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31/3-2; RESULTS AND IMPLICATIONS

Norsk Hydro a.s, Sept. 1984

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1. INTRODUCTION

This investigation aims to explain the variations seen in the fluid contacts and oil-leg thicknesses in the northern part of Troll East and eastern part of Troll West (Fig. 1). New geological information from well 31/3-2 gives rise to possible new explanations. The juxtaposition and sealing fault theories are discussed. On the basis of these new investigations further appraisal drilling in northern part of Troll is discussed.

2. OBSERVATIONS

2.1 Fluid contacts

Fluid contacts are discussed below based on interpretation of the log and RFT data.

Well 31/3-2

Logs: ?GOC: 1542.5 mMSL This GOC is not exclusively identified. The value is picked from dens./neutron logs.

OWC: 1553.5 MSL 50% water: This contact is picked above a 1 m thick calcite cemented string.

1554.5 mMSL 100% water: This contact is picked below the 1 m thick calcite string.

RFT: No gas points from RFT.
The most shallow oil point is at 1542.6 mMSL.
2 RFT samples containing gas and oil were also taken at 1542.6 mMSL.

Test: The well was tested at 1542 - 1552 mMSL.
To match the GOR behaviour gas had to be introduced in the upper part of the perforation.

RFT: The oil and water lines intersects at 1555.3 mMSL. Traces of gas and oil are reported at the sampling depth of 1552.8 mMSL. The uncertainty of the OWC is 1553 to 1556 mMSL with 1554.5 as the indicated value of free water oil contact.

Well 31/2-6

Logs:	GOC:	1546 mMSL	This GOC is picked form a clear shift on dens./neutron logs.
	OWS:	1556.5-1557	50-100% water: 50% is picked above a 0.5 m thick calcite cemented string.
		1557 mMSL	This OWC is picked at the bottom of the calcite cemented string.

RFT: No contacts can be established form the pressure points.
Deepest gas point at 1521 mMSL
Highest water point at 1590 mMSL.
One pressure point at 1548 mMSL which fits the water line, but oil was tested in the interval 1551-1554 mMSL.

Well 31/3-1

Logs:	GOC:	1546.5 mMSL	This GOC is picked below a calcite cemented string on the dens./neutron log.
	OWC:	1548 mMSL	50% water
		1551 mMSL	100% water

RFT: No contacts can be established from the pressure points. From the RFT sampling, gas was sampled at 1547 mSML gas, oil and water at 1551.2 mMSL.

Well 31/2-3

Logs:	GOC:	1545 mMSL	This GOC is form dens./neutron logs.
		1547 mMSL	This GOC is indicated from CPI.
	OWC:	1560 mMSL	50% water
		1564 mMSL	No movable hydrocarbons on CPI

RFT: No contacts can be established from the presssure points.
Deepest gas point at 1545.2 mMSL. Gas was sampled at 1543.5 mMSL.
Highest pressure point that fits to the water line is at 1560.4 mMSL.

The list above shows that the logs can more precisely than the RFT measurements define the fluid contacts. The reason is lack of pressure measurements in the oil zone except for 31/3-2.

The RFT data for the abovementioned wells plus 31/6-1 and 31/2-12 has been plotted to show the similarities/differences in pressure between the wells. This is shown in figure 2a.

It has to be noted that different types of gauges have been used for the wells. For wells 31/2-3 and 31/2-6 strain gauges are used, for wells 31/3-2 and 31/2-12 HP gauges while for wells 31/3-1 and 31/6-1 Flopetrol SDP/CRG crystal gauges are used. The two latter gauge types are of a higher quality than the strain gauges.

The difference between the wells are within 1 bar, which, bearing the comment above in mind, is not enough to conclude on different pressure regimes. There is on the contrary found to be differences between strain gauges and crystal gauges run together in the same well of the same order.

The data has therefore been replotted after adjusting all wells to a *common* water point at 1570 mMSL. This is shown in figure 2b. This figure does not give any justification to conclusion on different pressure regimes between the wells.

It should be noted that TVD corrections have been applied, and that no anomalous differences between drilled and true vertical depths, which can be caused by rig ballasting and tidal changes, have been recognized (see Table 1).

2.2 Juxtaposition of reservoir units the faults

The following fault throws, formation thicknesses and gross gas pay (on footwall blocks) have been interpreted near to the faults in positions A, B and C (Fig. 1):

		A	B	C
Throw on fault on top SOGNEFJORD FM	(m)	70	170	60
SOGNEFJORD FM	(m)	135	130	130
HEATHER FM UNIT B	(m)	25	25	30
FENSFJORD FM	(m)	125	150	150
Gross gas pay on footwall block	(m)	60	180	180

The fault at A has SOGNEFJORD FM in juxtaposition with itself over the HC-contacts. In positions B and C the SOGNEFJORD FM is in juxtaposition with the FENSFJORD FM over the HC-contacts.

Hence it is likely that across all three faults high poroperm sands are juxtaposed over the HC-contacts. We conclude, therefore, that juxtaposition of reservoir rocks with potential sealing lithofacies across the fault is unlikely, and does not provide an explanation for the varying oil leg thicknesses.

2.3 Micro-tectonic study 31/6-1

Gabrielsen (1984, SG Re. 125) performed a pilot study on deformation style and permeability reductions associated with micro-fractures in the reservoir in well 31/6-1.

His main conclusions are:

1. Fracturing of the reservoir which involves grain reorientation, mineralization and some grain size reduction can lead to a reduction in permeability.

2. Fractures of this kind are concentrated in steeply dipping swarms, which can be best described as fault zones.

3. The total effect of such fault zones is the sum of the effects from each fracture, i.e. permeability reduction increases with the width of the fault zone.

4. It is not yet possible to quantify the effect of fracturing on permeability reductions. It is, however, tentatively interpreted to be about one order of magnitude (Fig. 3).

5. Based on preliminary results from 31/6-2 clay smearing cannot be ruled out as an additional mechanism capable of leading to reduced permeability.

2.4 Cemented fault zone in well 31/3-2

The seismic interpretation (Fig. 4) indicates that well 31/3-2 penetrated a fault zone (the border fault between Troll east and west) just above or within the upper part of the BRENT interval in the footwall block.

On the velocity log (Fig. 5) LDL-CNL (Fig. 6) and ISF-sonic (Fig. 7) two cemented intervals (4 and 6 m thick on sonic log) are recognized. Not only is 6 m considered to be exceptionally thick for a cemented zone within the Troll area, but no similar cemented zone has been observed before at this particular stratigraphic level.

Another indication of the two cemented bands being associated with a steeply dipping fault zone is the fact that the sonic and ISF logs show quite different thicknesses on the same bands (Fig. 7). This may be explained by the sound waves taking the fastest path through the formation, in this case being the steeply dipping high velocity calcite cemented bands, to a critical distance above and below the actual intersection of the bands with the bore hole. Based on ISF thicknesses (2 and 3 m), the actual thickness of the cemented bands have been calculated (1.1 and 1.7 m) using a 55° dip on the fault (Fig. 8). The velocity log gives a seismic tie at 1.943 sec TWT to the top of the uppermost cemented band, which ties closely with the fault zone interpreted in the seismic. Accordingly, the cemented zones are interpreted to be intimately related to a fault zone.

To further document that the well has penetrated a fault zone the following table was made.

INTERVAL THICKNESSES

Well	Top FENSFJORD FM - top ETIVE FM interval (m)	BRENT GP. (m)	Top KROSSFJORD FM - top BRENT GP (m)
31/3-2	241	66,5 <	88,5
3-1	310*	37,5*	128,5*
	d = 69	d =69	d = 40
2-1	352	107	146
2-2	337	94	138
2-3	309*	106*	137*
	d = 68	d = 39.5	d = 49.5
2-4	345	124	123
2-5	342	125	135
6-1	302	30	85
6-2	328	44	75
6-3	301.5	42.5	175.5
6-5	328.5	37	138.8
5-2	318	78.5	132
5-3	320	158	97.5

* = wells closest to 31/3-2.

d = difference in thickness between actual well and 31/3-2

The table clearly shows that compared to wells in the vicinity, well 31/3-2 has an anomalously thin top FENSFJORD FM - top ETIVE FM interval. The same is true for the top KROSSFJORD FM - top BRENT GP interval, both are taken to indicate that section is missing in 31/3-2. The BRENT GP interval is thin and has fairly similar thicknesses in the Troll east wells compared to the Troll west wells which can be explained by depositional thinning by eastern onlap of this interval. The seismic suggests, however, that the uppermost part of the

BRENT GP may be missing in 31/3-2. The interpretation of the top BRENT GP reflection indicates a net slip on the fault of 35 ms TWT. This corresponds to a throw of 53 m, using an interval velocity of 3000 m/s. Picking uncertainty at top BRENT level amounts to ± 15 m. This throw corresponds reasonably well with the missing section within the top FENSFJORD FM - Top ETIVE FM interval (about 70 m) and the missing section from the top KROSSFJORD FM - top BRENT GP interval (40 - 50 m).

