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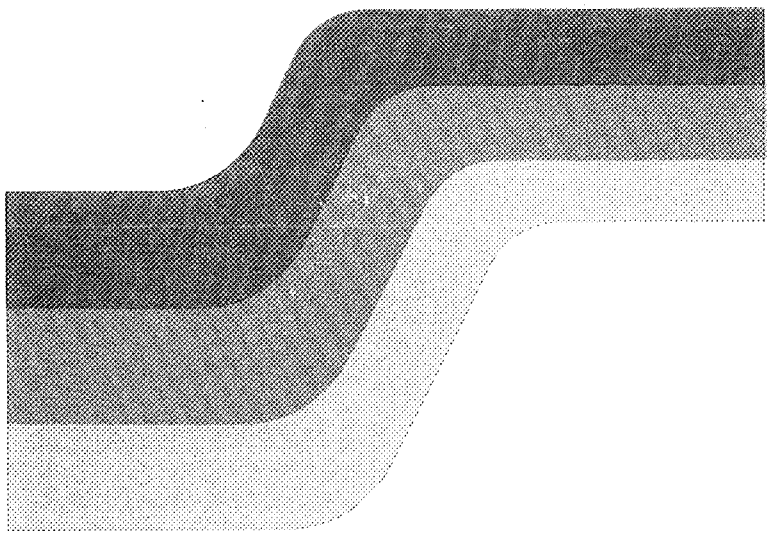
PETROPHYSICAL STUDY OF NORWEGIAN OFFSHORE CONTINENTAL SHELF WELL 6507/10-1



PETROPHYSICAL STUDY OF NORWEGIAN OFFSHORE CONTINENTAL SHELF WELL 6507/10-1

Prepared For

BP PETROLEUM DEVELOPMENT LIMITED
NORWAY

Prepared By

INTERCOMP RESOURCE DEVELOPMENT AND ENGINEERING (UK) LIMITED
LONDON

March 1983

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INTRODUCTION

This report summarises the results of INTERCOMP's analysis of well logs from the subject well.

The results of the analysis show good agreement with core measurements and this would seem to indicate that the correct methodology was used.

Following a brief description of reservoir geology, the report discusses the quality of the original data, documents the methods used and summarises the results.

Crossplots and the log analysis results on a level by level basis are bound separately as an Appendix, and the results are also shown graphically on a separate display.

RESERVOIR GEOLOGY

Although the essence of this study was an analysis of the well logs from 6507/10-1, there were a number of interesting geological features in the well which are commented upon in this section.

Heather Formation (2835 - 2881 m BRT)

This zone shows a similar succession to that found in the Brent Sand oil fields to the southwest, with the Heather Formation occuring between high energy sandstones below and deeper marine clays above. In both areas it comprises silts and mudstones, and in the oil field area it is separated by unconformities from both the Brent Formation below and the overlying Kimmeridge Formation above; as a result, its thickness is variable, being controlled by erosion and tilting of the fault blocks.

Mid Jurassic Formation (2881 - 2994 m BRT)

This zone is a high quality sandstone with excellent reservoir characteristics indicated by the uniformly high porosities throughout the section and very high measured permeabilities in the short core. Overall the section appears similar to the Etive sections in the Brent Sand oil fields which are characterised by coarsening up sequences and fairly uniform, good quality sands. Two marked coarsening-up sequences have their bases at 2908 m and 2917 m BRT and the low angle cross bedding seen in core also suggest a beach/barrier origin for the sands. In a reservoir, the shale zones at 2908 m and 2917 m BRT would probably form a marked barrier to flow, and it is noteworthy that zones of high porosity (and also therefore probably high permeability) occur immediately above and below these shalier zones. Zones such as these have caused severe water-tonguing problems in Brent Sand fields. Below the shaly zones, the sandstone is divided into several units of about 20 metres in thickness by minor shalier zones.

Drake Member (2994 - 3080.5 m BRT)

This zone, dominated as it is by silt and shale, is analogous to the Dunlin Formation to the south.

Cook Formation (3080.5 - 3299 m BRT)

Compared to the Middle Jurassic sandstones, the greater degree of shaliness, thinner sand units, mud clasts in the sand and the presence of both fining-up and coarsening-up units suggest an environment dominated by fluvio-deltaic sedimentation. Obviously any reservoir in sandstones of this type would be highly stratified, and the sands themselves would probably show permeabilities ranging over several orders of magnitude within a few metres.

Coal Unit (3299 - 3659 m BRT)

The mixture of coals, shales and sandstones suggest a delta top environment, rather more continental than in the Cook Formation above. The sandstones are probably river channels and some show typical sharp bases (e.g. at 3360 m and 3416 m BRT) with a slight tendency to fine upwards. In reservoir terms the sandstones again will probably show a marked stratification with the best permeabilities at the base of the channel sands. The reservoir quality will probably be very dependant on the clay content of the sands.

Overall, the section from the Coal Unit to the Drake Formation seems to be a transgressive sequence with conditions becoming increasingly marine upwards.

Triassic (3650 m BRT - TD)

The major sand in this unit again appears to be a channel with a sharp base and fining upwards sequence.

1. DATA REVIEW

The following logs are available for analysis:

ISF/BHC/MSFL/GR/CAL/SP	Run 5D
LDT/CNL/GR/CAL	Run 5A

In addition the following information was made available:

Routine core analysis	-	Geco
Lithological log	-	BP
Core description	-	BP
Sidewall core description	-	BP
RFT data	-	BP
Formation intervals	-	BP

1.1 Log Quality

Log quality is generally of a high standard. The ISF/BHC log is usable throughout and the calibrations fall well within expected tolerances. In places, borehole rugosity causes the MSFL pad to lose contact with the borehole wall, giving a rather spiky appearance, but this is not critical, particularly as hydrocarbon corrections were not required in this analysis.

The LDT/CNL appears to be of good quality over most of the hole. No calibration details were available on the print provided so it is not possible to comment on this, but the log responses all fall within the expected range. In places poor pad contact with the somewhat rugose borehole causes rather unreliable readings on the density and Pe curves. The presence of barite in the mud does not appear to have had a serious detrimental effect on the Pe curve, and this was used, where appropriate, in the analysis.

The logs were run at the recommended speed and do not appear to suffer from sticking or excess tension.

The provision of additional geological data is always appreciated and was useful in resolving some anomalies.

2. LOG ANALYSIS

An overview of the processes involved is shown in Figure 1.

2.1 Data Preparation

The log tape was read, decoded and loaded onto the computer. Core data were entered by hand and merged with the raw log data. Plots were made of the data on a composite log in order to verify the computer file against the source logs.

The playbacks were checked for depth matching and the core data were shifted to give better agreement with log depths. The synthetic microlog values were also played back, purely as a matter of interest since these were available on the tape, but not on the log prints. This will enable an assessment to be made as to the usefulness of requesting such playbacks to be made on a regular basis.

Environmental corrections were applied in accordance with the chart book.

Crossplots of the matched and corrected data were produced to aid parameter selection, and these are shown in the Appendix grouped by zone. The plots include some derived values such as M and N values and:

- apparent porosity - being (ϕ CNL + ϕD)/2, uncorrected for clay or hydrocarbon effects
- apparent matrix density - from the neutron density crossplot, again with uncorrected values
- apparent water resistivity - ϕA^2 RILD
- apparent volumetric photo-electric absorption index - $Umaa = \frac{Pe\ \rho b}{1 - \phi a}$

