statoil

WELLFILE

PRESSURE GRADIENT CALCULATIONS
WELLS 1/9-3, 1/9-4
DONE BY PETROPHYSICAL SECTION
PRODUCTION DEPARTMENT STATOIL
JAN. 1978

Den norske stats oljeselskap a.s

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CONTENT PAGE

Abstract

This report is intended to be a pressure gradient "follow-up" of the two STATOIL wells 1/9-3 and 1/9-4.

Diagrams of calculated pressure gradients from D_c-exponents and sonic logs are shown together with pressure gradients from mud loggers.

Summary

Well 1/9-3 was drilled to 2771.m and plugged for reentry. 13 3/8" csg was run with casing shoe at 2761.2 m. The estimated pore pressure at this depth is 1.59 g/cc equivalent mud weight.

Well 1/9-4 was drilled to 3710. m and plugged for reentry. In the chalk at 3100. m the bit-sub twisted off. The well was plugged back and sidetracked with reentry into the old hole. A second sidetrack was drilled to 3270 m when the core stuck in the hole. A third sidetrack was done with kick off point at 3059. m and the well was drilled to TD.

The problems during drilling the chalk in 1/9-4 was caused by the pressure difference between the hole and the formation. High mudweight had to be used to balance the formation below the 9 5/8" casing from 2650m - 2800 m.

Hydrostatic and overburden gradient

An average hydrostatic gradient of 1.02 g/cc has been used in the calculations.

Fig. 1 shows the integrated FDC-logs versus depth for the wells 1/9-3 and 1/9-4.

The overburden gradient is calculated from the following formula:

$$PO = \frac{DW * PSW + RHOB * (D - D_{sb})}{D}$$

PO = Overburden gradient (g/cc)
PSW = Spesific gravity of seawater (1.03 g/cc)
D = Depth measured from RKB (m)
D_{sb} = Depth of seabottom (m)
Dw = Water depth (m)
RHOB= Average bulk density of overburden (g/cc)

Pore pressure gradient calculations

Pore pressure gradients have been calculated quantitatively from sonic log and the D_c-exponent.

The Equivalent Depth Method have been used for both pressure indicators.

Trend lines have been shifted for the D_c-exponent when bit size changes and obvious shifts are seen on the plots.

Diagrams with pressure gradients from the two indicators are shown in fig. 2 for well 1/9,3 and fig. 5 for well 1/9-4.

At the present time our experience with the sonic log are better than the D_c-exponent and the well discussions are based on the sonic log pressure calculations.

Pore pressure calculations for well 1/9-3

The well was spudded on the 12th August 1977. Water depth is 76.5 m and RKB is 35.77 m.

The 36" csg was set at 170. m in a normal hydrostatic pressured zone.

The 20" csg was set at 434. m. The calculated pore pressure at casing shoe was 1.07 g/cc. Leak off test at 2 m below 20" shoe tested to 1.5 g/cc equivalent mud weight with no leak off.

The 16" csg was set at 1345 m in a zone with a pore pressure gradient calculated to 1.40 g/cc. The leak off test at the shoe (2 m of new formation was drilled) showed 1.98 g/cc equivalent mud weight.

The pore pressure gradient increases to 1.61 g/cc at 1600 m, to 1.80 g/cc at 1800 m and to a maximum of 1.83 g/cc at approximately 2200 m. A pressure gradient regression is then seen down to 2770. m where the 13 3/8" csg was set.

Calculated pore pressure gradient at the 13 3/8" csg shoe is 1.59 g/cc.

The 13 3/8" csg has been set in an interval where a clear pore pressure gradient regression is seen.

A correlation between the sonic log plots from well 1/9-1 and 1/9-3 indicate that the 13 3/8" csg is set approximately 60 m higher in Lower Eocene compared with the 9 5/8" csg in well 1/9-1.

A pore pressure gradient regression below the 13 3/8" csg is expected down to 2900 m where the pore pressure gradient will increase to 1.61 g/cc at 3050 m.

The log shale responses are shown in fig. 9 - 10 the plotted D_c-exponent in fig. 11 and total gas in fig. 12.

Pore pressure gradients from sonic log, predicted gradients and from mud logger are shown in fig. 4.

Calculated pore pressure gradients from sonic log and D_c-exponent are presented in fig. 2.

Pore pressure calculations for well 1/9-4

This well was spudded on the 14th August 1977. Total depth for the well was 3710 m. Water depth was 75 m and RKB to sea level was 25.5 m.

The 30" casing was set at 152.m in a normal hydrostatic pressured zone.

20" casing was set with the shoe at 424.m. The pore pressure gradient at this depth is normal hydrostatic. A leak off test resulted in 1.39 g/cc equivalent mud weight.

The 13 3/8" casing was run and casing shoe landed at 1375.m. The calculated pore pressure at this depth is 1.30 g/cc. A leak off test yielded 2.08 g/cc equivalent mud weight.

Pore pressure increases to 1.69 at 1650.m. A slight regression in pressure gradient to 1.64 g/cc at 2000 m. A maximum pressure gradient of 1.86 g/cc is seen at 2250. m.

From 2250 m a pressure gradient decrease is seen down to approximately 2600 m.

The 9 5/8" casing was set at 2580. m. The calculated pore pressure gradient at the shoe is 1.69 g/cc. A leak off test at the shoe tested to 2.05 g/cc without leak off.

Below the 9 5/8" casing shoe pore pressure gradient from sonic log shows 1.72 g/cc at 2640 m and 1.75 g/cc at 2770 m.

This pressure gradient increase are confirmed by the shale density plot from FDC-log and the density measured on drilled out samples. (fig. 14 and 18).

The pore pressure problems below the 9 5/8" casing shoe do not seem to be caused by a too high pore pressure at the casing shoe. The pore pressure gradient trend for this well are different than expected from 1/9 alpha structure. The pressure gradient regression is more abrupt in a short interval from 1.75 g/cc at 2770. m to 1.50 g/cc at 2950. m.

A more suitable setting depth would have been approximately 2840 m where the pore pressure gradient is calculated to be 1.60 g/cc.

The drillstem tests in Ekofisk and Tor formations gave pore pressure gradients of 1.59 g/cc at 3130.m and 1.56 g/cc at 3294. m.

A 7" liner was run and set at 3352.m. The leak off test yielded 2.03 g/cc.

The pressure gradient at T.D. are calculated to be 1.6 g/cc. The pressure calculation at this depth is uncertain due to the relatively thin shale section and the limestone interbedding in the shale. A higher pore pressure gradient as shown by the D_c-exponent, are more probable.

Log shale responses are shown in fig. 13-15, D_c-exponent in fig. 16 and ROP in fig. 17. Calculated and predicted pore pressure gradients are shown in fig. 6 with the results from mudlogger.

Fracture gradients

Fracture gradients have been calculated from the methods of Eaton & Pannebaker and Andersen, Ingram & Zanier. See Abnormal pressure report on well 1/9-1, 1/9-2, Appendix B.

Fracture gradients well 1/9-3

Fracture gradients calculated for this well are much lower than showed by the leak off tests. (fig. 3).

The suggested reason for this is that the mechanical properties of the shales are different than assumed. The division of horizontal stresses to the vertical stresses are approaching 1 and are higher than used.in the calculations.

In addition the formation breakdown pressure are higher than injection pressure, which are calculated with these methods.

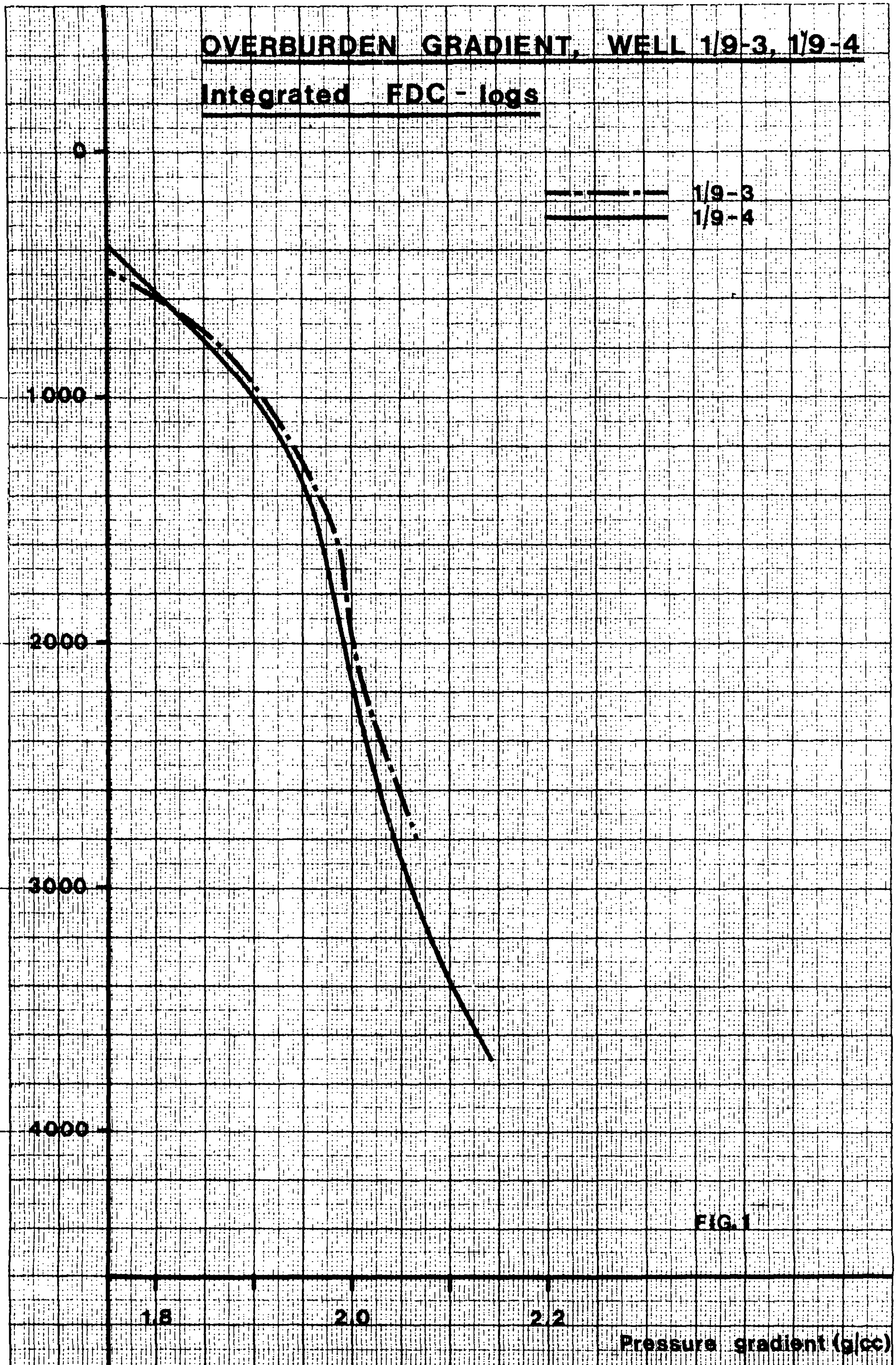
Most probably the fracture gradient are between the two fracture gradient curves in sand or silty formations while in shales the fracture gradients are equal to or higher than results from the Andersen, Ingram and Zanier method.