The SHDT dipmeter log (Fig. 9) has been interpreted over the interval where the fault may have been penetrated. The relatively high and chaotic dips (yellow) recorded between 1945 and 1955 mRKB are the most striking feature of the dipmeter log. A distinct red pattern immediately above, and a blue pattern below this chaotic zone can also be recognized. Both the red and blue patterns are interpreted to be structural in origin. The red pattern appears to be independent of the stratigraphy as the top BRENT GP boundary is located within it. The lithologies within the high dip blue pattern are interbedded coals and claystones, precluding a sedimentological explanation for the blue pattern.

The azimuths within the red and blue patterns are to the south whereas the azimuths within the green pattern above and below are to the north and northeast. The border fault was active in TERTIARY hence it was a post-rift normal, fault probably planar, where associated normal drag could be expected along the fault plane. Fig. 10 shows how these observations have been used to picture a structural model of the fault zone.

We conclude that well 31/3-2 probably penetrated the NW-SE trending border fault between Troll east and west at top BRENT FM level, between 1940 and 1955 mRKB. The two cemented bands within this interval are interpreted to indicate that cementation along the fault zones has occured.

The well 31/2-8 has also penetrated a NE-SW trending fault zone within the JURASSIC interval (TARBERT FM). This can be recognized on the seismic and the dipmeter log. No cementation can be seen on the logs associated with this fault zone.

2.5 Match of 31/3-2 well test

The model

A 3-dimensional radial model of 180 degrees consisting of 11 x 2 x 16 gridblocks was used in the study. Fig 11 shows the location of the grid, the symmetry plane and the division into two different regions. Region 1 (60^{o}) has a dip of about 4^{o} while region 2 (120^{o}) is almost flat.

To obtain the initial GOR of 344 Sm^3/Sm^3 a thin gas layer of 0.2 m was put on top of the oil column at the well. This layer is completed.

Fig. 12 shows the simulation model. The thickness of the oil column is 11 m, while the gas column in region 1 varies from 0.2 m a the well to 15.6 m at the external boundary. Region 2 contains a gas layer of 0.2 m in radius of R_2 = 105 m from the well. From R_2 to R_e no gas is present.

Rock properties (table 2) are averaged values from core measurements where such data are available (1542.5 - 1550.5 and 1556 - 1565 mMSL) In the remaining intervals log data has been used.

Fig. 13 shows the gas-oil-ratio and the bottom hole pressure vs. time relationship obtained in the well test and in the simulation study.

Sensitivity studies

The two radii R_1 and R_2 (Fig. 12) are important parameters controlling the GOR behavior during the siumulation. Sensitivity studies have shown that R_2 determines the shape of the GOR-curve before gas break through and R_1 determines the time at which gas break through will occur.

Fig. 14 indicates the gas advancement towards the well during production. Initially gas is only produced from layer 1. Due to the restricted volume of gas present in region 2, GOR decreases as the gas from this area is produced. A reduction of R_2 results in a smaller recoverable gas volume from region 2 and hence a faster decline of the GOR-curve.

The gas in region 1 advances towards the well through layer 2 and 3. The time at which the gas reaches the well is dependant on the mobility of the gas and the distance R_1 from the well to the dip. Thus different R_1's will result in BT at different times. From these observations R_1 was determined to be 34.5 m and R_2 to be 105 m.

Sensitivity studies on permeability showed that to obtain the initial GOR a kh-product of about 500 mD-m in layer 1 was required. The initial gas rate and the level of the GOR-curve were strongly influenced by variations of the permeability in the different layers, but the shape of the GOR curve remained almost unaltered.

Conclusions

1. A geological model which gives an acceptable match of the GOR vs. time relationship has been developed.

2. To obtain a reasonable match of the well test a gas layer of 0.2 m was introduced at the top of the completion interval.

3. The simulation result has been obtained by varying the distance, R, from the well to the dip and the volume of gas determined by the radius R^{2-}, recoverable from the "flat part" of the model.

4. The model verifies the assumption of a gas oil contact at 1542 mMSL.

2.6 Mapping in the 31/3-2 area

SH, ST, SG and NH have performed general mapping of the area by using a 1 x 1 km deep seismic grid (8007 & 8116). Only SG and NH have carried out additional detailed mapping of the 31/3-2 area based on a water gun survey (NH 8366) with a 200 m line spacing (Fig. 11 and Encl. 1).

The general mapping show no major differences between the interpretations done by the four companies in the northern communication area. All interpretations show no communication within the gas phase. There are significant differences in the general mapping, however, in the southern communication area. Here NH, SG and SH have interpreted communication between Troll east and west within the gas phase whereas ST has no communication. We anticipate that when the watergun data, which is currently being processed, is interpreted by all four companies, the resulting maps will be more similar than at present. Only ST has mapped an additional NE-SW trending, SE hading fault, with a 40 m net slip, within the gas area some 2.5 km SE of well 31/3-2. According to ST's interpretation this fault defines the southeastern limit of a small fault compartment within which 31/3-2 was drilled.

3. INTERPRETATION

The 2-3 m difference between 31/2-6 and 31/3-2 HC-contacts, the 2.5-6.5 m difference in OWC and the 4 m difference between GOC in 31/3-2 and 31/3-1 have to be given a geological explanation. A geological explanation has also to be given for the variations in oil-leg thickness.

The juxtaposition of reservoir and non-reservoir lithologies across the faults is not regarded as a viable explanation of the different HC-contacts and oil leg thicknesses in this area of the Troll field. The required stratigraphic geometry across the faults is not present.

The most obvious explanation is one of sealing faults caused by diagenesis and different types of deformation along the fault planes (Fig. 15). Sealing faults may enable slightly different pressure regimes to develope within each fault compartment and hence produce different HC-contacts and oil-leg thicknesses.

4. CONCLUSIONS

Based on 31/3-2 results as enlarged above and earlier investigations the following conclusions, may be listed:

- 31/3-2 penetrated the border fault between Troll East and Troll West at Brent gp level.

- This fault zone is highly cemented.

- Seismic flatspot terminates immediately south of 31/3-2 as interpreted on airgun and water gun surveys.

- Both fault A (70m net slip) and fault C (60 m net slip) are planar normal faults having a NW-SE trend and were both active in early Tertiary.

- TVD conversions in all wells on Troll have confirmed that the OWC in 31/3-2 is 3.5 m shallower than the OWC in 31/2-6, being on the north side of fault A.

- Capillary pressure contrasts between the sediments on each side of fault A cannot explain the difference in OWC between 31/3-2 and 31/2-6. High poroperm Sognefjord fm is in juxtaposition over the fault. Highly cemented fault zone is the most probable cause.

- Pressure data from the wells in the area have not a satisfactory reproducibility and resolution to diagnostically decide if the pressure regimes are different in the different fault compartments.

- A simulation of the 31/3-2 oil test demands a 0.2 m thick gas column in the uppermost part of the perforated interval to match the GOR-development during the real test. This indicates a 11 m oil column.

- GOC in 31/3-1 is almost similar to the nearest Troll West wells. The oil column in 31/3-1 is some 1.5-4.5

m thick, however. Cementation along the fault zone C between 31/3-1 and 31/3-2 may cause this difference.

- If the changes in HC contacts occur over fault zones A and C, seismic mapping shows that the fluid contacts as seen in 31/3-2 represents the HC contacts in northern, triangle formed, fault compartment in Troll East (approx. 10 km^2).