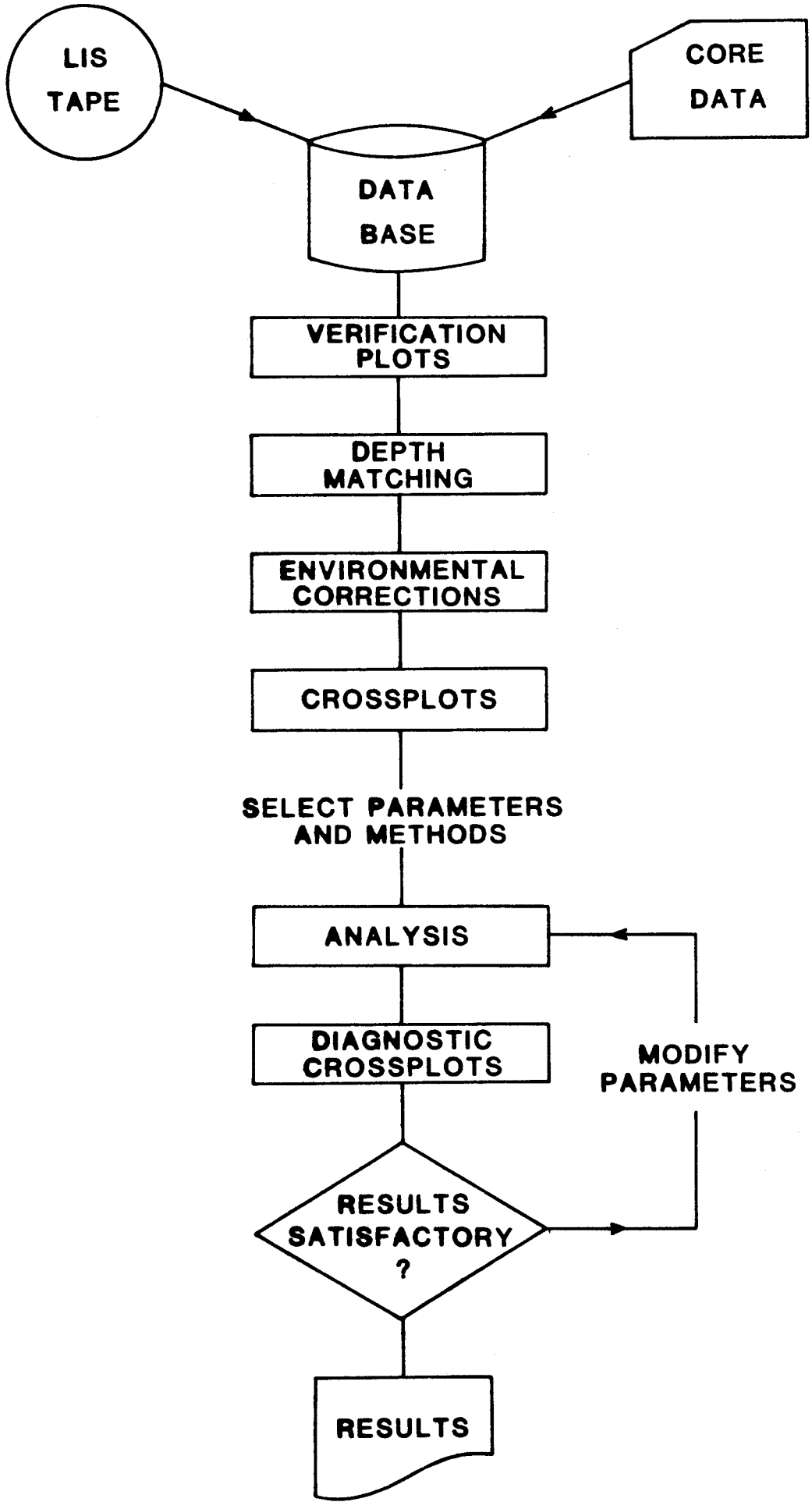
PROCESSES IN LOG ANALYSIS BY COMPUTER
LIS TAPE
CORE DATA
DATA BASE
VERIFICATION PLOTS
DEPTH MATCHING
ENVIRONMENTAL CORRECTIONS
CROSSPLOTS
SELECT PARAMETERS AND METHODS
ANALYSIS
DIAGNOSTIC CROSSPLOTS
MODIFY PARAMETERS
RESULTS SATISFACTORY ?
RESULTS

FIGURE 1

2.2 Selection of Method and Parameters

Inspection of the available data suggests that the majority of the section is composed of sand and shale, with some interbedded coals, indicating a normal complex lithology approach would be appropriate. However, the presence of heavy minerals in the mid-Jurassic and the Cook could present problems. Study of the crossplots indicates that, while some heavy minerals are indeed present, this proportion is not too great.

To determine the effect of these minerals, a run was made using INTERCOMP "ROCKS" program, which fits a lithological matrix solution to a number of input porosity logs. Thus, the density, neutron, sonic, gamma ray, spontaneous potential, and photoelectric capture cross section logs were used to solve for proportions of sand, clay, glauconite, mica, siderite, limestone and pyrite. Results from this program indicated that while some glauconite was present in both the mid-Jurassic and the Cook, mica content was less than 10%, pyrite was negligible and siderite occurred only sporadically in the Cook.

Since the program assigns equal weight to each of the input logs, it was felt that, in view of the fairly low proportions of heavy minerals, a normal neutron-density crossplot porosity method would give a more accurate solution, and this in fact proved to be the case as shown by the excellent agreement with core data.

Shale Volume (Vsh)

This was taken from the minimum shale volume as indicated from the SP, gamma ray, neutron, deep induction, neutron-density and density-sonic crossplots. (In zones where hole conditions are poor, the program does not use the crossplot indicators.)

Porosity

This was taken from the neutron-density crossplot after correcting for shale.

In zones of bad hole, the sonic log was used, with the appropriate matrix velocity.

True Formation Resistivity (Rt)

This was taken from the deep induction log after environmental corrections.

Formation Factor (F)

Taken as:

$$F = \frac{a}{\phi m}$$

with a = 1 and m = 2.0. (Since Rw was derived from crossplots, this could be taken that "a" is in reality a lower value such as .81 in the Humble formula, but in any case it is unimportant in a 100% water bearing well).

Formation Water Resistivity (Rw)

This was obtained from crossplots, and is therefore perhaps more appropriately described as "aRw".

Water Saturation

This was calculated using the Indonesia equation. Once again in a water bearing well, the choice of equation is not particularly important, but correct use gives added confidence to the other results.

Parameter Values

These are shown for each zone at the beginning of the results section in the Appendix.

3. RESULTS

The computed results on a level-by-level basis are shown in the Appendix, followed by the post-interpretation crossplots. The results are discussed below.

Heather (2835-2881 m BRT)

This zone is mainly shale/mudstone with some thin interbedded limestone streaks showing some porosity. The maximum value is 23.7 % and the average values are:

Cut off 10%	Average = 14.16	6.4 m net
Cut off 5%	Average = 10.02	15.24 m net

Apparent water salinity is 12000 ppm.

Mid Jurassic (2881-2994 m BRT)

This reservoir offers an extremely attractive target with good porosity and permeability throughout. Porosity values up to 32% are seen with average values of:

Cut off 10%	Average = 24.43	109.88 m net
Cut off 5%	Average = 24.14	111.86 m net

Apparent water salinity is around 90000 ppm.

As discussed previously, the presence of heavy minerals in this section is slight and apparently does not cause the derived porosities to be too far out as seen by the good agreement with core data and the fact that the calculated water saturations are fairly consistent around the 100% value. (Although the results listings use a value of Sw limited to 100, the post-interpretation crossplots show unlimited values.)

Drake (2994-3080.5 m BRT)

This zone is almost entirely shale. Most log evaluation programs would reset the derived values to show 100% shale throughout this zone. There does, however, appear to be some porosity development, but his is poor. With a 5% cut off, average porosity is 8.36% with 13.11 m net.

Cook (3080.5-3299 m BRT)

This is another excellent reservoir and offeres an attractive target. Porosity ranges up to 28% with averages as follows:

Cut off 10%	Average = 18.46	187.3 m net
Cut off 5%	Average = 17.36	215.04 net

Poroperm characteristics are not quite as attractive as the mid Jurassic, largely due to the increased shaliness.

As discussed previously, the heavy mineral content is not too high and would appear to consist mainly of glauconite with occasional mica and a small amount of pyrite.

Apparent water salinity is 117000 ppm.

Coal Unit (3299-3650 m BRT)

This unit is made up of interbedded coals, sands and shales. The whole unit is quite thick and the net sand is quite extensive, thus:

Cut off 10%	Average porosity = 19.75	222.35 m net
Cut off 5%	Average porosity = 17.99	260.45 m net

The results display shows a somewhat spiky appearance in places. This is due to bed resolution problems. Coal is flagged by the program when certain log conditions are met, and shown as "other" on the display, but occasionally is

apparently flanked by high porosity spikes as the density log moves towards the coal readings. It would be possible to edit out these spikes, but then some genuine reservoir porosity could be lost.

The base of the Coal Unit was given as 3650 m BRT, and parameters for the zone were kept constant down to this level. It is interesting to note that there is an apparent change in water salinity at around 3600 m. Throughout most of the unit the apparent salinity is approximately 122000 ppm, but below 3600 m and into the Triassic unit as defined the salinity increases to 188000. This would suggest that the top of the Triassic is, perhaps, around 3600 m, rather than 3650.

Triassic (3650-TD)

This shows some quite attractive reservoir development with porosities up to 24%. Average values are:

Cut off 10%	Average = 19.11	13.72 m net
Cut off 5%	Average = 17.79	15.54 m net.

As noted above, the apparent water salinity is much higher than the overlying formations at 188000 ppm.

Permeability

With only 30 core permeability measurements compared to 860 m of log, extrapolation of any transform based on the core measurements is somewhat risky. However, the transform gives a good match with core in the Cook, and may be used as a qualitative permeability index elsewhere. The equation used is shown below:

$$\text{Log}_{10}\ \text{Klog} = \frac{\log \phi - 1.16}{0.98} - \frac{\text{Vclay}}{10.}$$

RESULTS SUMMARY

ZONE	5% CUT-OFF Porosity (%)	5% CUT-OFF Net Reservoir (m)	10% CUT-OFF Porosity (%)	10% CUT-OFF Net Reservoir (m)
Heather	10.02	15.24	14.16	6.6
Mid Jurassic	24.14	111.86	24.43	109.88
Drake	8.36	13.11	14.35	2.59
Cook	17.36	215.04	18.46	187.3
Coal Unit	17.99	260.45	19.95	222.35
Triassic	17.79	15.54	19.11	13.72

CONCLUSIONS

The well encountered a number of attractive reservoirs, the most attractive being the Mid Jurassic.