Refined input data to fracture gradient calculations will be established.

Fracture gradients 1/9-4

The same comments for well 1/9-3 also do apply for the well 1/9-4. (fig. 7).

From the acid treatment in DST-2 (3235-3255.m) breakdown pressure calculated is 1.90 g/cc equivalent mudweight in the chalk.



OVERBURDEN GRADIENT, WELL 1/9-3, 1/9-4
Integrated FDC - logs
1/9-3
1/9-4
0
1000
2000
3000
4000
1.8
2.0
2.2
Pressure gradient (g/cc)
FIG. 1

EMO A 4

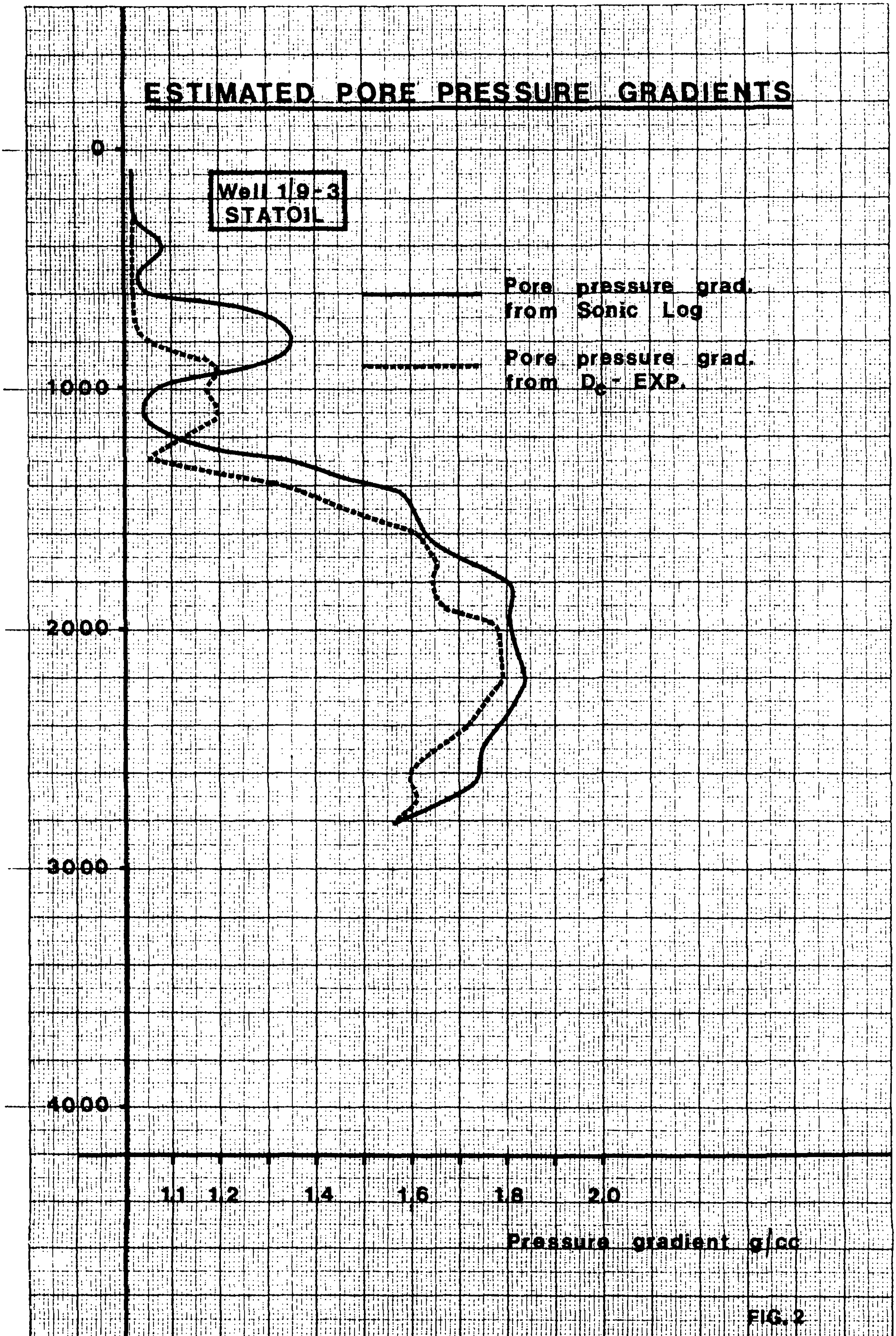
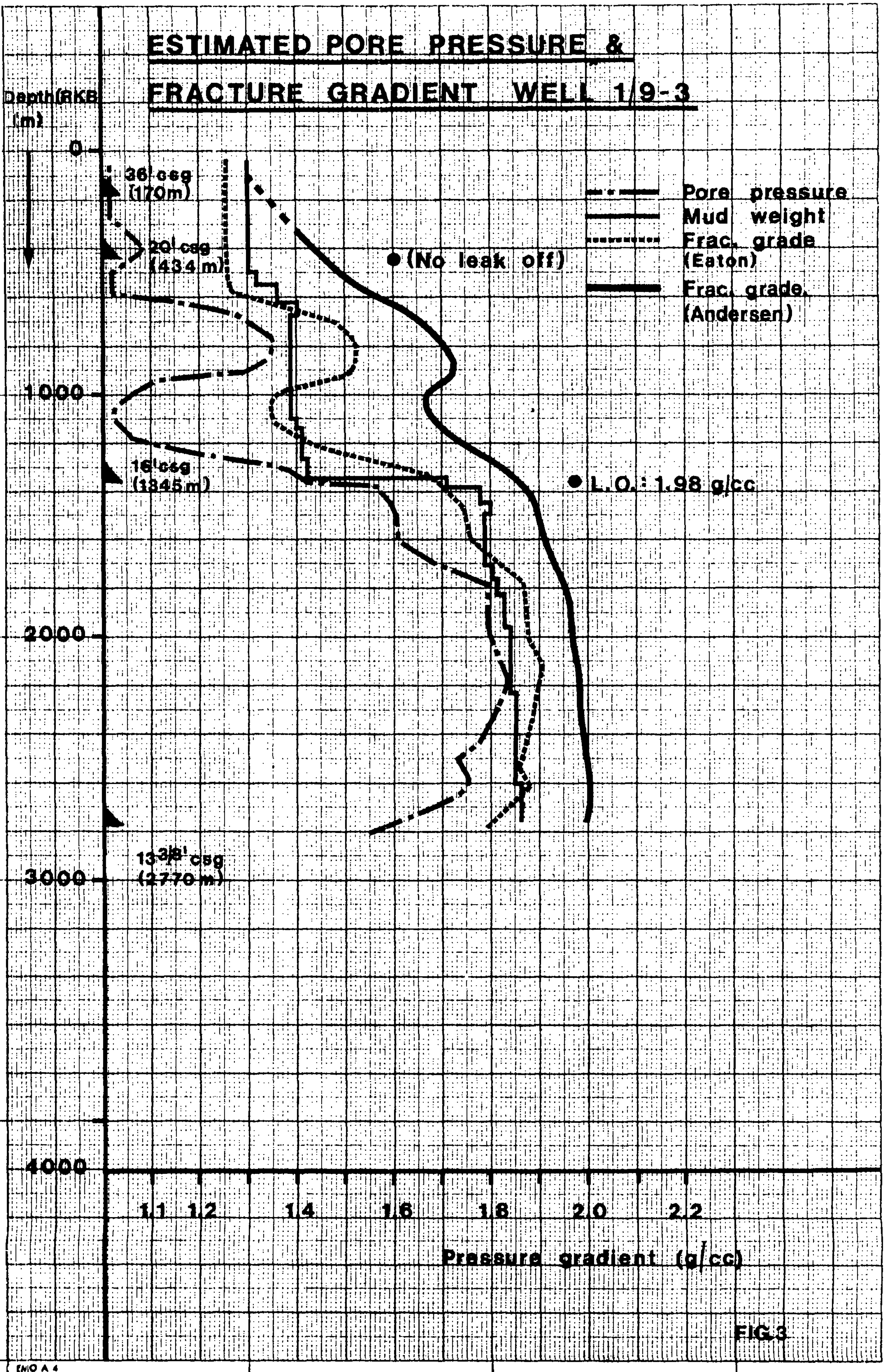
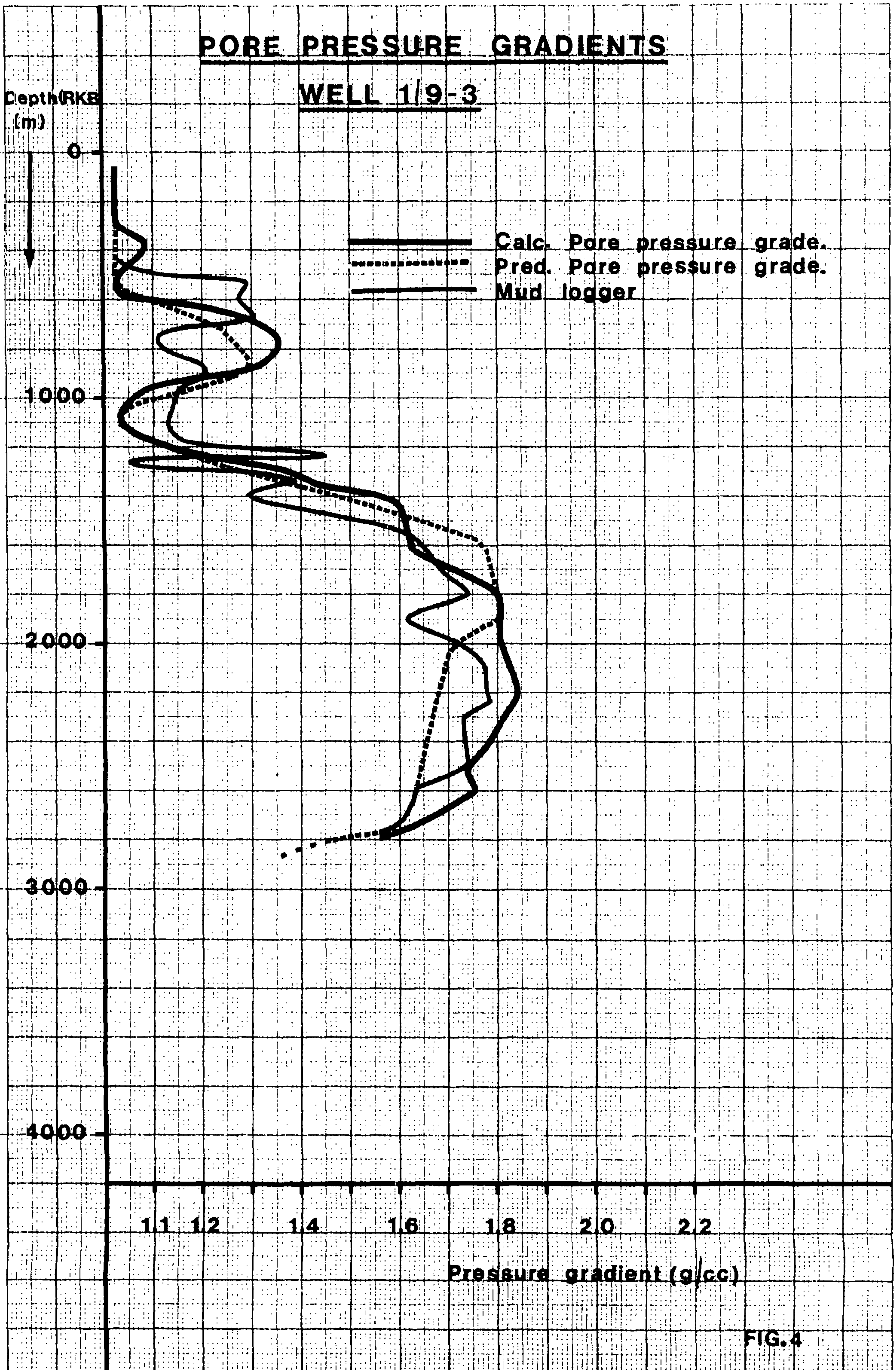