- Assuming 11 m oil column and average 31/2 reservoir parameters some 30 x 10^6 Sm^3 OIP may exist in this compartment.

- 31/3-2 and 31/3-1 show different development of the Sognefjord fm. This facies change may take place in the oil-triangle south of 31/3-2. The facies change may have bearings to the producibility of the thin oil column.

5. RECOMMMENDATIONS

NH should drill a well (31/3-4) in the southern part of the oil-triangle in 1985. The well should be located north of, but near fault C, between well 31/3-1 and 31/3-2. A vertical borehole will be drilled to TD in the Drake fm. Then the well will be plugged back, side tracked and deviated southwestwards to penetrate fault zone C in the gas interval. Both boreholes should core the reservoir interval and the fault zone.

The objectives are:

1) To document the GOC in northern fault compartment in Troll East.

2) To core a fault zone in HC-bearing part of the reservoir.

3) To perform RFT pressure measurements in the gas zone on both sides of the fault.

4) To investigate the lateral extension of reservoir layers in a detail only achievable by drilling of production wells.

5) To investigate where the changes in sedimentary facies in the Sognefjord fm between 31/3-1 and 31/3-2 occur.

6) To perform a production test within the oil zone.

The outlined procedure is untraditional, but may give data concerning communication barriers within the reservoir with implications to the total Troll depletion. If results with significant implications are obtained, they have to be applied in the depletion plan phase II.

Table 1

Difference (in dm) between Drilled Depth (DD) and True Vertical Depth (TVD) over the HC contacts in the Troll wells.

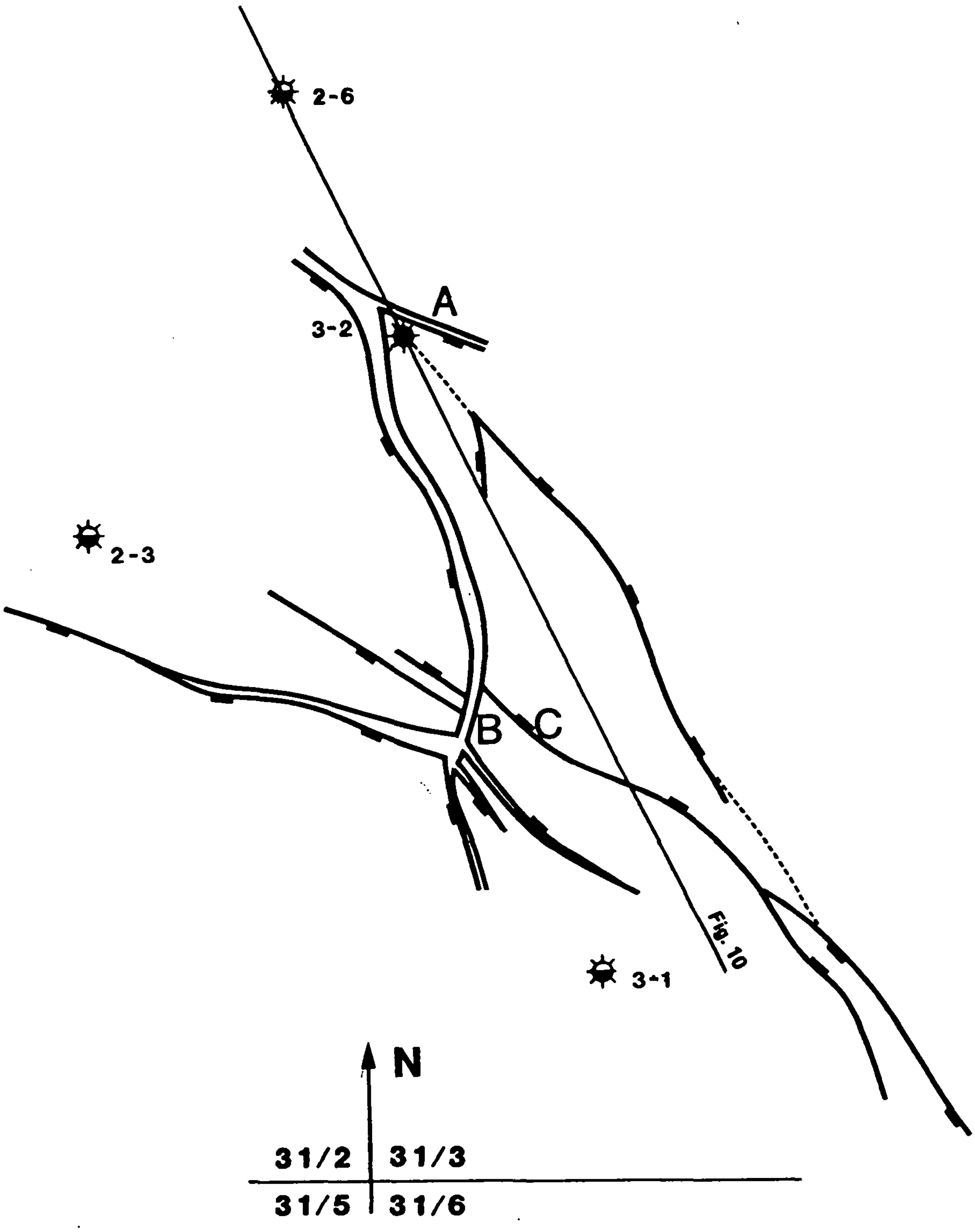
	DD-TVD (dm)
31/2-1	1
-2	1
-3	1
-4	.5
-5	.5
-6	1
-7	.5
-9	1.5
-11	1
-12	2
-13	2277 (Deviated 45^{o})
-14	0
31/3-1	1.5
-2	1
31/6-1	3
-2	.5

Table 2 Rock properties

Layer	Interval m - MSL	Thickness m	K_H mD	K_V mD	Ø %	S_{iw} %	
1	1541.8 -1542	0.2	2625	2025	24.7	43.0	GOC
2	1542 -1542.75	0.75	3500	2700	23.9	24.0	
3	1542.75-1544	1.25	3500	2700	29.6	24.0	
4	1544 -1545.5	1.5	8.5	4.6	23.9	43.0	Perf. int.
5	1545.5 -1546.25	0.75	44	11.0	25.1	43.0	
6	1546.25-1547	0.75	2436	2436	23.9	24.0	
7	1547 -1548	1.0	8737	4841	23.9	24.0	
8	1548 -1549	1.0	5330	6880	23.9	24.0	
9	1549 -1550.5	1.5	3000	3000	25.6	24.0	
10	1550.5 -1552	1.5	3000	3000	27.0	24.0	
11	1552 -1553	1.0	3000	3000	26.3	24.0	WOC
12	1553 -1553.5	0.5	3000	3000	17.3	100.0	
13	1553.5 -1554	0.5	3000	3000	17.3	100.0	
14	1554 -1557	3.0	4533	3606	25.0	100.0	
15	1557 -1558	1.0	3000	3000	26.9	100.0	
16	1558 -1908	350.0	500	125	28.0	100.0	