The logging suite available was adequate to define the reservoir parameters satisfactorily, and the normal complex lithology approach to the analysis appears to give excellent results.

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LOG-DATA PLAYBACK DISPLAY

B.P. PETROLEUM DEVELOPMENT LTD. NORWAY EXPLORATION

WELL: 6507/10-1   COAL UNIT   4 FEB 83

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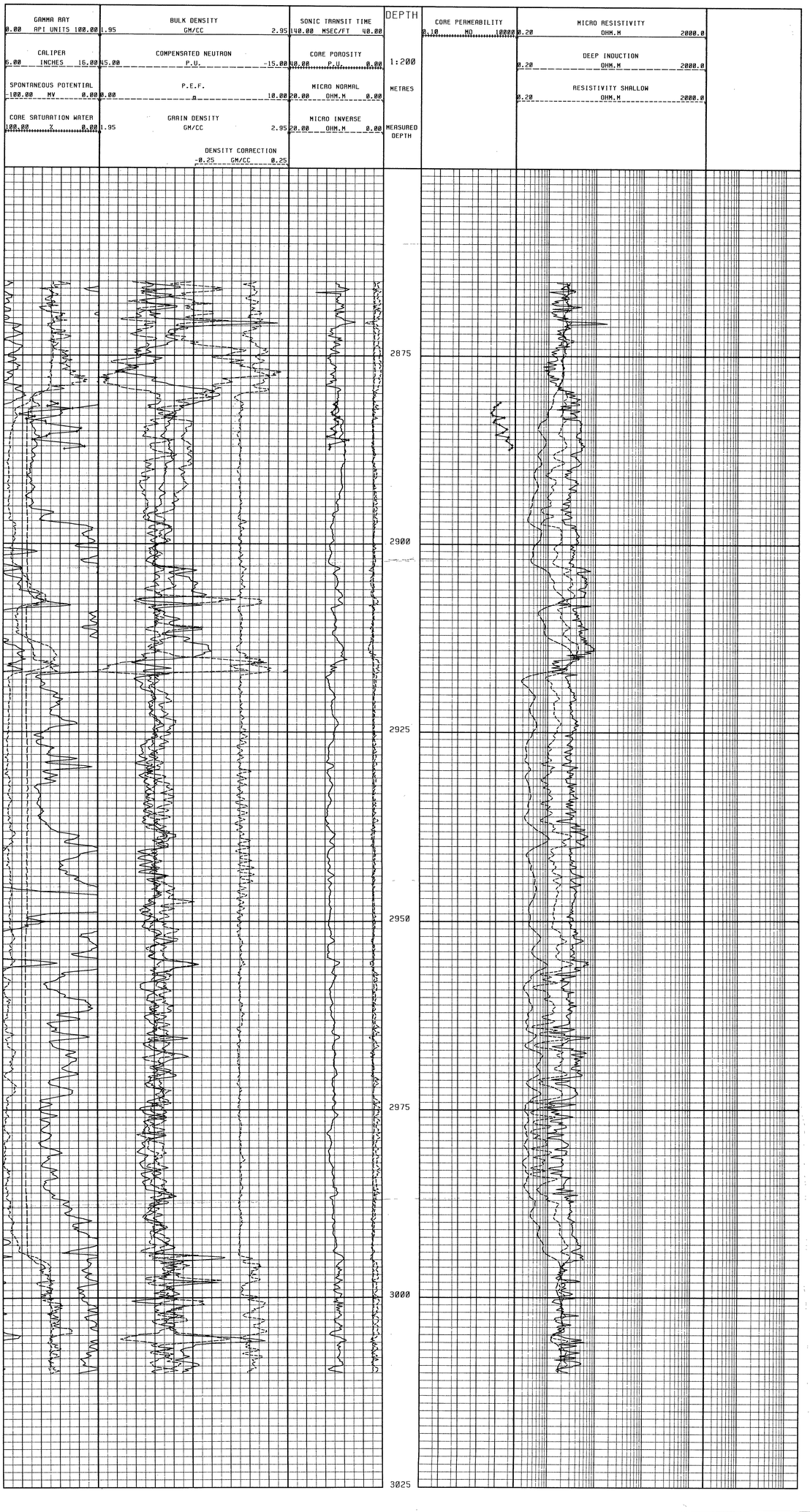
LOG-DATA PLAYBACK DISPLAY

B.P. PETROLEUM DEVELOPMENT LTD. NORWAY EXPLORATION

WELL: 6507/10-1 MID-JURASSIC 4 FEB 83



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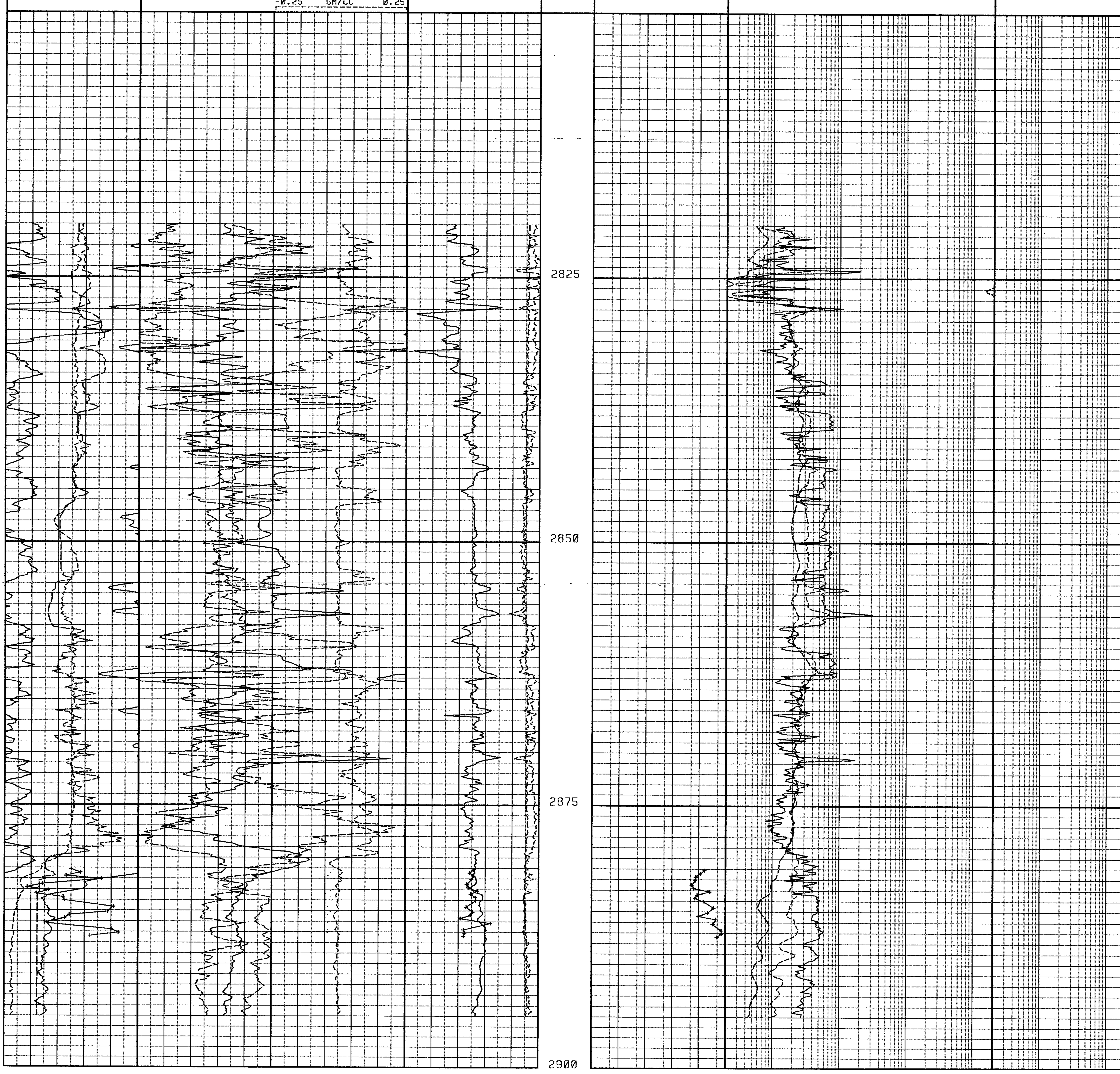
LOG-DATA PLAYBACK DISPLAY