ESTIMATED PORE PRESSURE GRADIENTS
Well 1/9-3
STATOIL
Pore pressure grad. from Sonic Log
Pore pressure grad. from Dc - EXP.
0
1000
2000
3000
4000
1.1
1.2
1.4
1.6
1.8
2.0
Pressure gradient g/cc

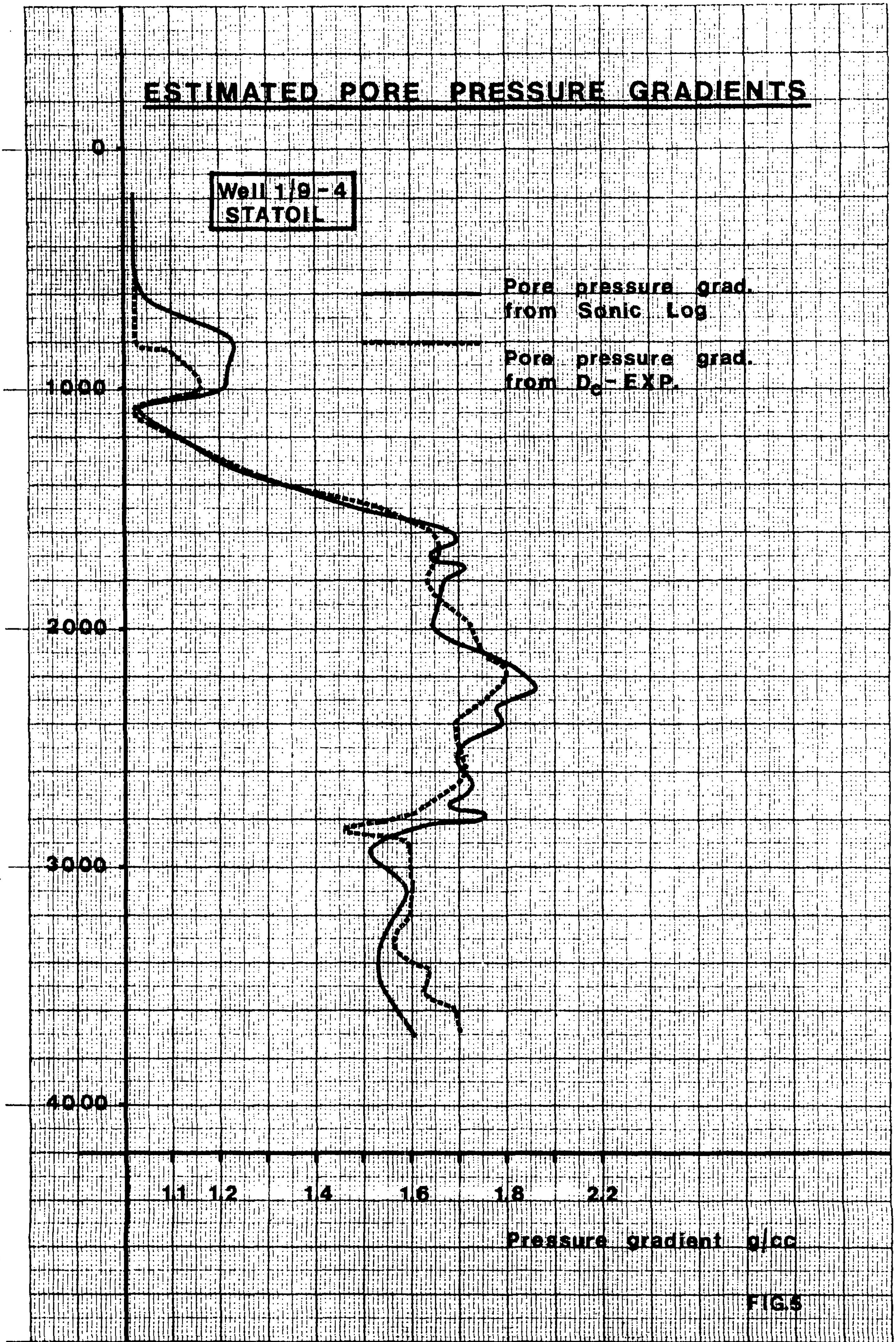
FIG. 2

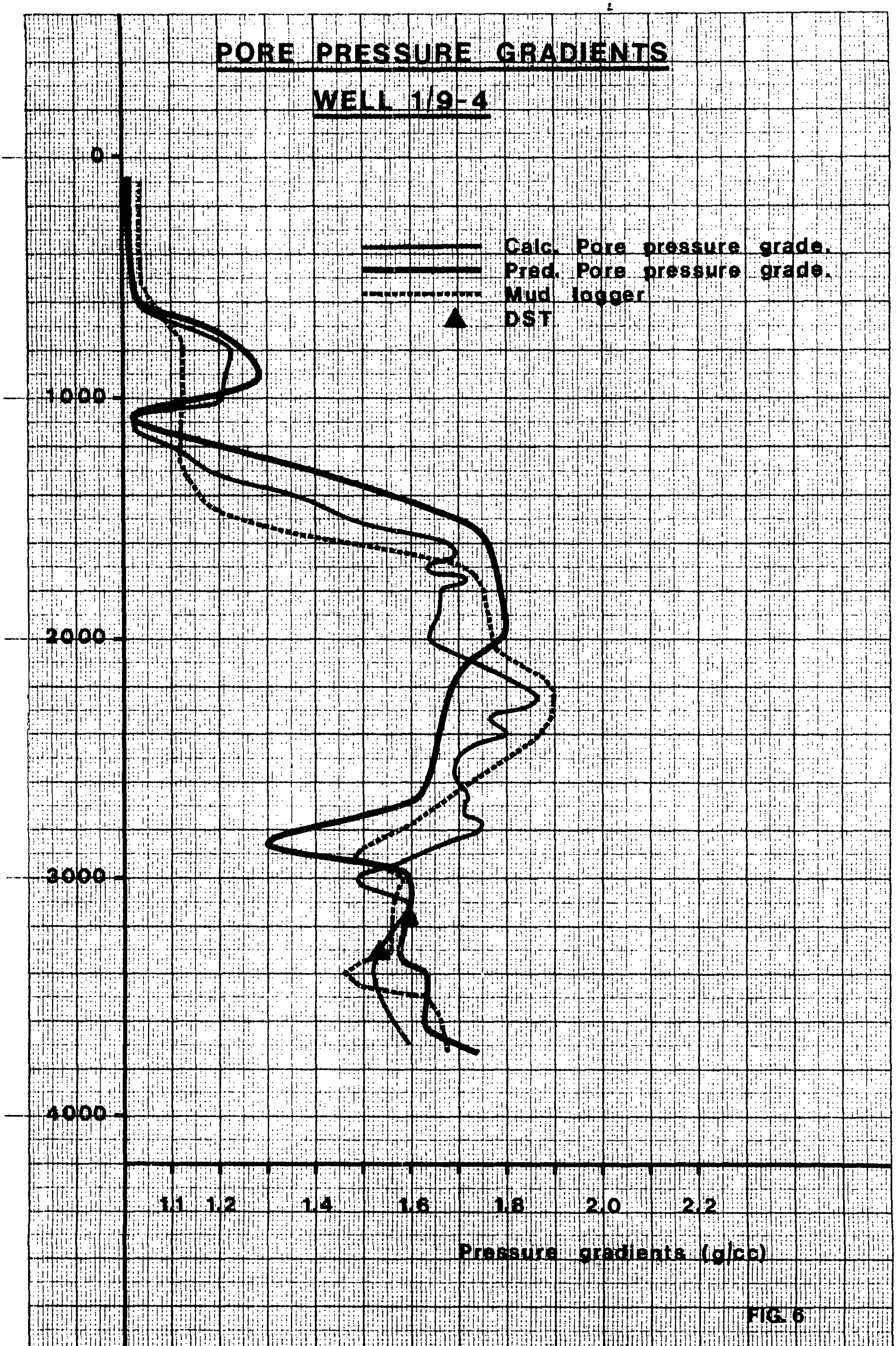

ESTIMATED PORE PRESSURE &
FRACTURE GRADIENT WELL 1/9-3
Depth(RKB)
(m)
0
1000
2000
3000
4000
36' csg
(170m)
20' csg
(434 m)
16' csg
(1845 m)
13 3/8' csg
(2770 m)
Pore pressure
Mud weight
Frac. grade
(Eaton)
Frac. grade.
(Andersen)
(No leak off)
L. O.: 1.98 g/cc
1.1
1.2
1.4
1.6
1.8
2.0
2.2
Pressure gradient (g/cc)
FIG.3
EMO A 4