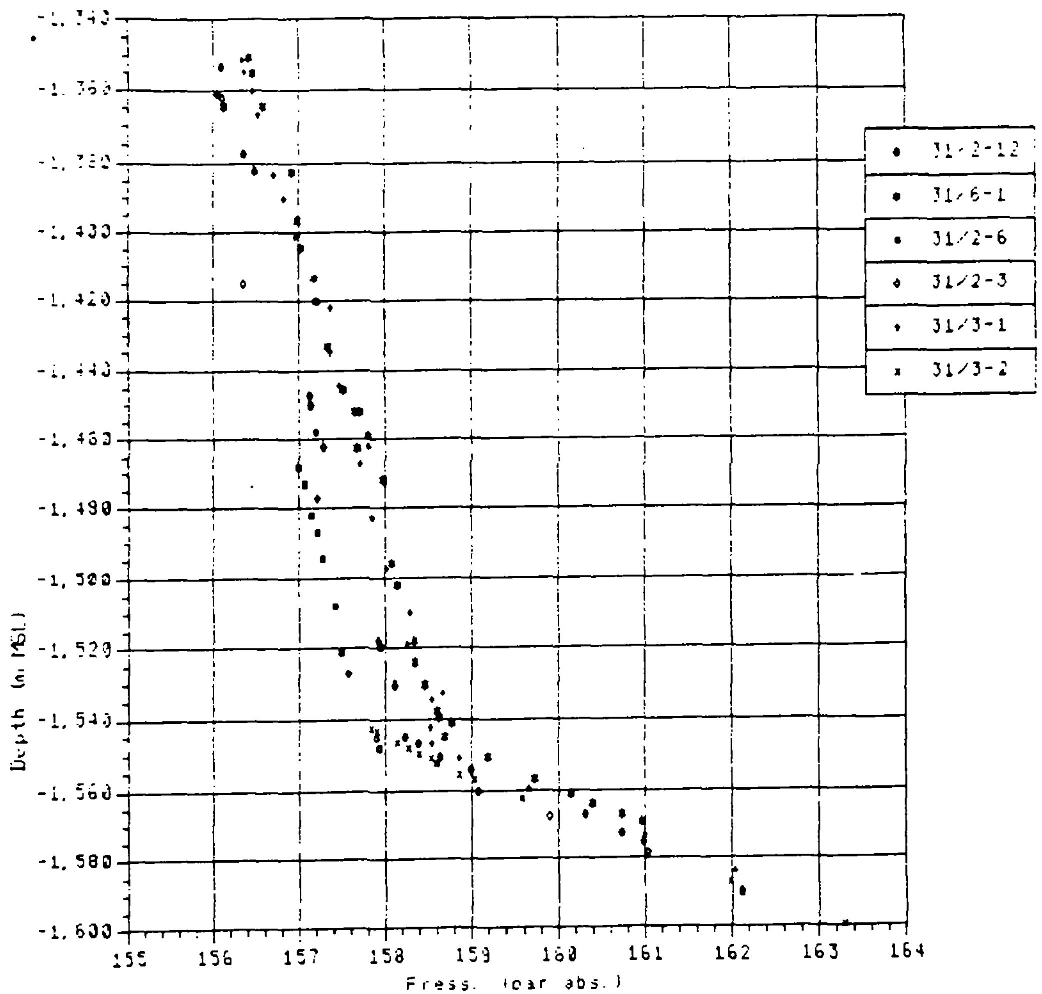
Note: Layer 9,13 and 15 contain tight streaks with radius 19.7 m
Horisontal and vertical permeability = 0.05 mD

