, indicate HYDROCARBONS ONLY.

   b) If any of the line segments have a negative slope, down and to the right, HYDROCARBONS AND SALTWATER is indicated. Obviously, the mud chlorides SHOULD increase but not necessarily.

   c) A steep line slope indicates reduced permeability AND the steeper the slope, the lower the permeability. Steep is a relative term BUT the dashed lines separating the GAS, OIL and NON-PRODUCIBLE areas of the graph are there for comparison.

* OIL plots whose line slope is somewhat steeper than the MIDDLE dashed line indicate low permeability.

* OIL plots whose line slope is equal to or less than the MIDDLE dashed line indicate good permeability.

* GAS plots whose line slope is somewhat steeper than the TOP dashed line indicate low permeability.

* GAS plots whose line slope is equal to or less than the TOP dashed line indicate good permeability.