PORE PRESSURE GRADIENTS
WELL 1/9-3
Depth(RKB) (m)
0
1000
2000
3000
4000
Calc. Pore pressure grade.
Pred. Pore pressure grade.
Mud logger
1.1
1.2
1.4
1.6
1.8
2.0
2.2
Pressure gradient (g/cc)

FIG. 4


ESTIMATED PORE PRESSURE GRADIENTS
Well 1/9-4
STATOIL
Pore pressure grad. from Sonic Log
Pore pressure grad. from D_c-EXP.
0
1000
2000
3000
4000
1.1
1.2
1.4
1.6
1.8
2.2
Pressure gradient g/cc
FIG.5



PORE PRESSURE GRADIENTS
WELL 1/9-4
Calc. Pore pressure grade.
Pred. Pore pressure grade.
Mud logger
DST
0
1000
2000
3000
4000
1.1
1.2
1.4
1.6
1.8
2.0
2.2
Pressure gradients (g/cc)

FIG. 6

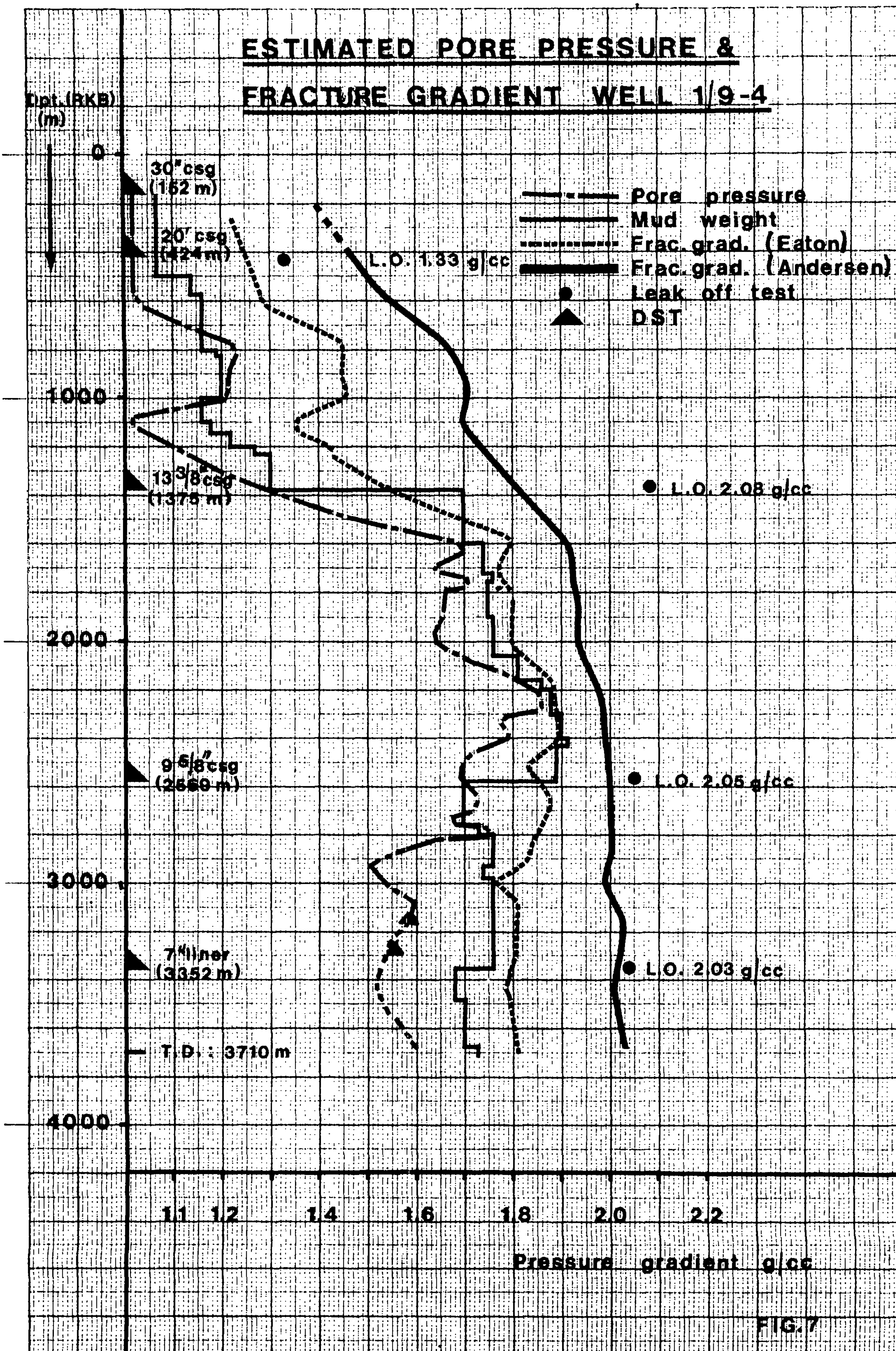

ESTIMATED PORE PRESSURE &
FRACTURE GRADIENT WELL 1/9-4
Dpt.(RKB) (m)
0
1000
2000
3000
4000
30"csg (152 m)
20"csg (424 m)
13 3/8"csg (1375 m)
9 5/8"csg (2560 m)
7"liner (3352 m)
T.D. : 3710 m
Pore pressure
Mud weight
Frac. grad. (Eaton)
Frac. grad. (Andersen)
Leak off test
DST
L.O. 1.33 g/cc
L.O. 2.08 g/cc
L.O. 2.05 g/cc
L.O. 2.03 g/cc
1.1
1.2
1.4
1.6
1.8
2.0
2.2
Pressure gradient g/cc

FIG.7

EMO A 4

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Eine Achse logar. geteilt, von 1 bis 10 Einheit 250 mm die andere gleichm. in mm