B.P. PETROLEUM DEVELOPMENT LTD. NORWAY EXPLORATION

WELL: 6507/10-1   HEATHER   4 FEB 83

GAMMA RAY 0.00 API UNITS 100.00	BULK DENSITY 1.95 GM/CC 2.95	SONIC TRANSIT TIME 140.00 MSEC/FT 40.00	DEPTH	CORE PERMEABILITY 0.10 MD 10000	MICRO RESISTIVITY 0.20 OHM.M 2000.0	
CALIPER 6.00 INCHES 16.00	COMPENSATED NEUTRON 45.00 P.U. -15.00	CORE POROSITY 40.00 P.U. 0.00	1:200		DEEP INDUCTION 0.20 OHM.M 2000.0	
SPONTANEOUS POTENTIAL -100.00 MV 0.00	P.E.F. 0.00 10.00	MICRO NORMAL 20.00 OHM.M 0.00	METRES		RESISTIVITY SHALLOW 0.20 OHM.M 2000.0	
CORE SATURATION WATER 100.00 % 0.00	GRAIN DENSITY 1.95 GM/CC 2.95	MICRO INVERSE 20.00 OHM.M 0.00	MEASURED DEPTH			
	DENSITY CORRECTION -0.25 GM/CC 0.25					



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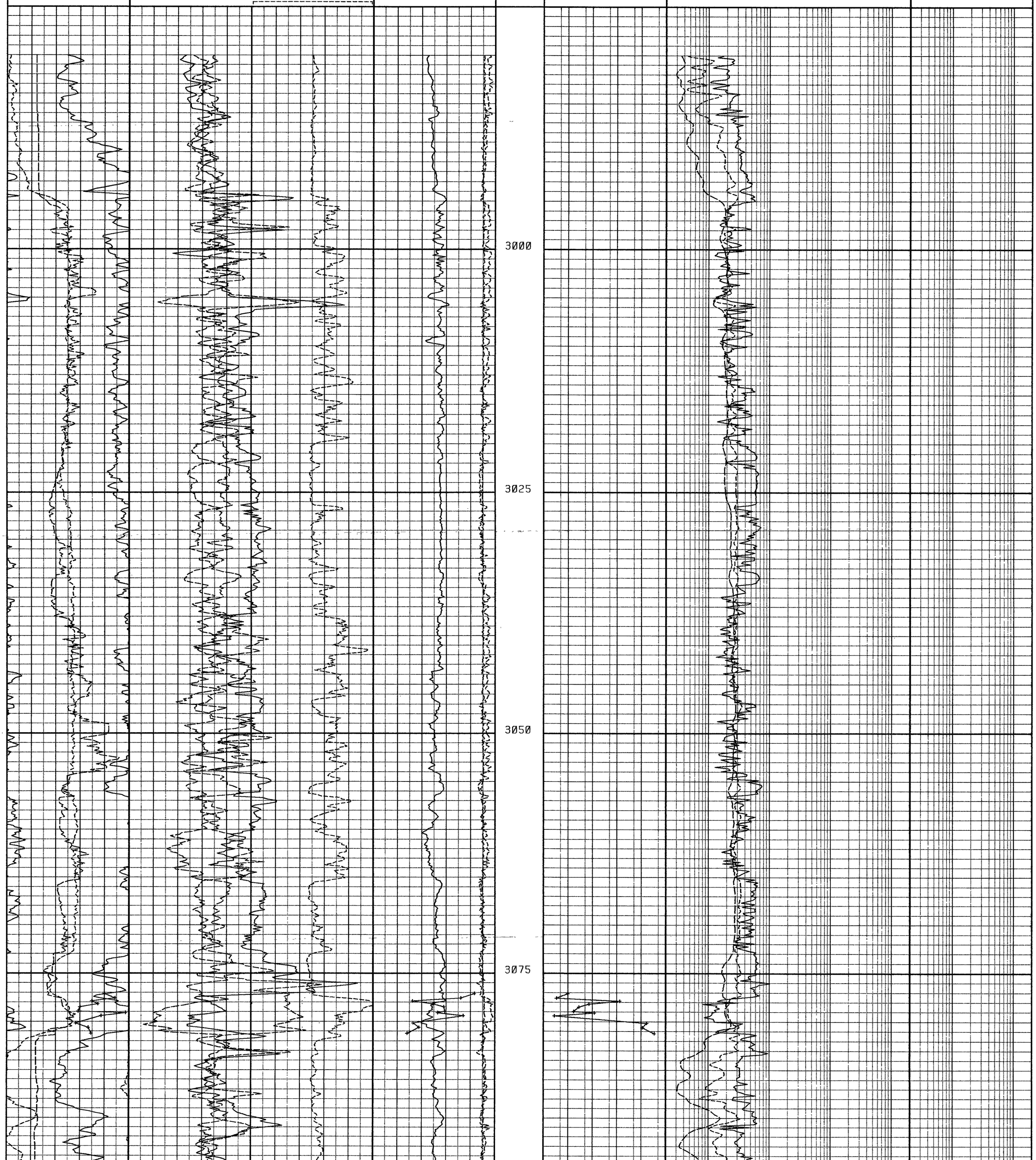
LOG-DATA PLAYBACK DISPLAY

B.P. PETROLEUM DEVELOPMENT LTD. NORWAY EXPLORATION

WELL: 6507/10-1 DRAKE

4 FEB 83

GAMMA RAY	BULK DENSITY	SONIC TRANSIT TIME	DEPTH	CORE PERMEABILITY	MICRO RESISTIVITY	
0.00 API UNITS 100.00	1.95 GM/CC 2.95	140.00 MSEC/FT 40.00		0.10 MD 10000	0.20 OHM.M 2000.0	
CALIPER	COMPENSATED NEUTRON	CORE POROSITY			DEEP INDUCTION	
6.00 INCHES 16.00	45.00 P.U. -15.00	40.00 P.U. 0.00	1:200		0.20 OHM.M 2000.0	
SPONTANEOUS POTENTIAL	P.E.F.	MICRO NORMAL	METRES		RESISTIVITY SHALLOW	
-100.00 MV 0.00	0.00 10.00	20.00 OHM.M 0.00			0.20 OHM.M 2000.0	
CORE SATURATION WATER	GRAIN DENSITY	MICRO INVERSE	MEASURED DEPTH			
100.00 % 0.00	1.95 GM/CC 2.95	20.00 OHM.M 0.00				
	DENSITY CORRECTION -0.25 GM/CC 0.25					



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LOG-DATA PLAYBACK DISPLAY

B.P. PETROLEUM DEVELOPMENT LTD. NORWAY EXPLORATION

WELL: 6507/10-1   TRIASSIC   9 FEB 83

GAMMA RAY 0.00 API UNITS 100.00
CALIPER 6.00 INCHES 16.00
SPONTANEOUS POTENTIAL -100.00 MV 0.00
CORE SATURATION WATER 100.00 % 0.00

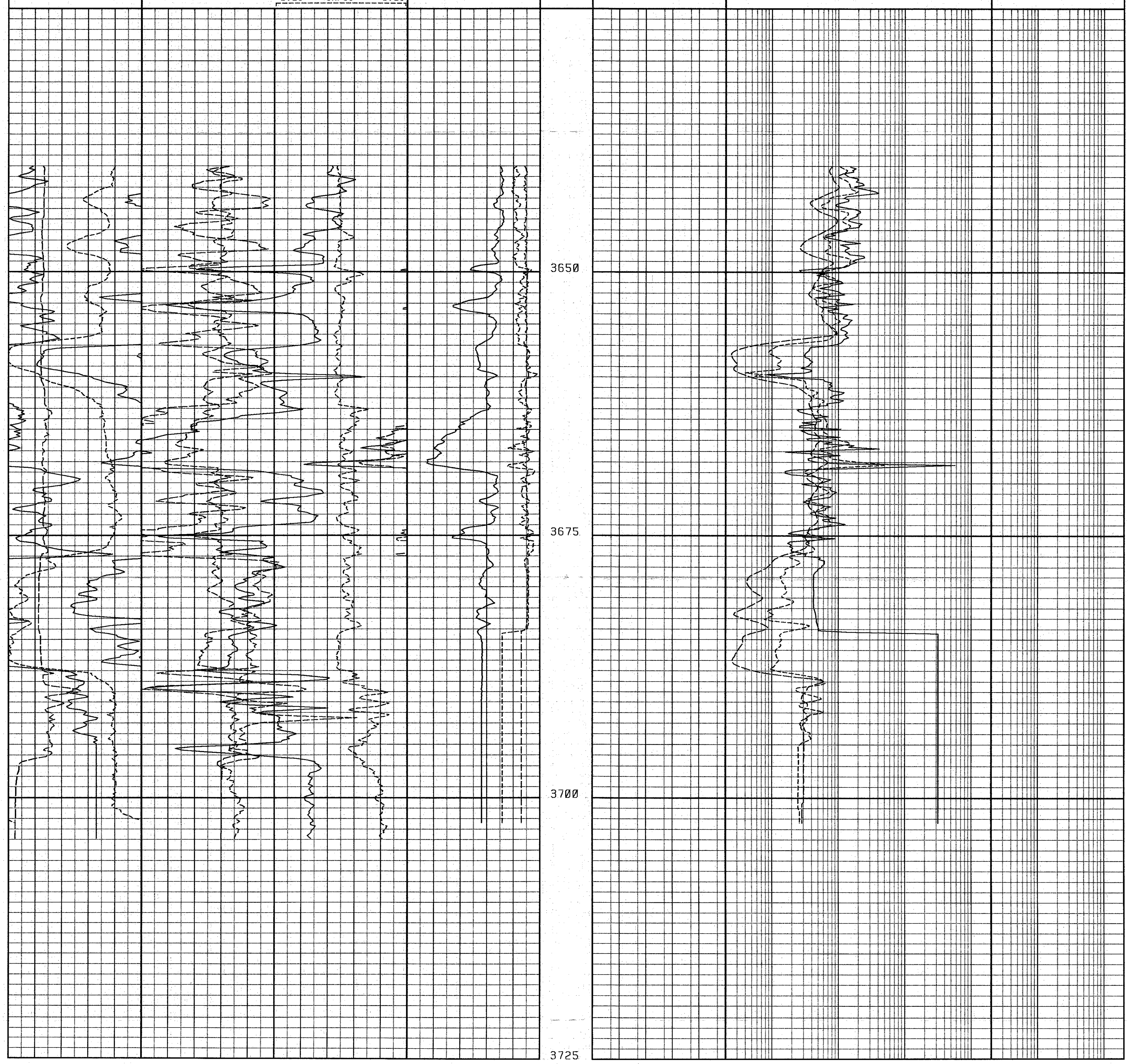
BULK DENSITY 1.95 GM/CC 2.95
COMPENSATED NEUTRON 45.00 P.U. -15.00
P.E.F. 0.00 10.00
GRAIN DENSITY 1.95 GM/CC 2.95
DENSITY CORRECTION -0.25 GM/CC 0.25