Index map



1 : 100 000

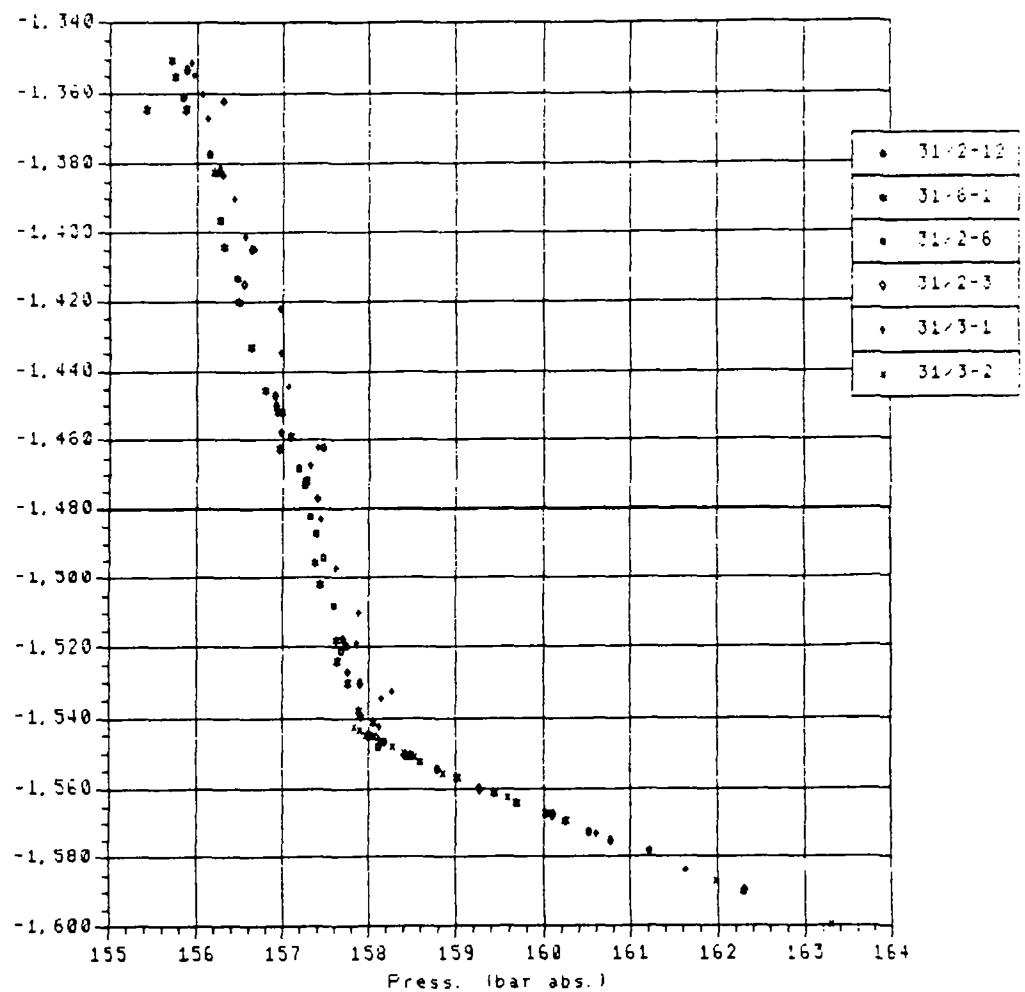
TROLL



a

TROLL

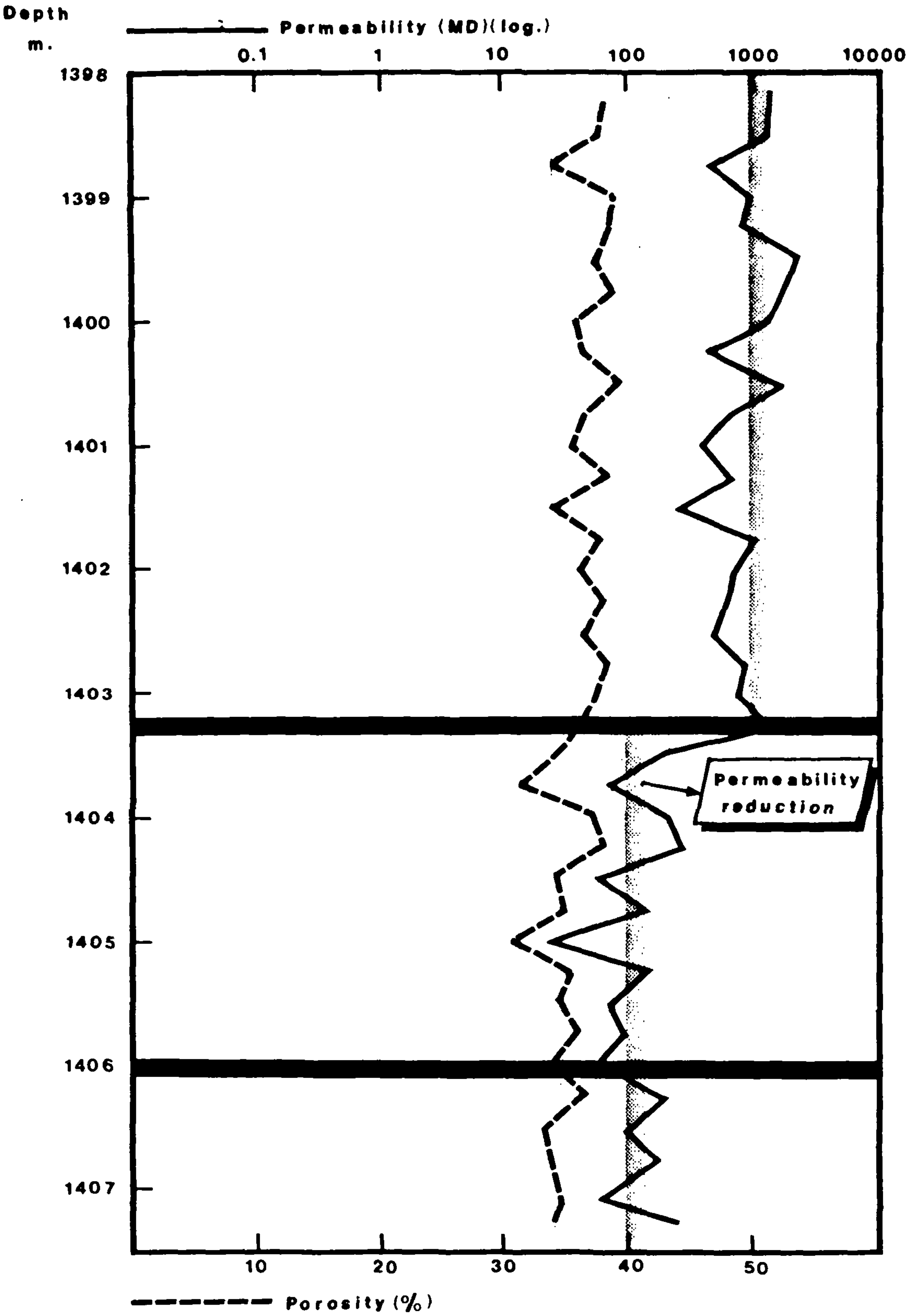
Common water point at 1570m MSL



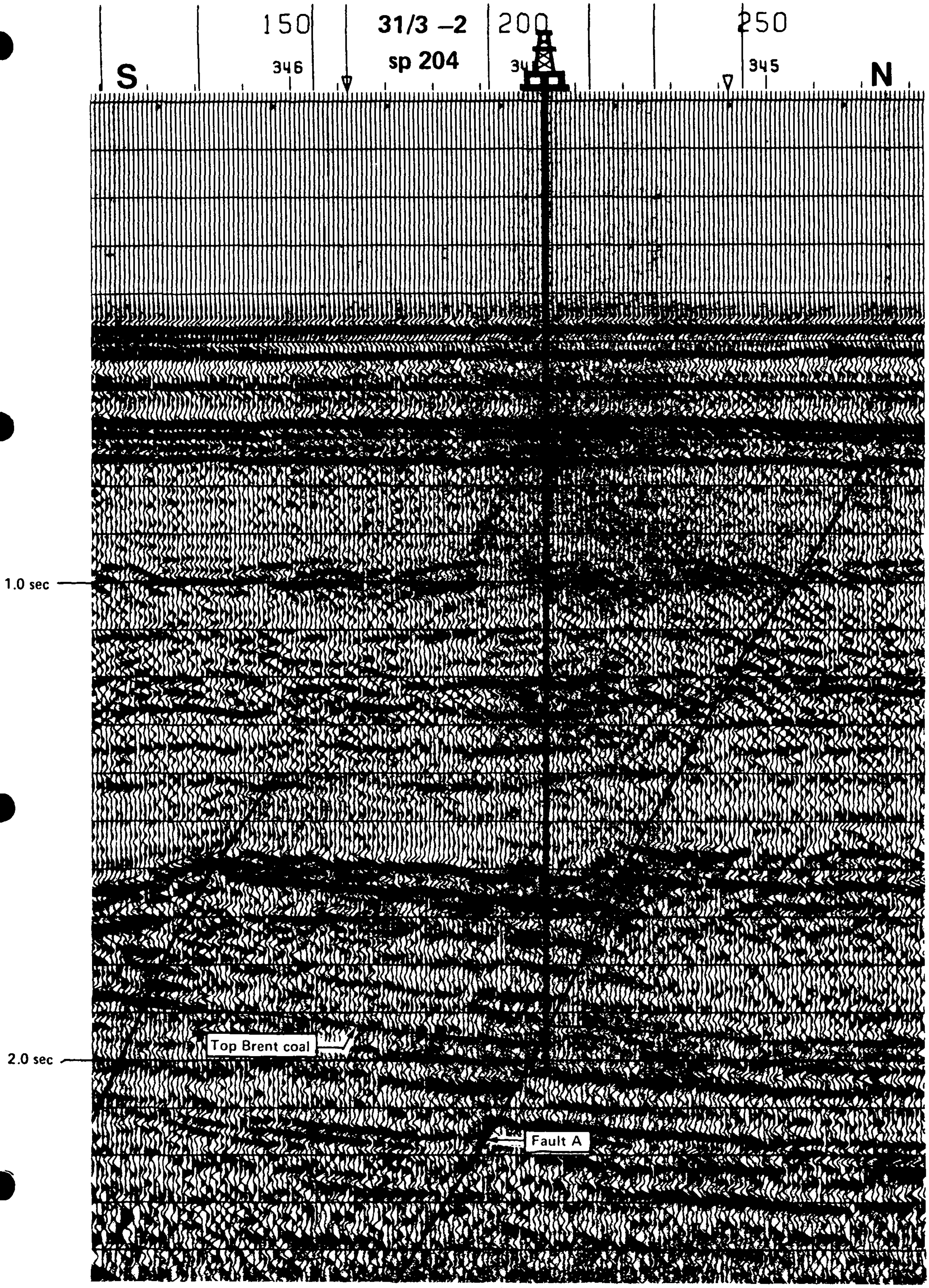
b

Fig. 2

31/6-1


Depth
m.
Permeability (MD)(log.)
0.1
1
10
100
1000
10000
1398
1399
1400
1401
1402
1403
1404
1405
1406
1407
Permeability
reduction
10
20
30
40
50
Porosity (%)