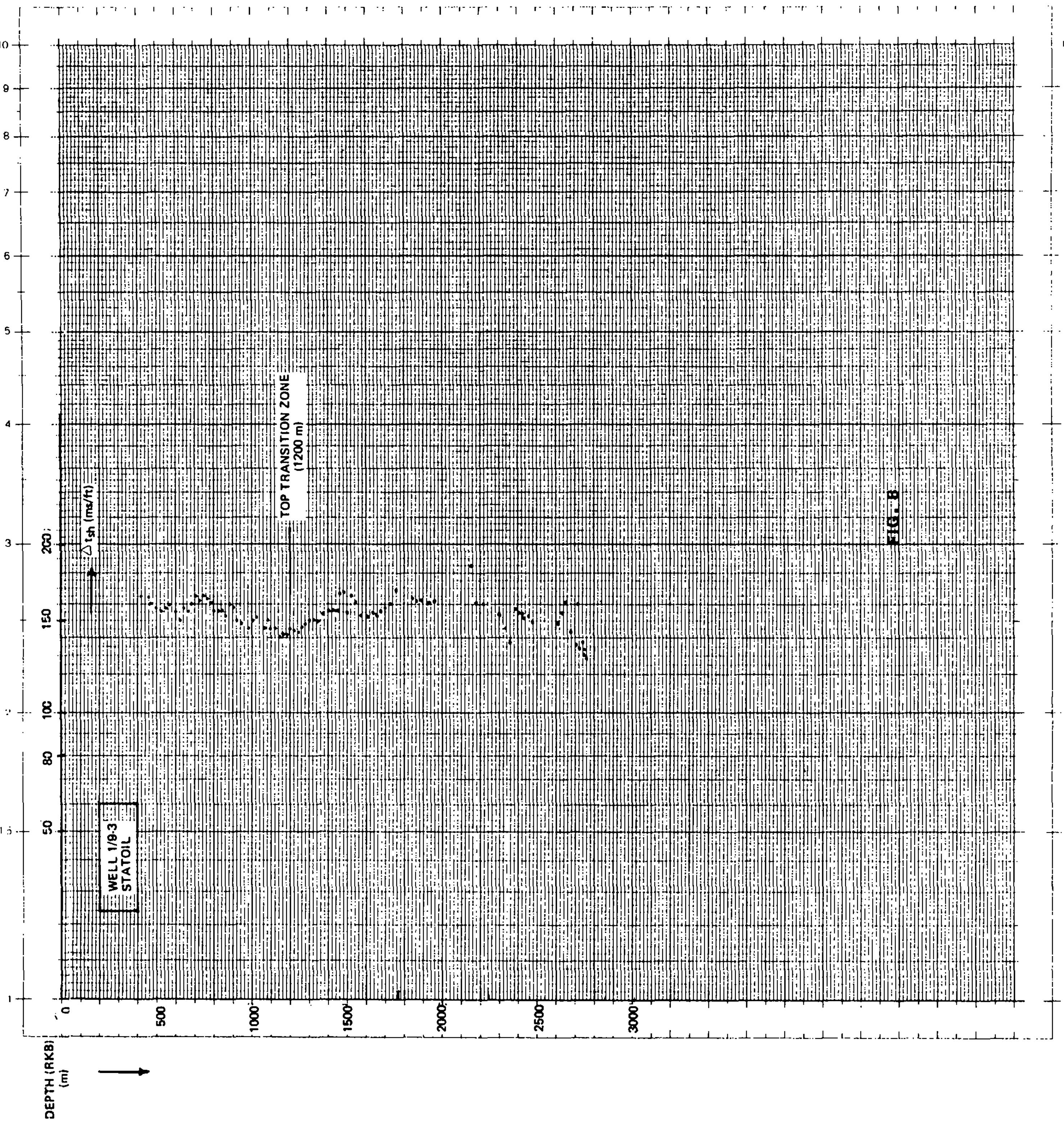


FIG. 8

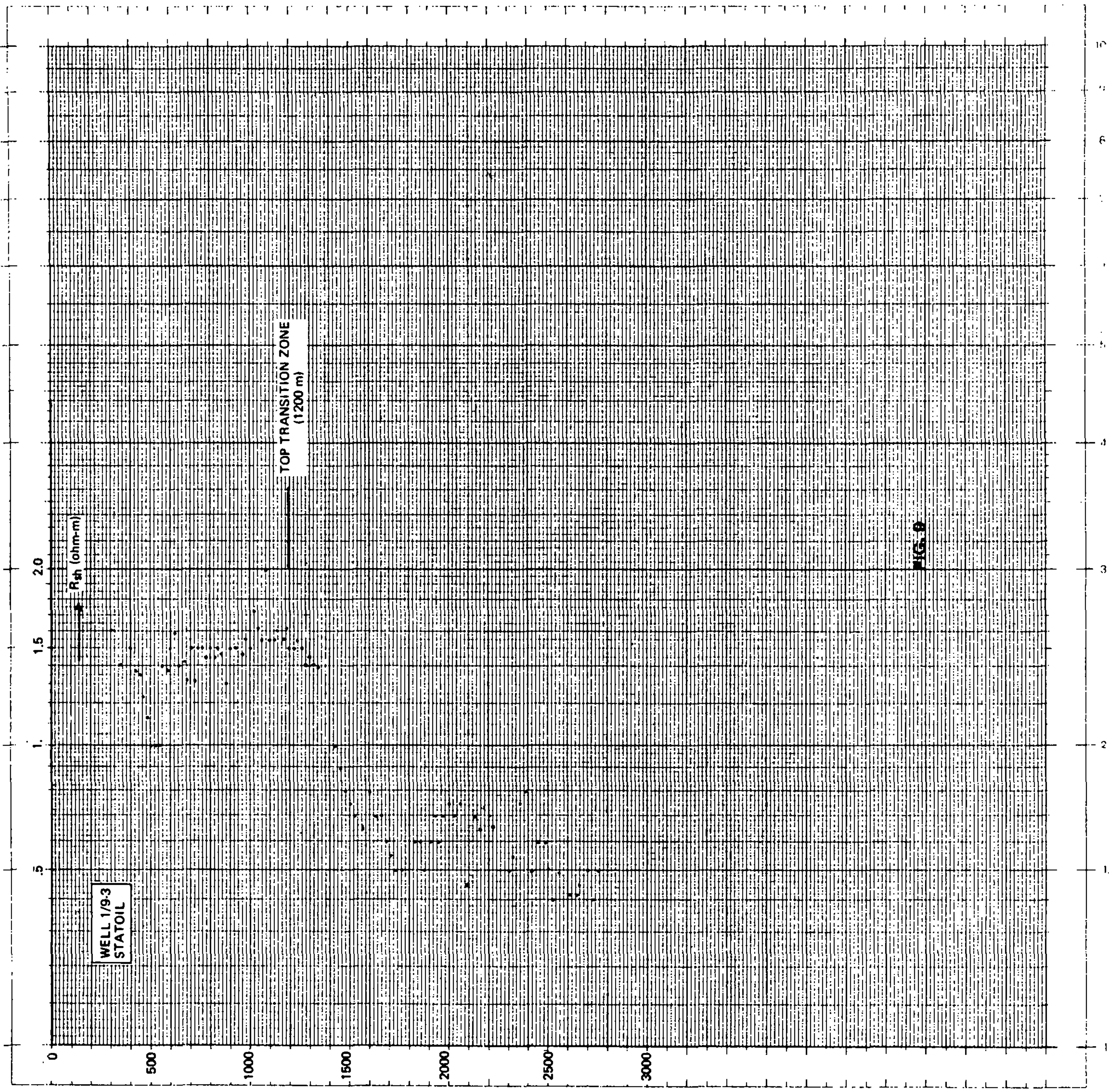

TOP TRANSITION ZONE (1200 m)
R_sh (ohm-m)
WELL 1/9-3
STATOIL
2.0
1.5
1.
.5
0
500
1000
1500
2000
2500
3000

FIG. 8

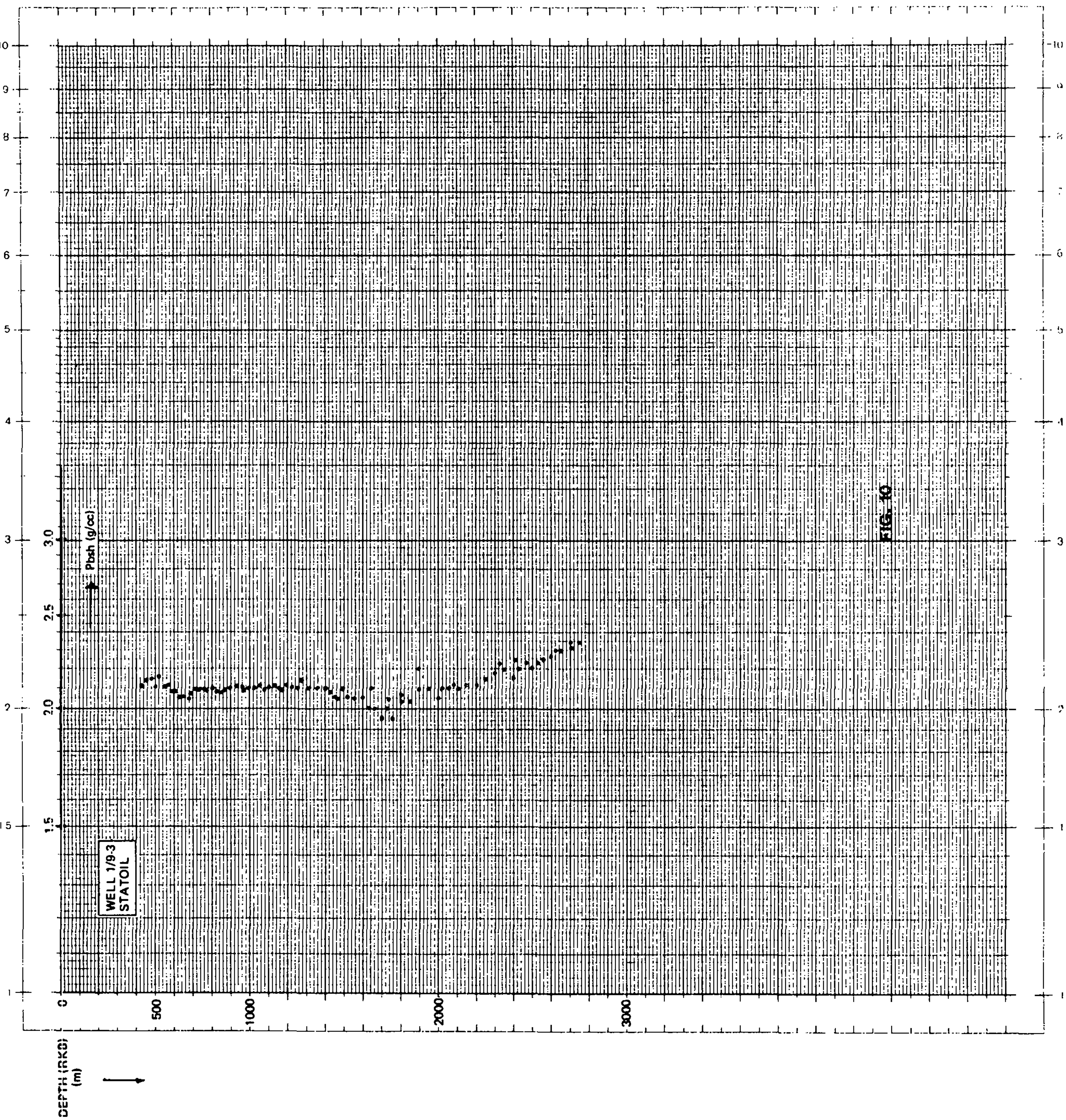

Pbsh (g/cc)
3.0
2.5
2.0
1.5
WELL 1/9-3
STATOIL
0
500
1000
2000
3000
DEPTH (RKB)
(m)