SONIC TRANSIT TIME 140.00 MSEC/FT 40.00
CORE POROSITY 40.00 P.U. 0.00
MICRO NORMAL 20.00 OHM.M 0.00
MICRO INVERSE 20.00 OHM.M 0.00

DEPTH
1:200
METRES
MEASURED DEPTH

CORE PERMEABILITY 0.10 MD 10000

MICRO RESISTIVITY 0.20 OHM.M 2000.0
DEEP INDUCTION 0.20 OHM.M 2000.0
RESISTIVITY SHALLOW 0.20 OHM.M 2000.0



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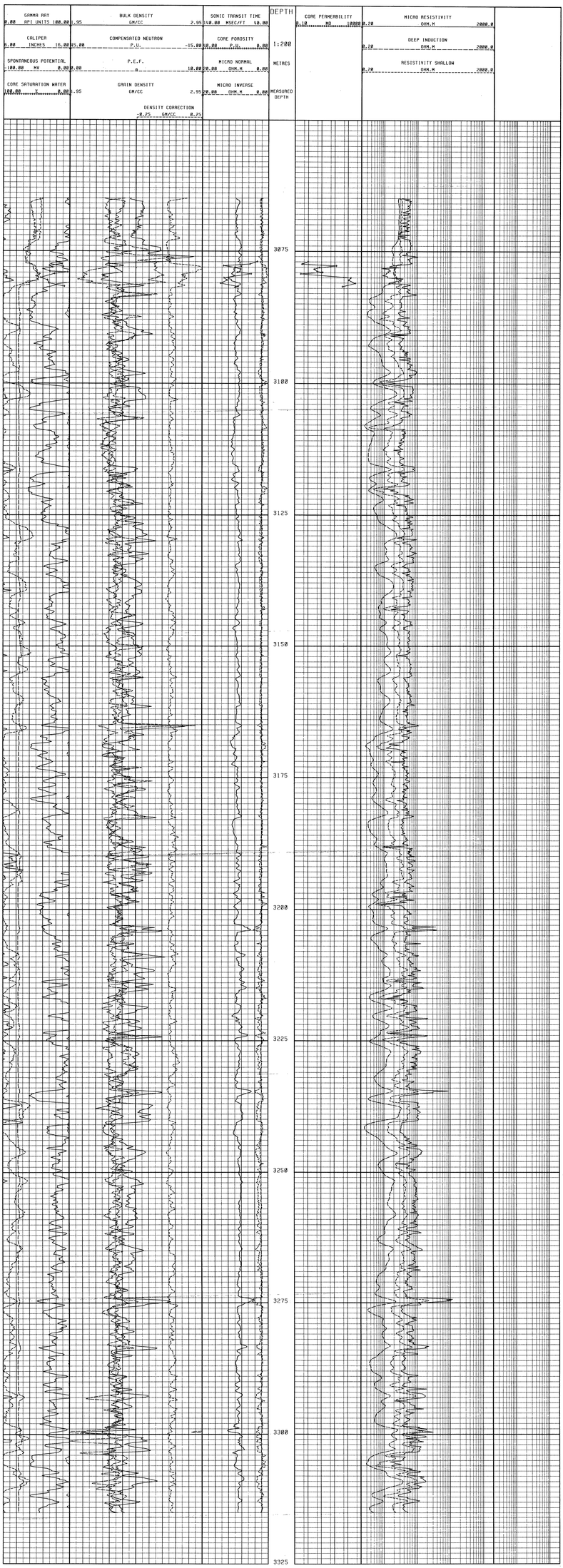
LOG-DATA PLAYBACK DISPLAY

NOCS 6507/10-1 WL 46 Copy 1

B.P. PETROLEUM DEVELOPMENT LTD. NORWAY EXPLORATION

WELL: 6507/10-1 COOK — 14 FEB 83



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RESULTS DISPLAY

BP PETROLEUM DEVELOPMENT LTD. NORWAY

EXPLORATION

WELL: 6507/10-1 -TRIASSIC 24 MAR 83

ANNOTATIONS	PERMEABILITY	FLUID AND MATRIX DENSITIES	DEPTH	SATURATIONS	FLUID VOLUME	MATRIX COMPOSITION
		APPARENT HYDROCARBON DENSITY 0 GM/CC 1	1:200	...CORE SATURATION	RESIDUAL H-CARBON / FLUSHED H-CARBON / WATER	SHALE / OTHER / MATRIX / POROSITY
	CORE 0.1 MD 10000	MATRIX DENSITY 2 GM/CC 3	METRES	CONNATE WATER 100 % 0	50 % 0	100 % 0
	COMPUTED 0.1 MD 10000	APPARENT SECONDARY POROSITY 0 % 20	MEASURED DEPTH	INVADED ZONE 100 % 0	...CORE POROSITY	
				CALIPER-BIT SIZE -4 0 INCHES 12		

3650

3675

3700

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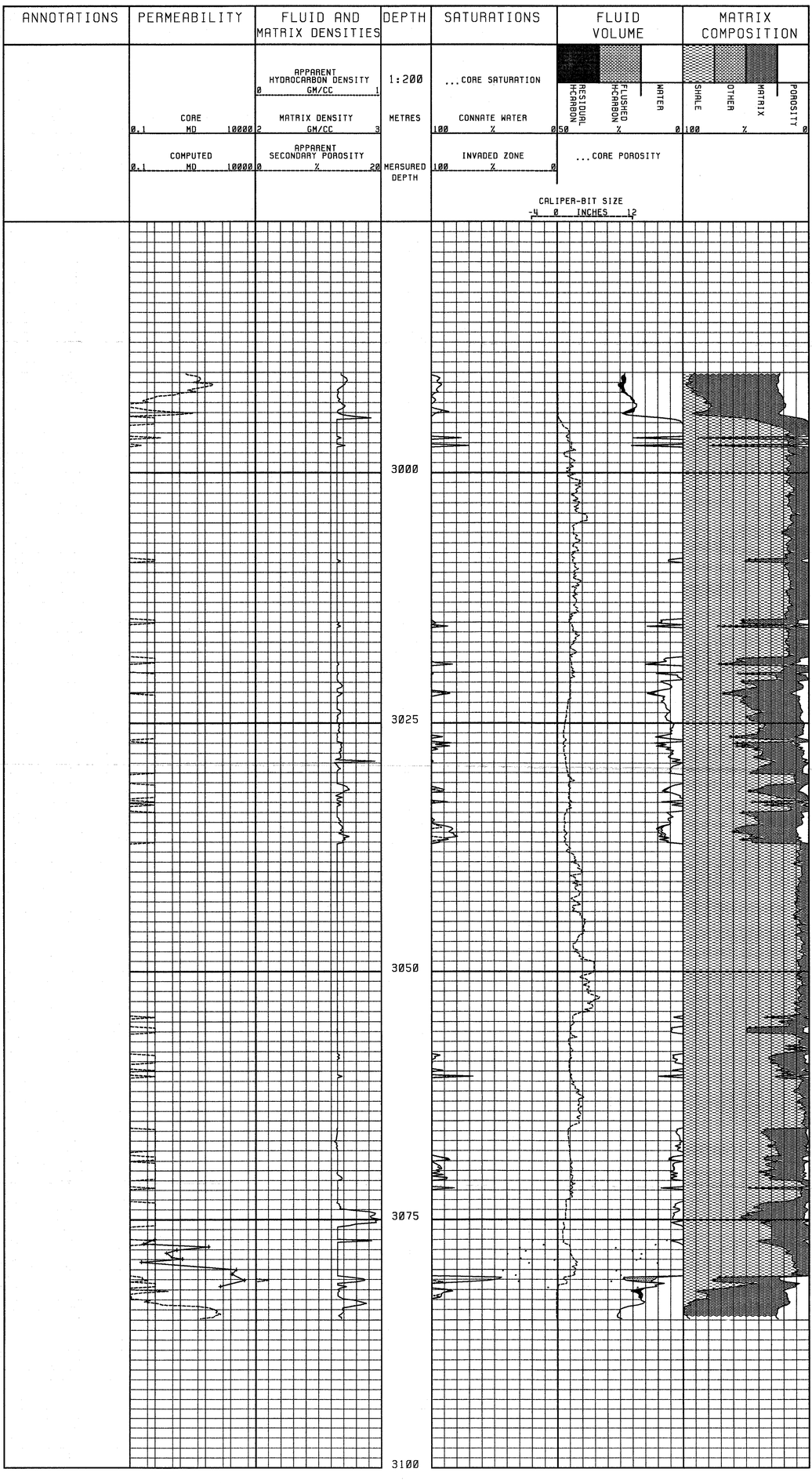
RESULTS DISPLAY