ST 8007-338 Seismic interpretation of fault A



Velocity log

Well 31/3-2

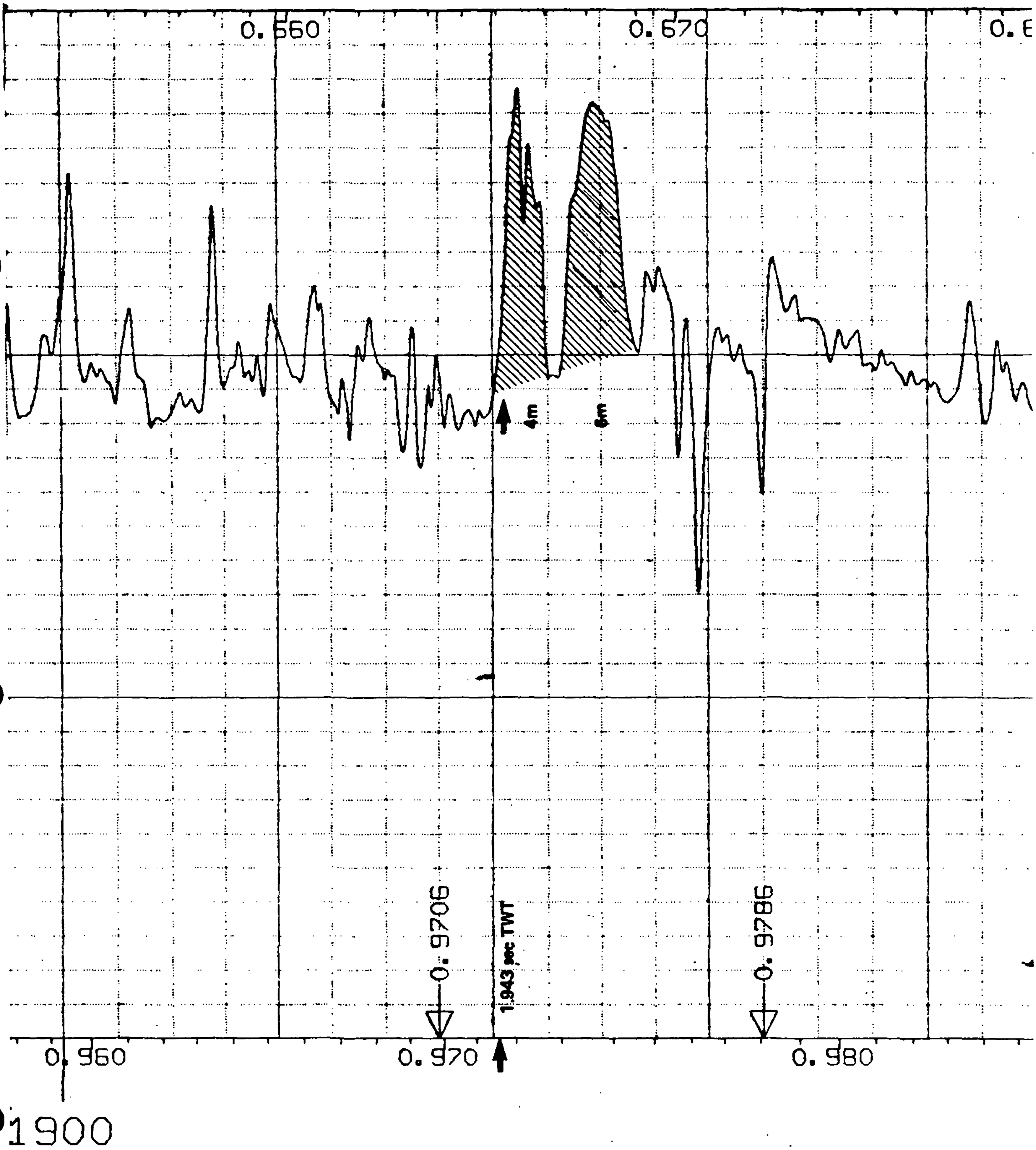
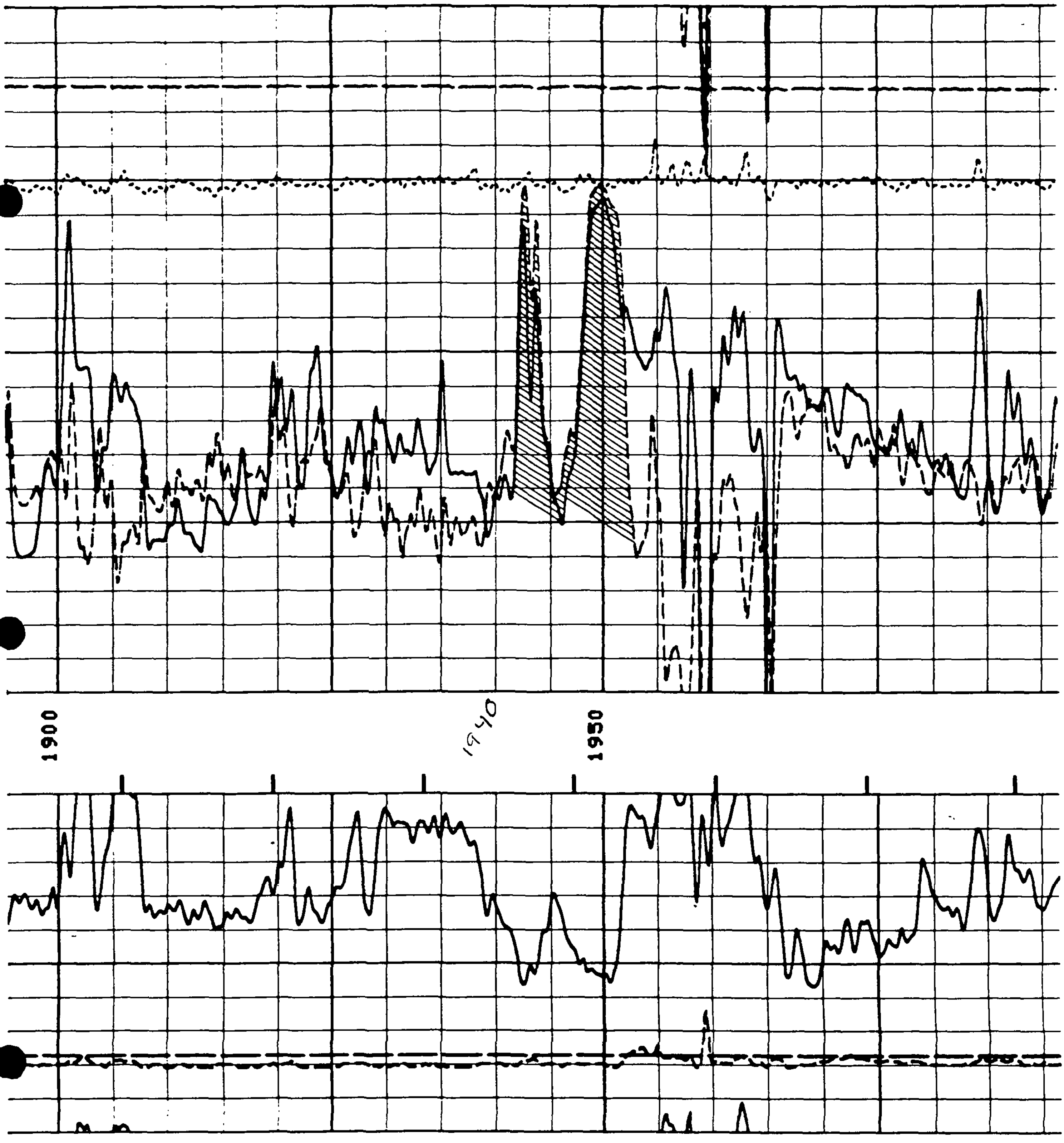