FIG. 10

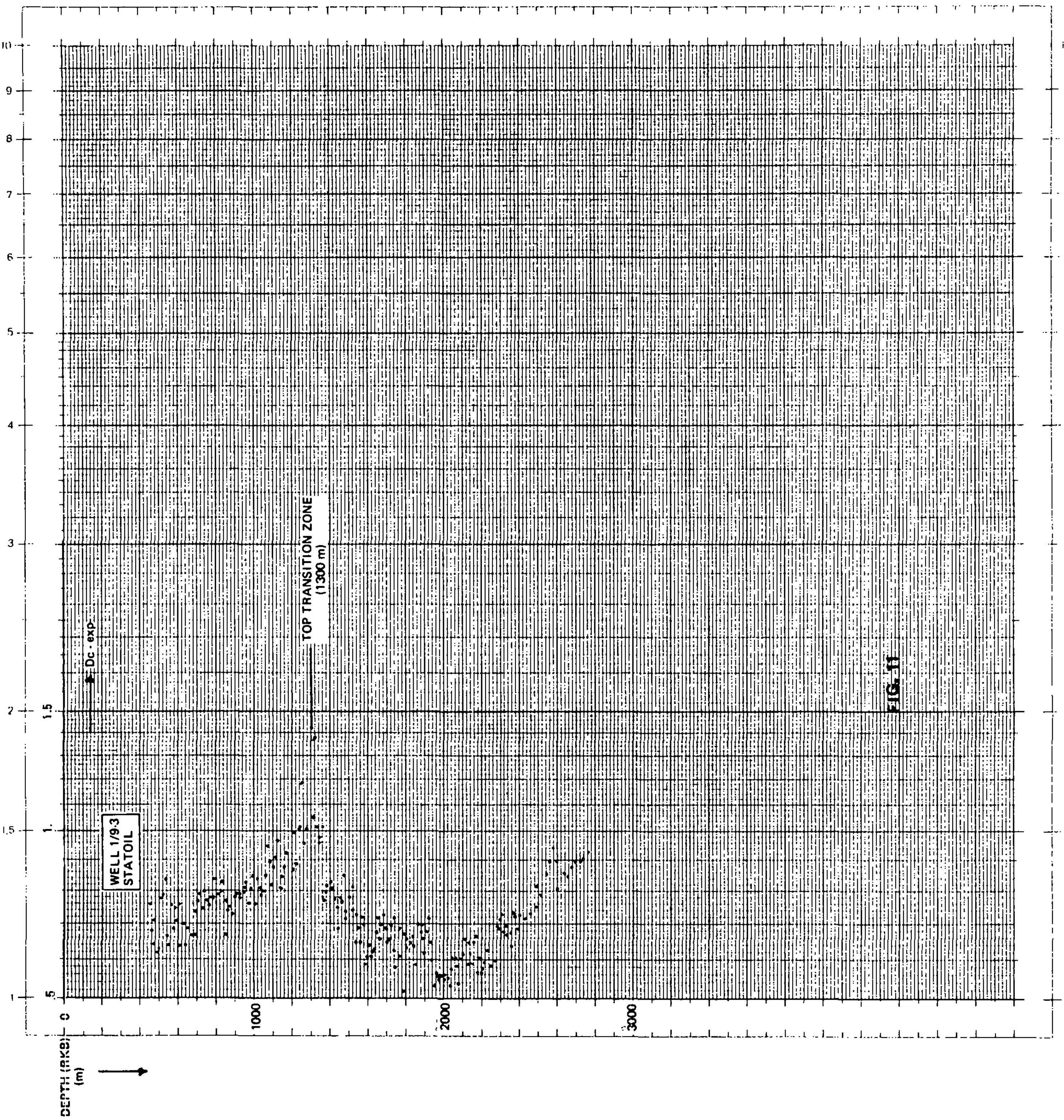

Dc - exp
TOP TRANSITION ZONE
(1300 m)
WELL 1/9-3
STATOIL
.5
1.
1.5
0
1000
2000
3000
DEPTH (RKB)
(m)

FIG. 11

TOTAL GAS (Exploration Logging)

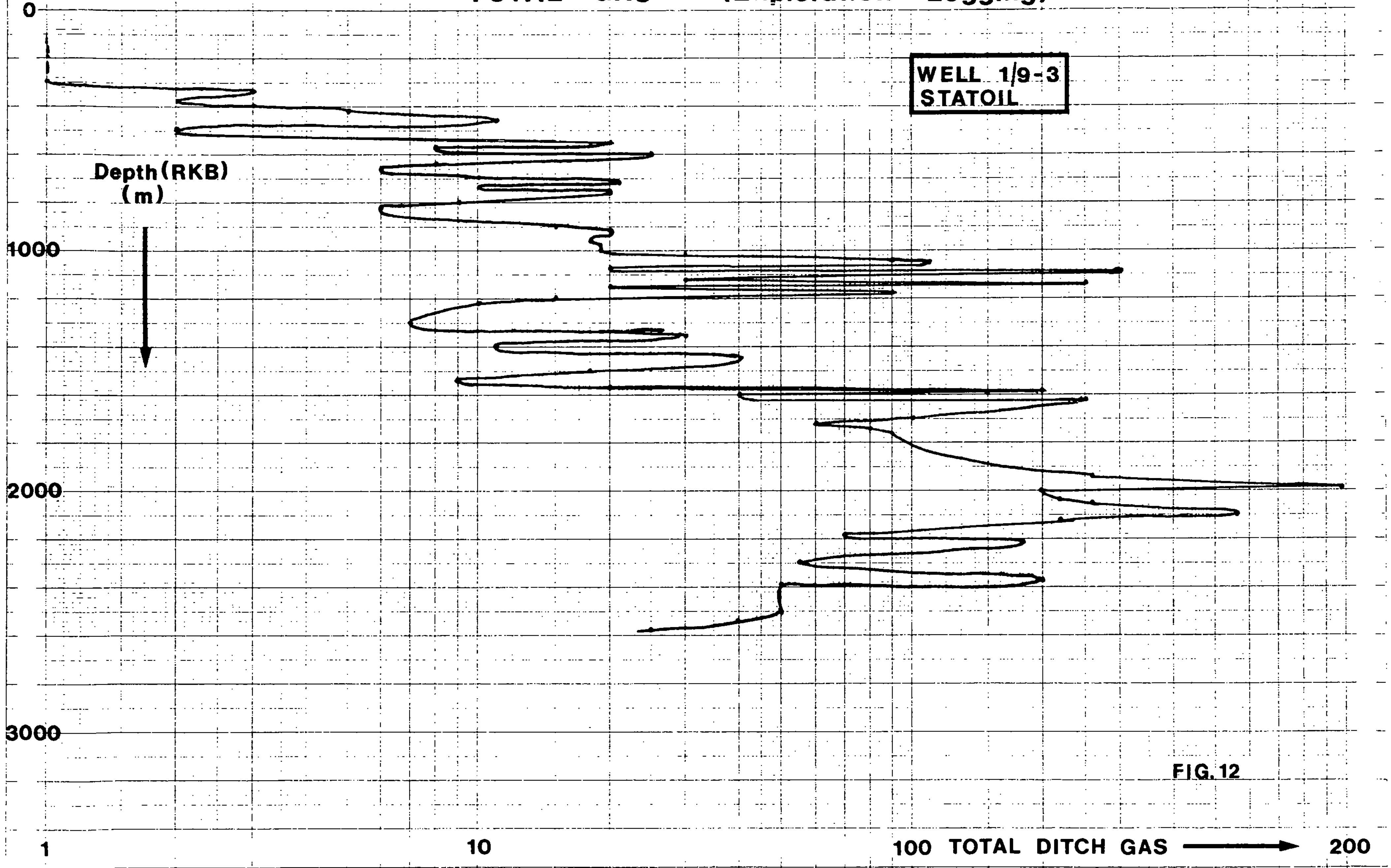


FIG. 12

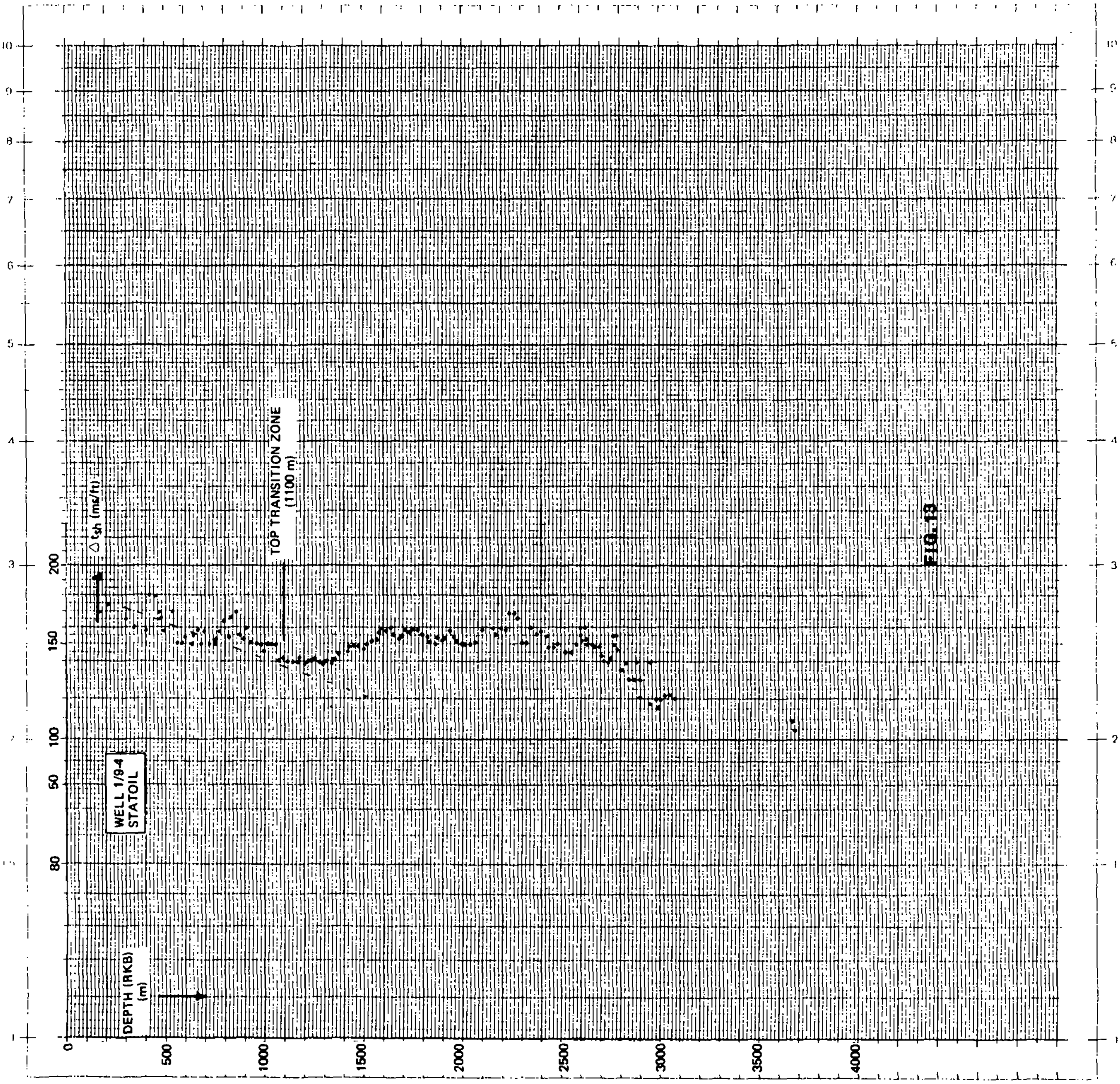

Δt_{sh} (ms/ft)
200
150
100
50
80
TOP TRANSITION ZONE
(1100 m)
WELL 1/9-4
STATOIL
DEPTH (RKB)
(m)
0
500
1000
1500
2000
2500
3000
3500
4000