BP PETROLEUM DEVELOPMENT LTD. NORWAY EXPLORATION

WELL: 6507/10-1 -DRAKE 24 MAR 83



Nocs 6507/10-1 Copy 1

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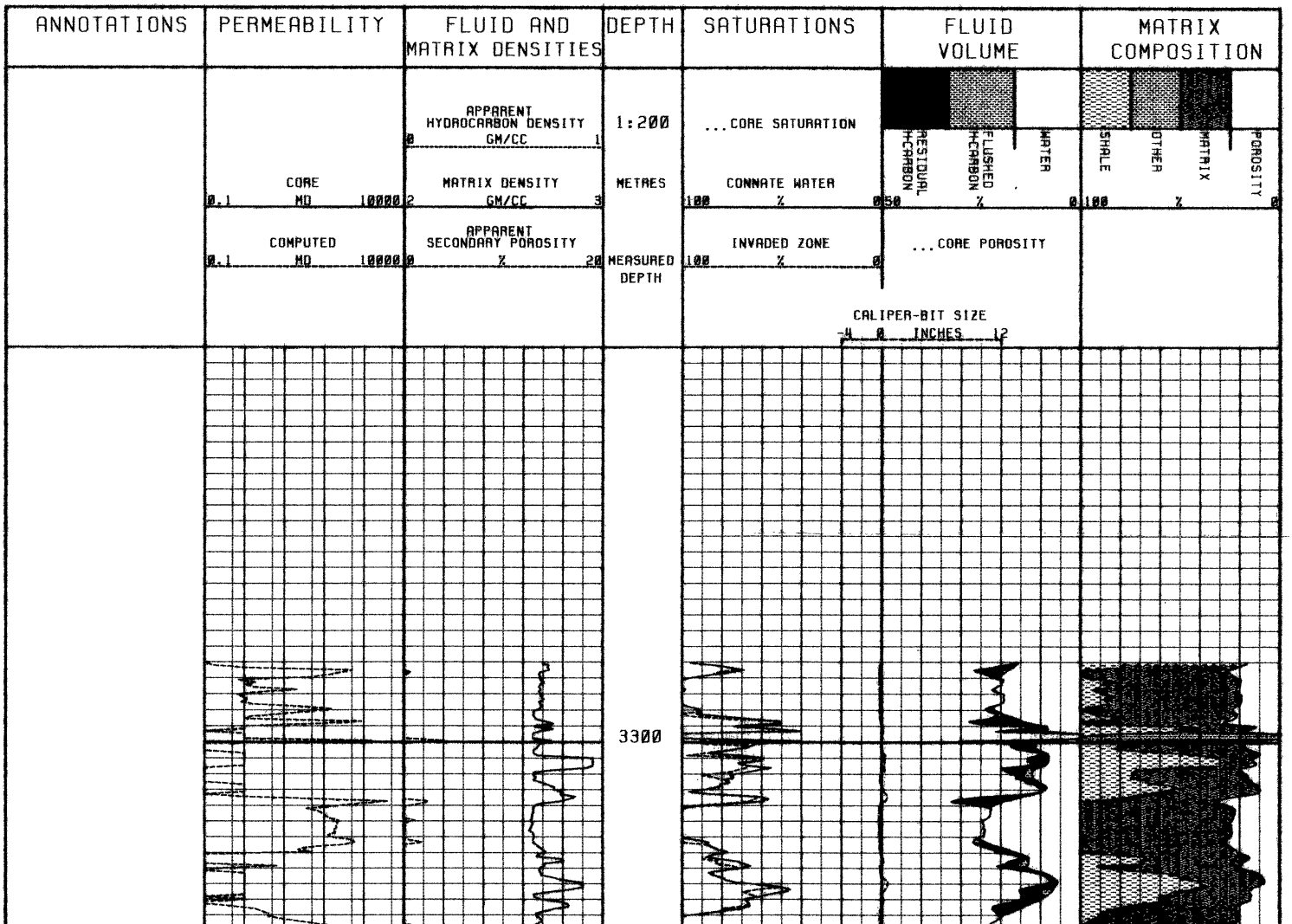
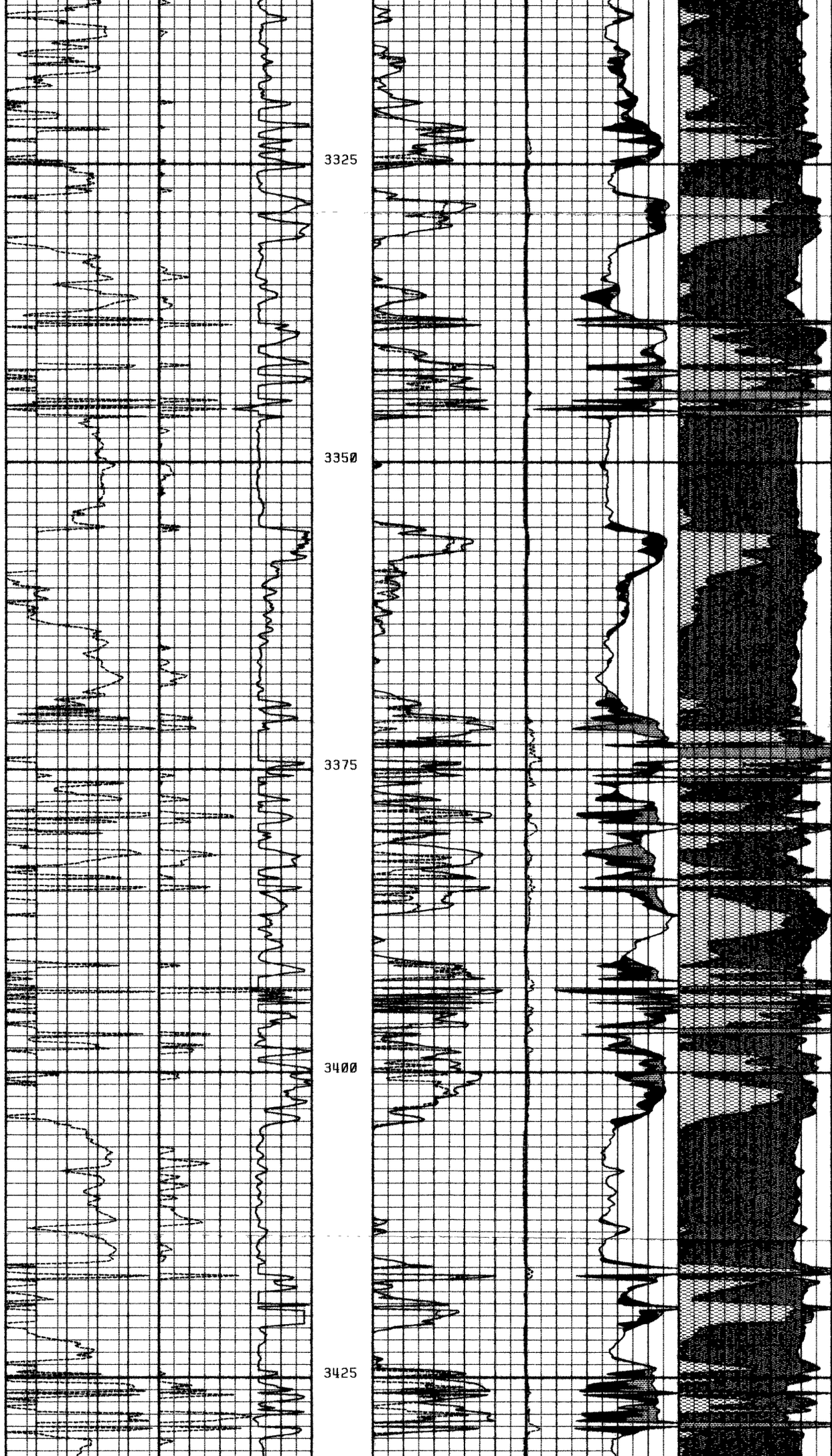
RESULTS DISPLAY