Fig. 6

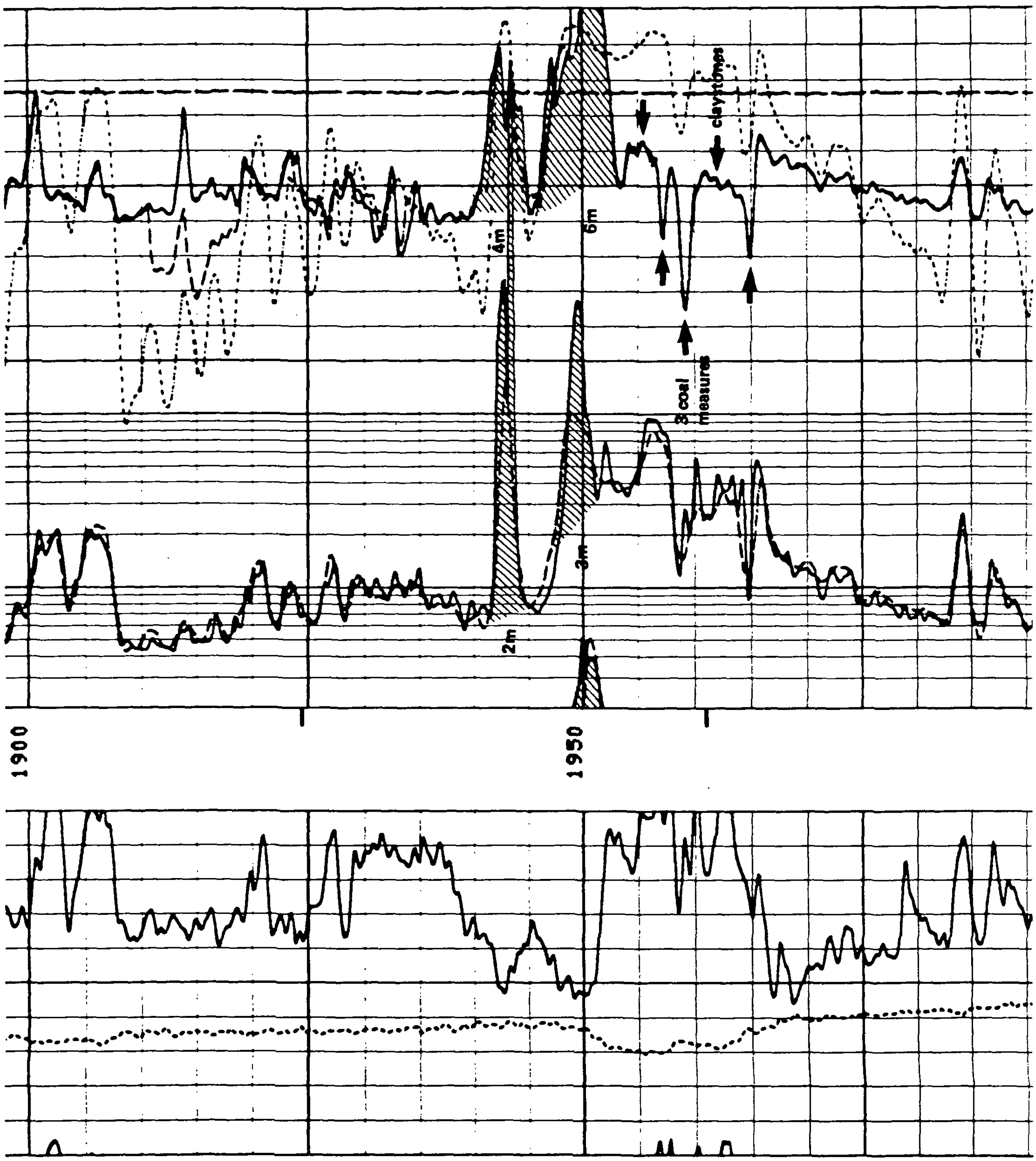
LDL - CNL - GR

Well 31/3-2

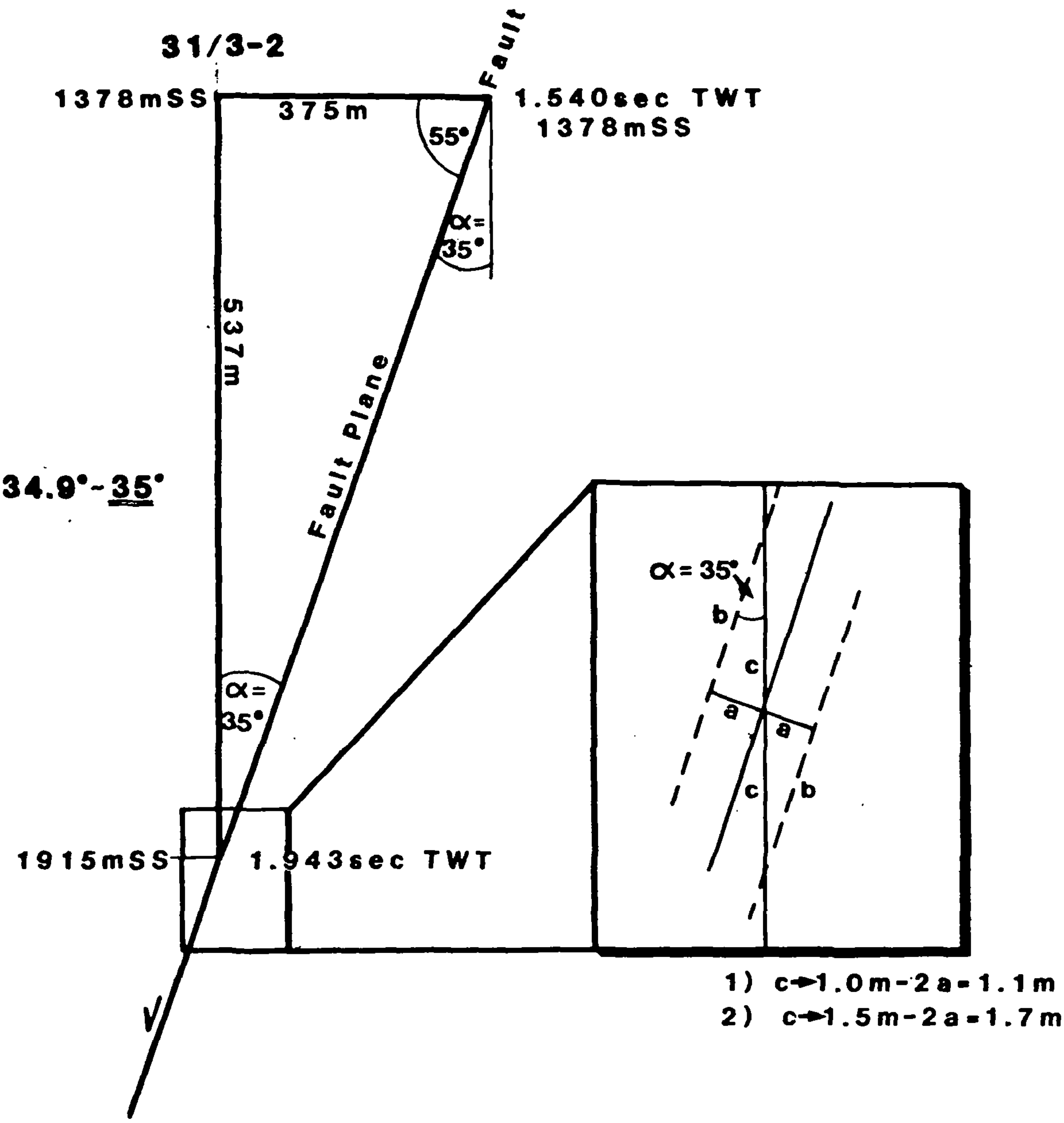


ISF - LSS - GR

Well 31/3-2



Calculation of real thickness of cementation along border fault



$tg\,\alpha = \frac{375}{537} \leftrightarrow \alpha = 34.9° \sim \underline{35°}$

1) UPPER FAULT ZONE:

$c = 1.0 \rightarrow \underline{2a} = 2 \times \sin 35° \times c = 2 \times 0.574 \times 1.0 = \underline{1.1\,m}$

2) LOWER FAULT ZONE:

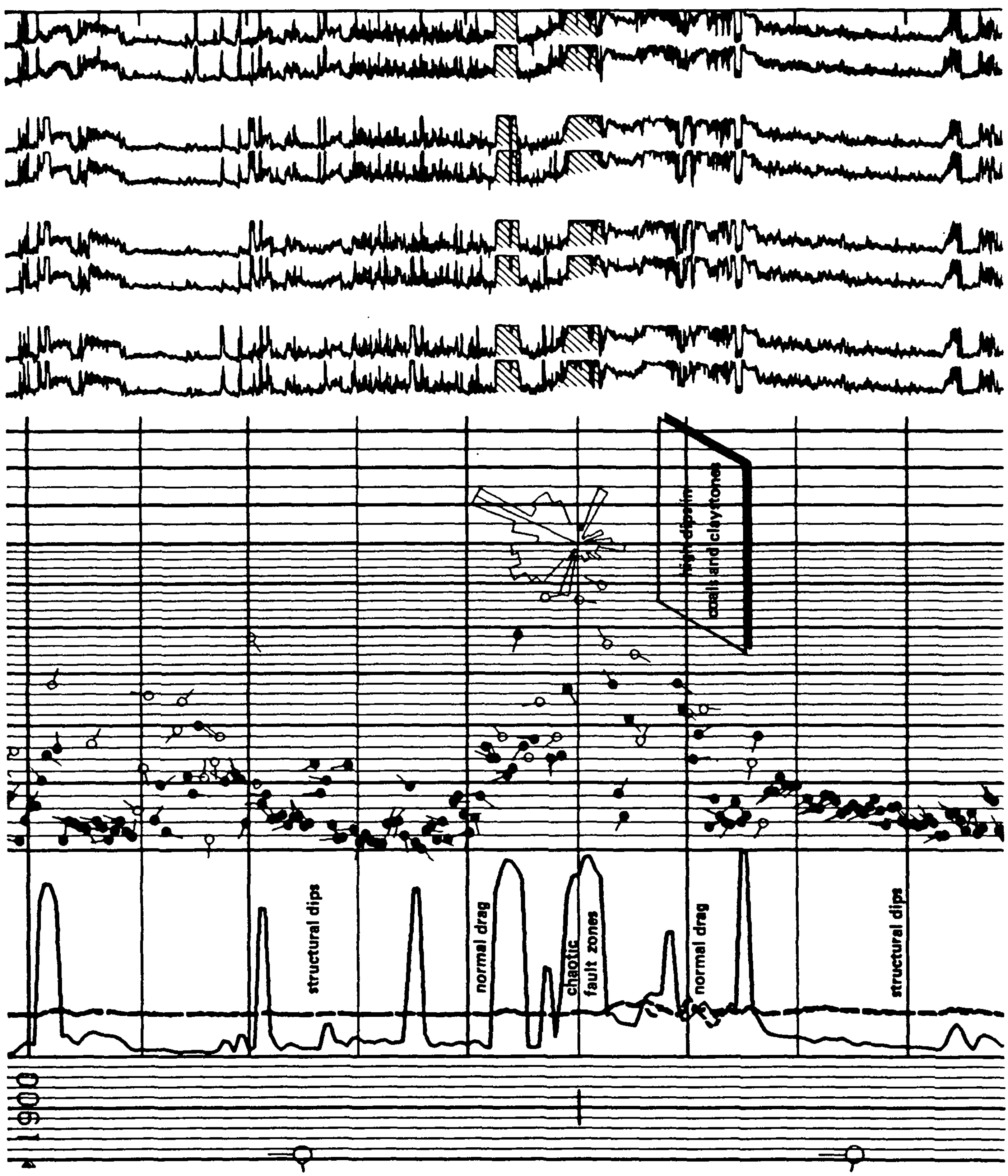
$c = 1.5 \rightarrow \underline{2a} = 2 \times \sin 35° \times c = 2 \times 0.574 \times 1.5 = \underline{1.7\,m}$

C is taken from the ISF-log: reading the thinnest and probably the most realistic thickness of the cemented fault zone.