FIG. 13

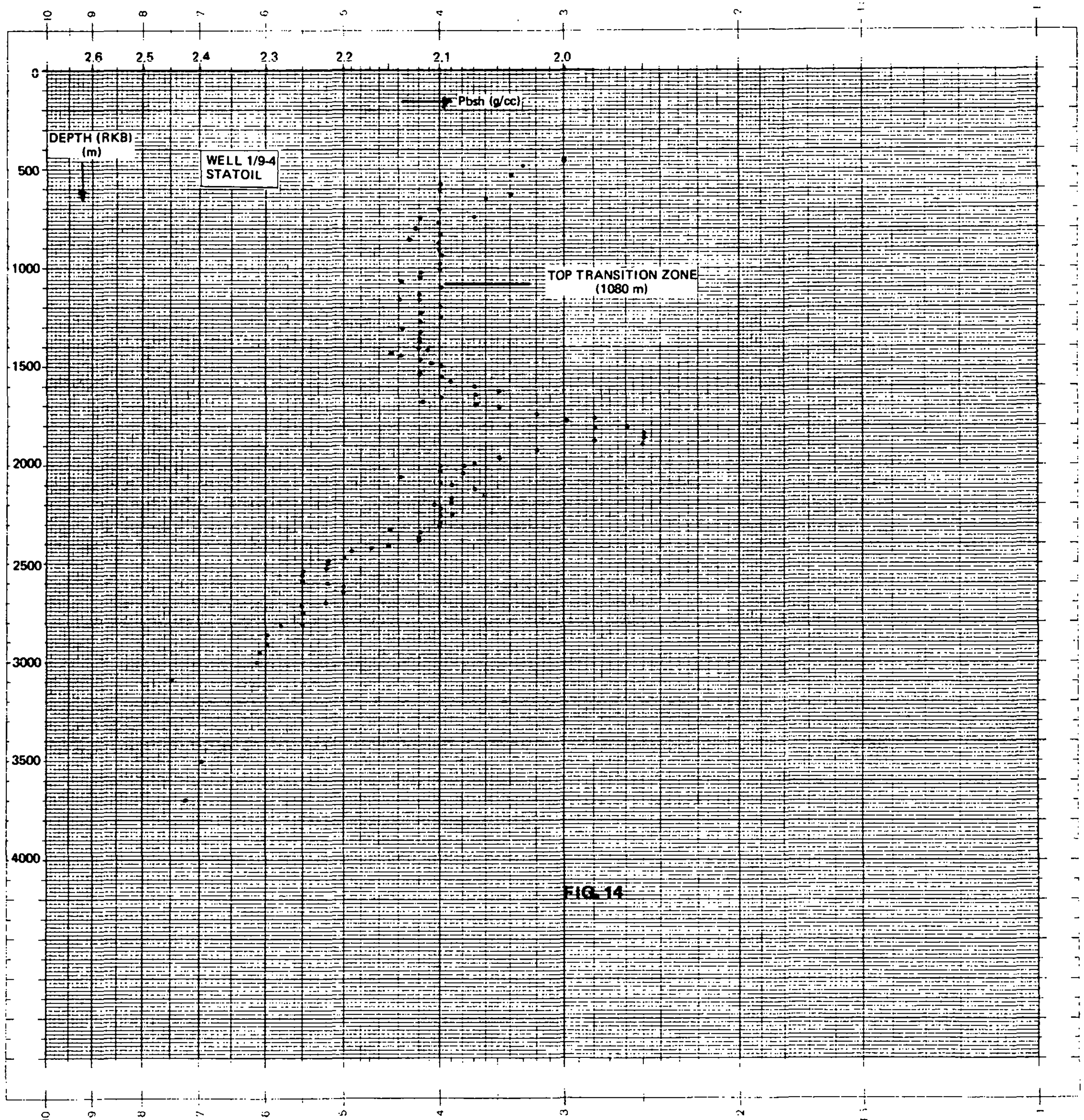
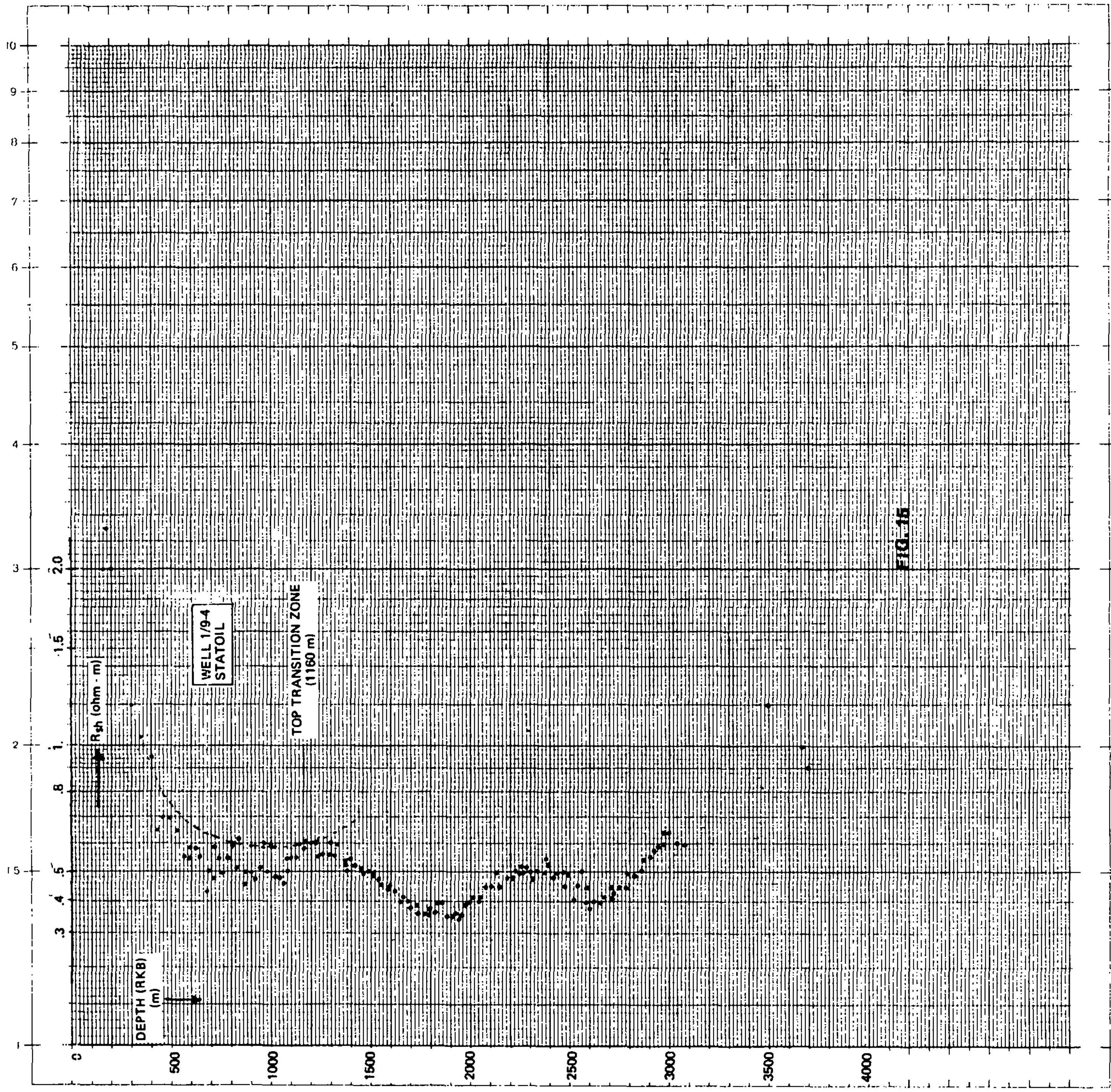

DEPTH (RKB)
(m)
WELL 1/9-4
STATOIL
Pbsh (g/cc)
TOP TRANSITION ZONE
(1080 m)
2.6
2.5
2.4
2.3
2.2
2.1
2.0
0
500
1000
1500
2000
2500
3000
3500
4000

FIG. 14



WELL 1/9-4
STATOIL
TOP TRANSITION ZONE
(1160 m)
R_{sh} (ohm · m)
DEPTH (RKB)
(m)
2.0
1.5
1.
.8
.5
.4
.3
0
500
1000
1500
2000
2500
3000
3500
4000
FIG. 15

Eine Achse logar. geteilt, von 1 bis 10, Einheit 250 mm, die andere gleichm. in mm