BP PETROLEUM DEVELOPMENT LTD. NORWAY
EXPLORATION

WELL: 6507/10-1 -COAL UNIT 24 MAR 83

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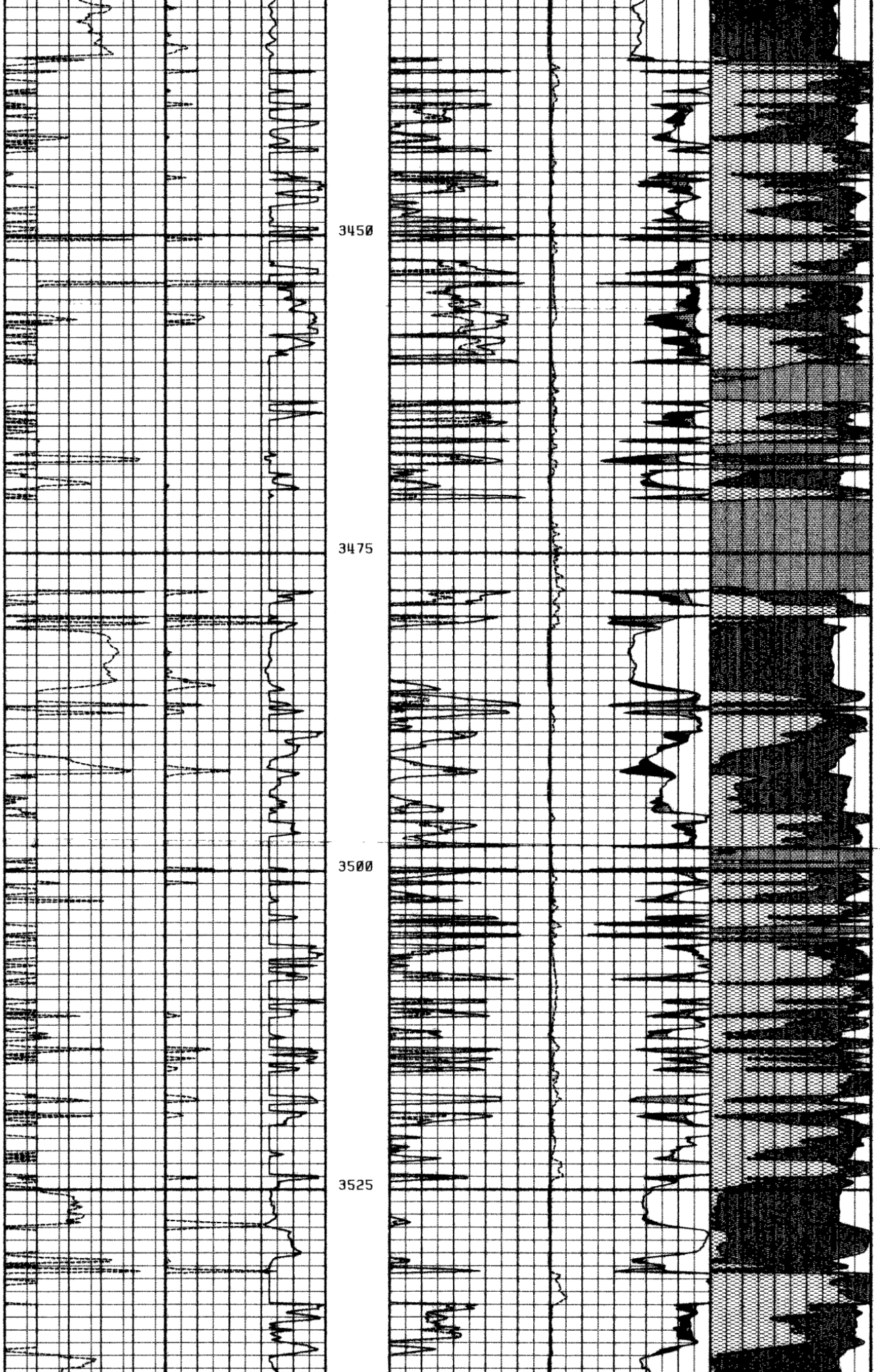
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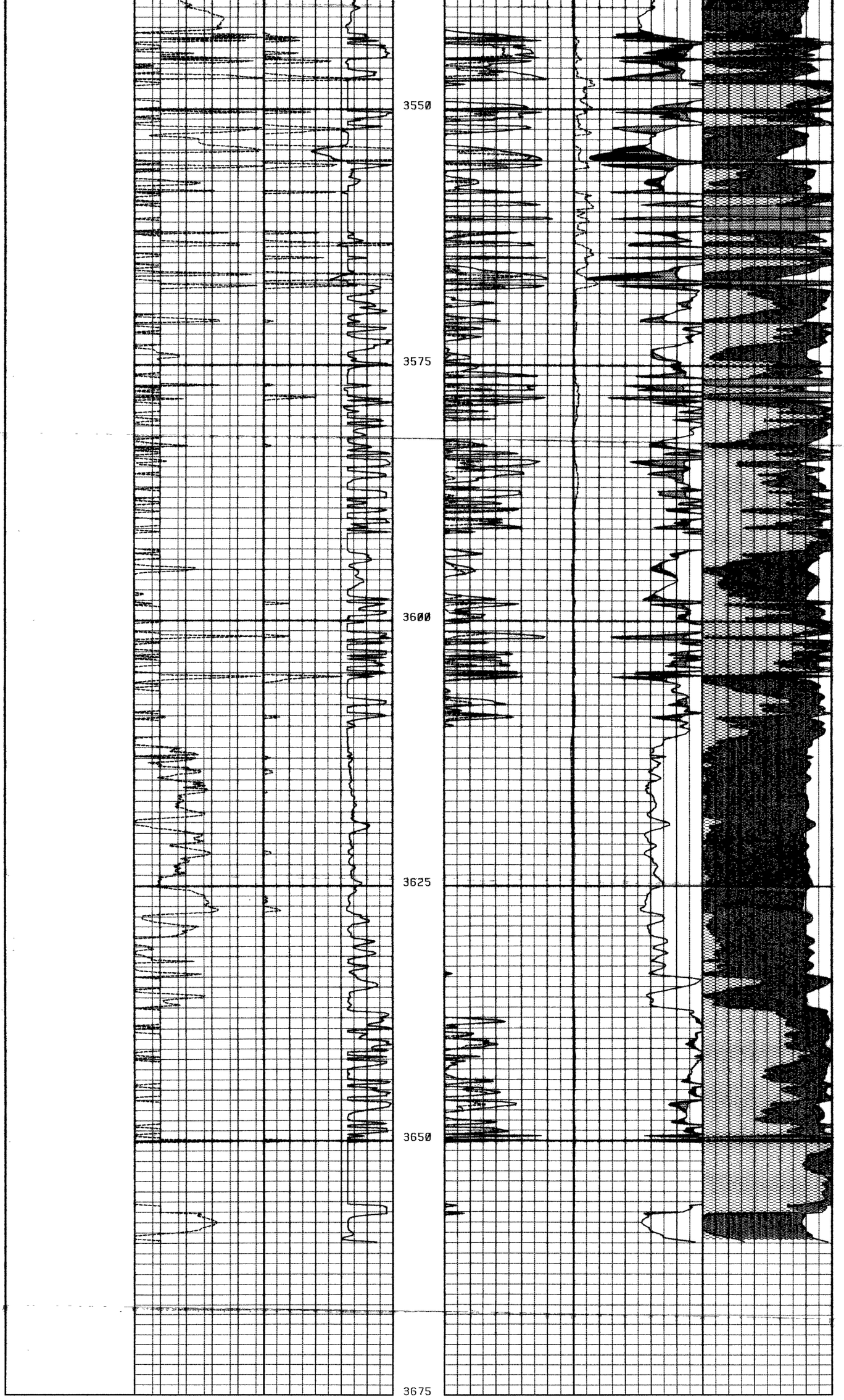
3550
3575
3600
3625
3650
3675