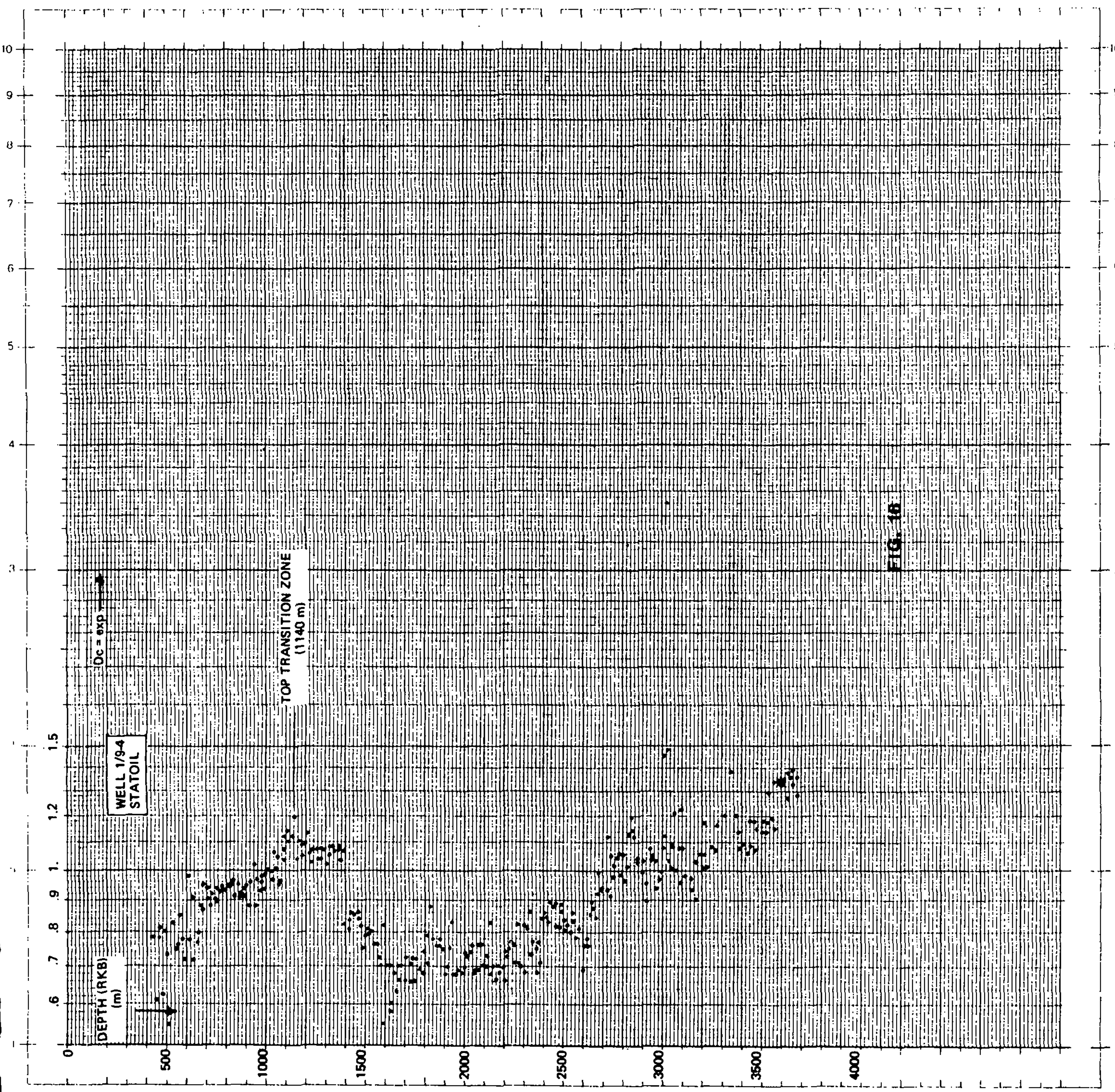
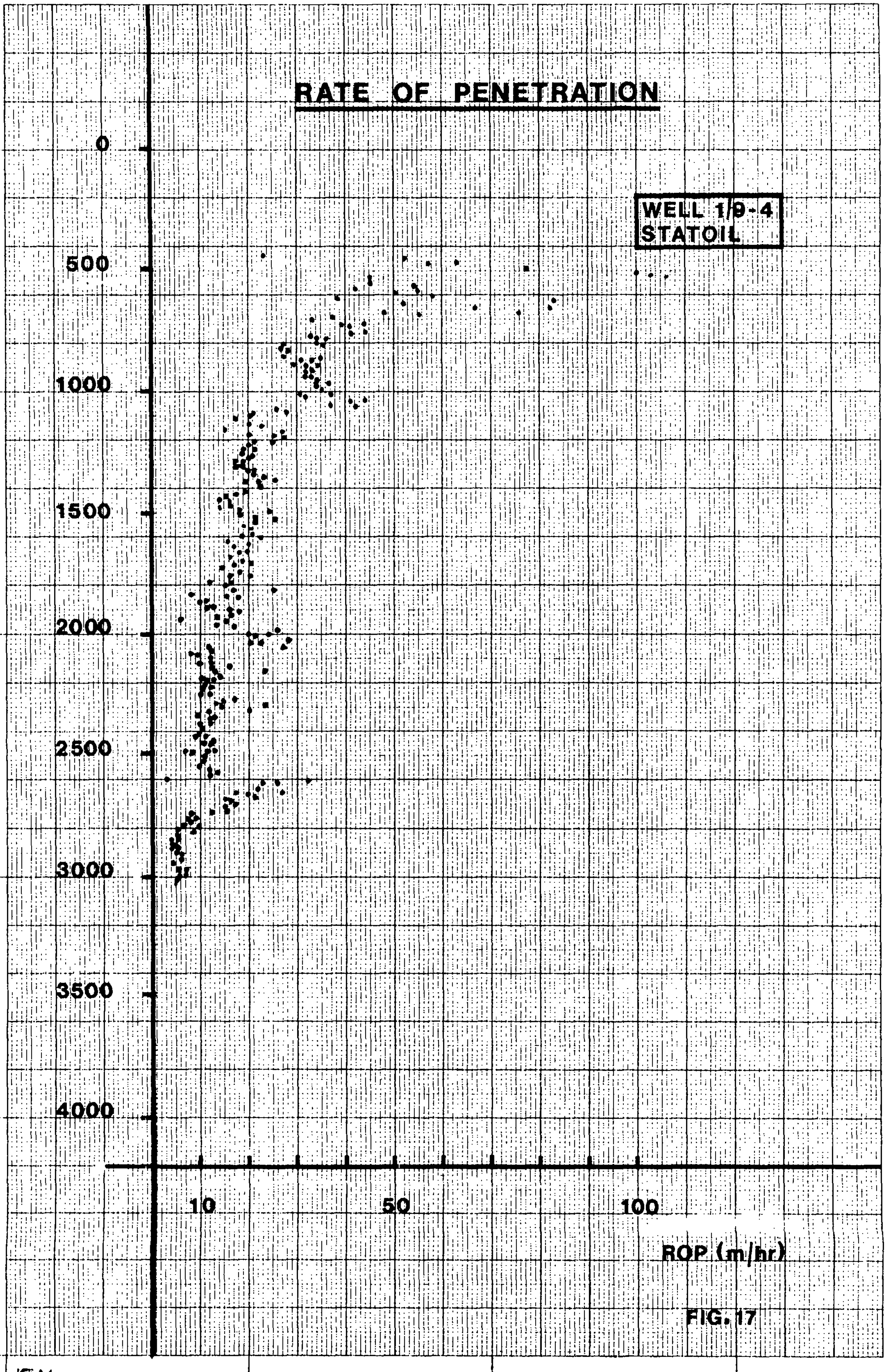


FIG. 16


RATE OF PENETRATION
WELL 1/9-4
STATOIL
0
500
1000
1500
2000
2500
3000
3500
4000
10
50
100
ROP (m/hr)
A4
FIG. 17

SHALE DENSITY

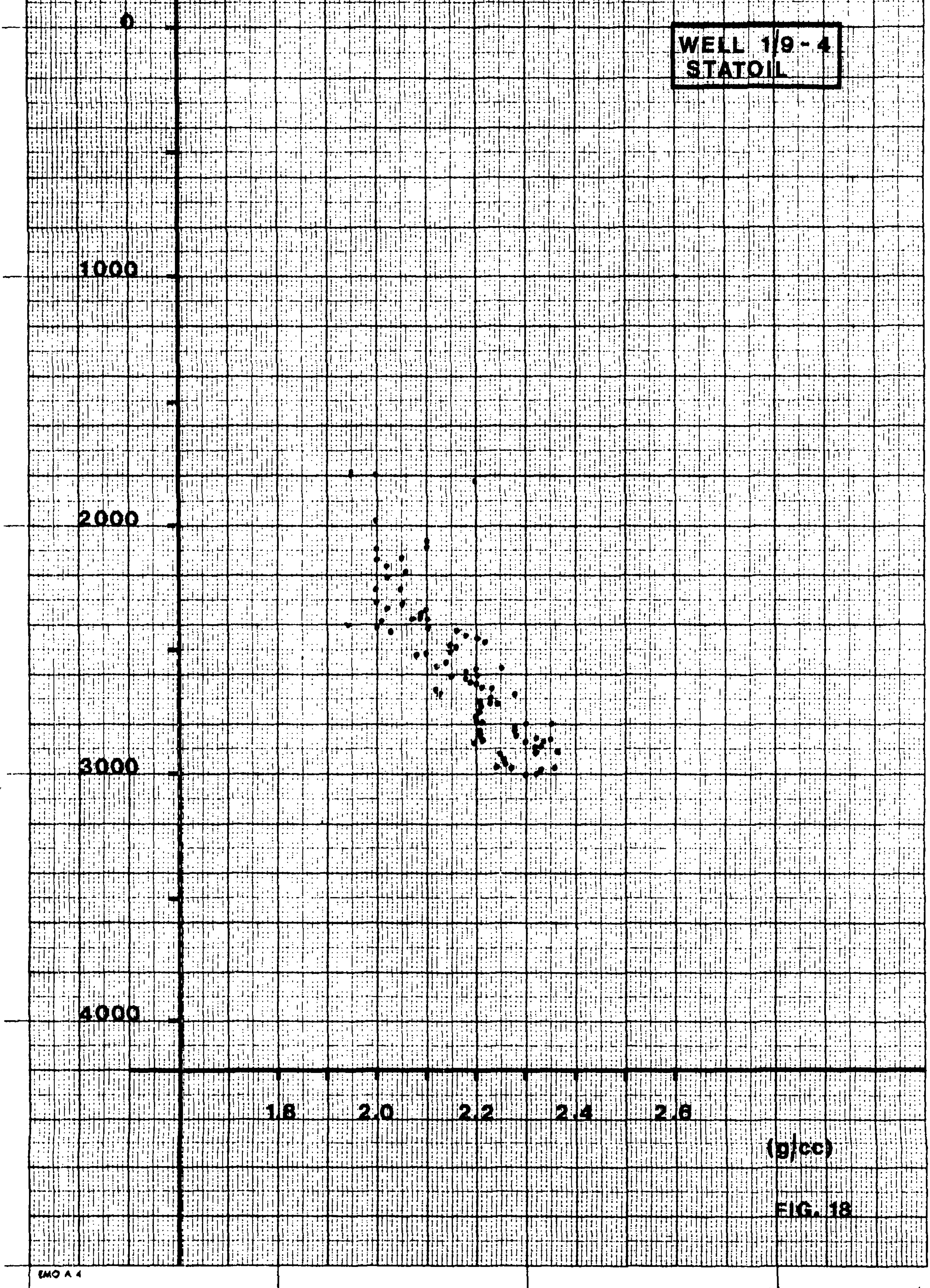


FIG. 18

EMO A 4