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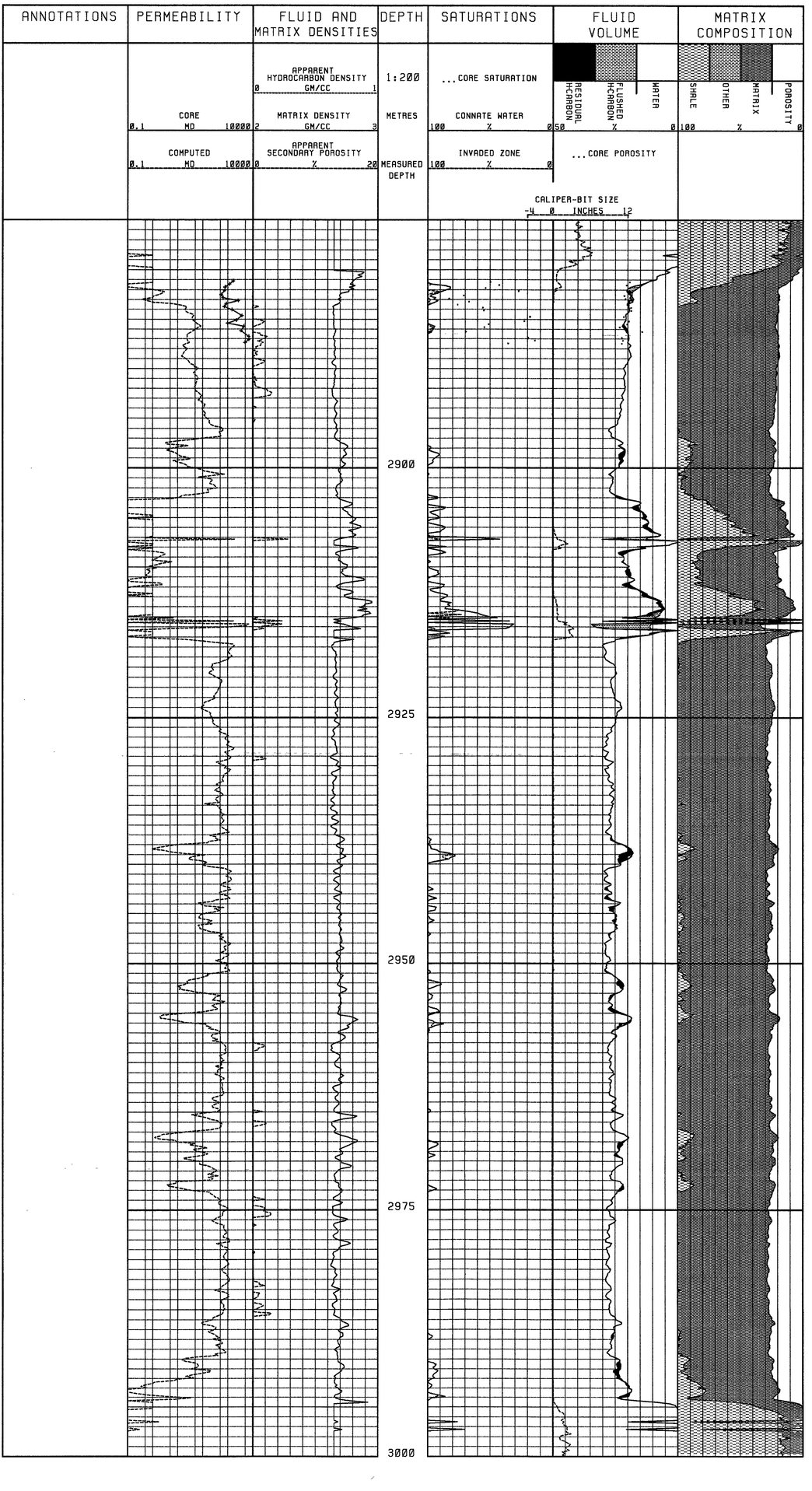
RESULTS DISPLAY

BP PETROLEUM DEVELOPMENT LTD. NORWAY

EXPLORATION

WELL: 6507/10-1 -MID JURASSIC 24 MAR 83



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RESULTS DISPLAY

BP PETROLEUM DEVELOPMENT LTD. NORWAY

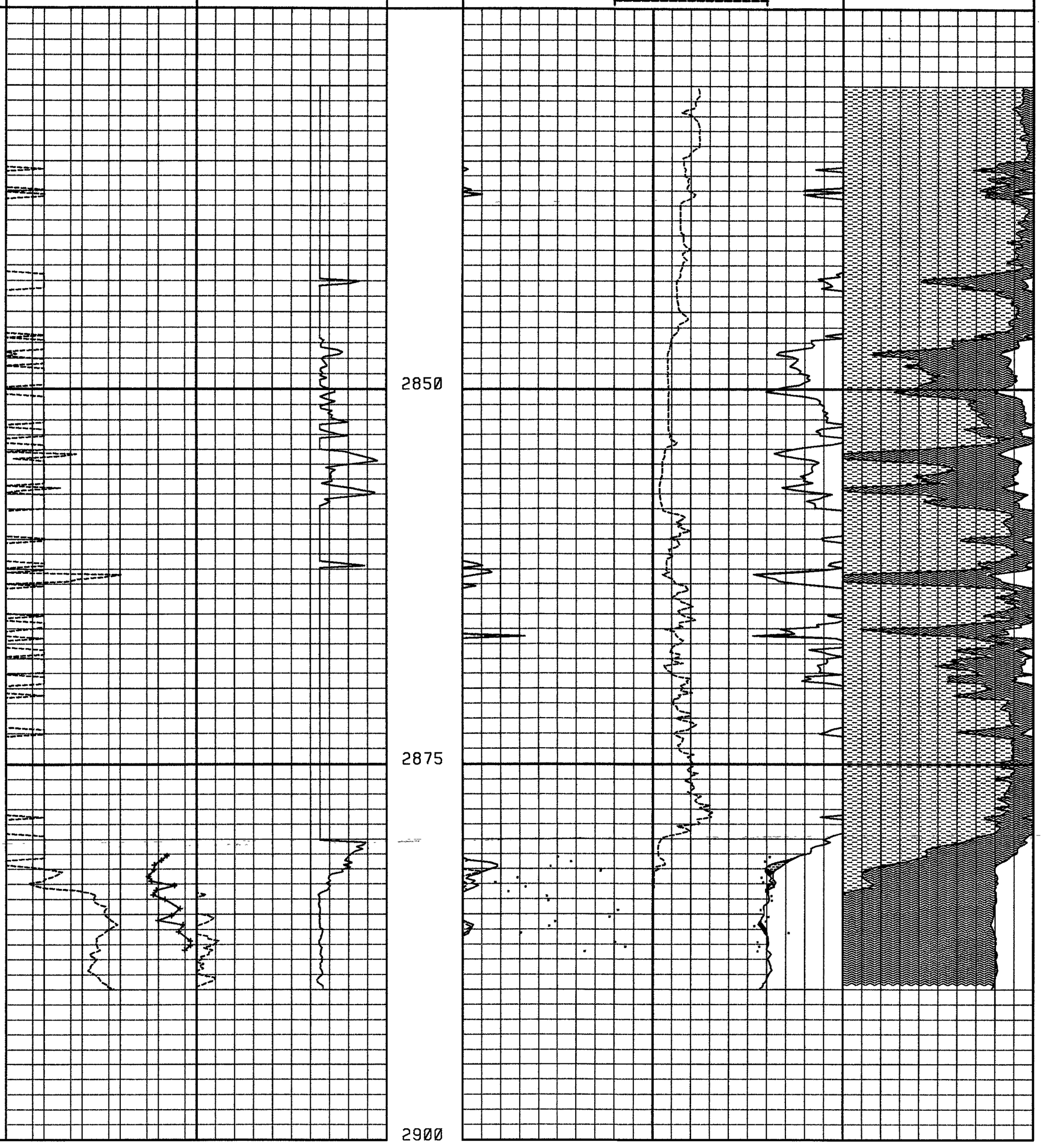
EXPLORATION

WELL: 6507/10-1 -HEATHER

24 MAR 83

ANNOTATIONS	PERMEABILITY	FLUID AND MATRIX DENSITIES	DEPTH	SATURATIONS	FLUID VOLUME	MATRIX COMPOSITION
	CORE 0.1 MD 10000 COMPUTED 0.1 MD 10000	APPARENT HYDROCARBON DENSITY 0 GM/CC 1 MATRIX DENSITY 2 GM/CC 3 APPARENT SECONDARY POROSITY 0 % 20	1:200 METRES MEASURED DEPTH	...CORE SATURATION CONNATE WATER 100 % 0 INVADED ZONE 100 % 0	RESIDUAL H-CARBON / FLUSHED H-CARBON / WATER 50 % 0 ...CORE POROSITY	SHALE / OTHER / MATRIX / POROSITY 100 % 0

CALIPER-BIT SIZE -4 0 INCHES 12



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WELL: 6507/10-1 -COOK 25 MAR 83