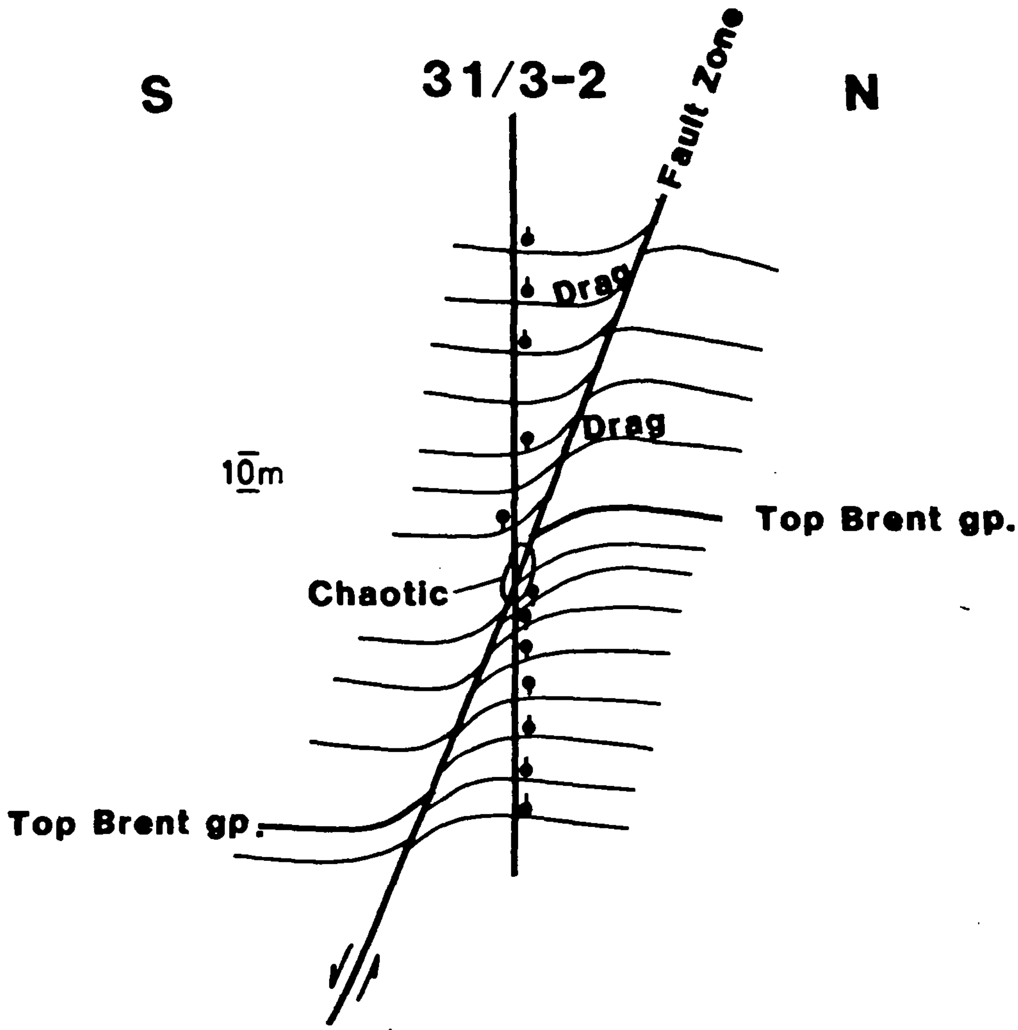
SHDL

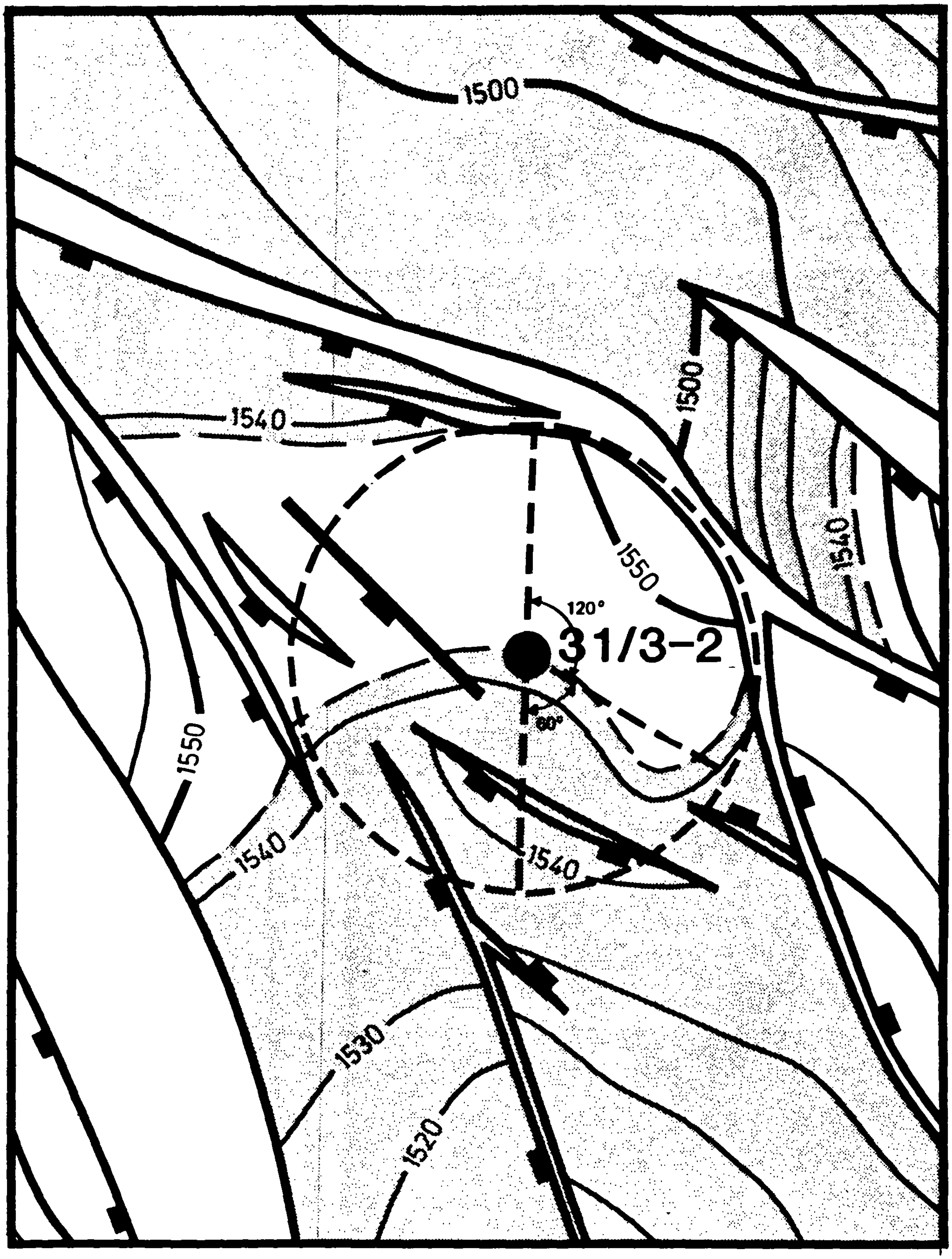
Stratigraphic high – resolution dipmeter log

Well 31/3–2



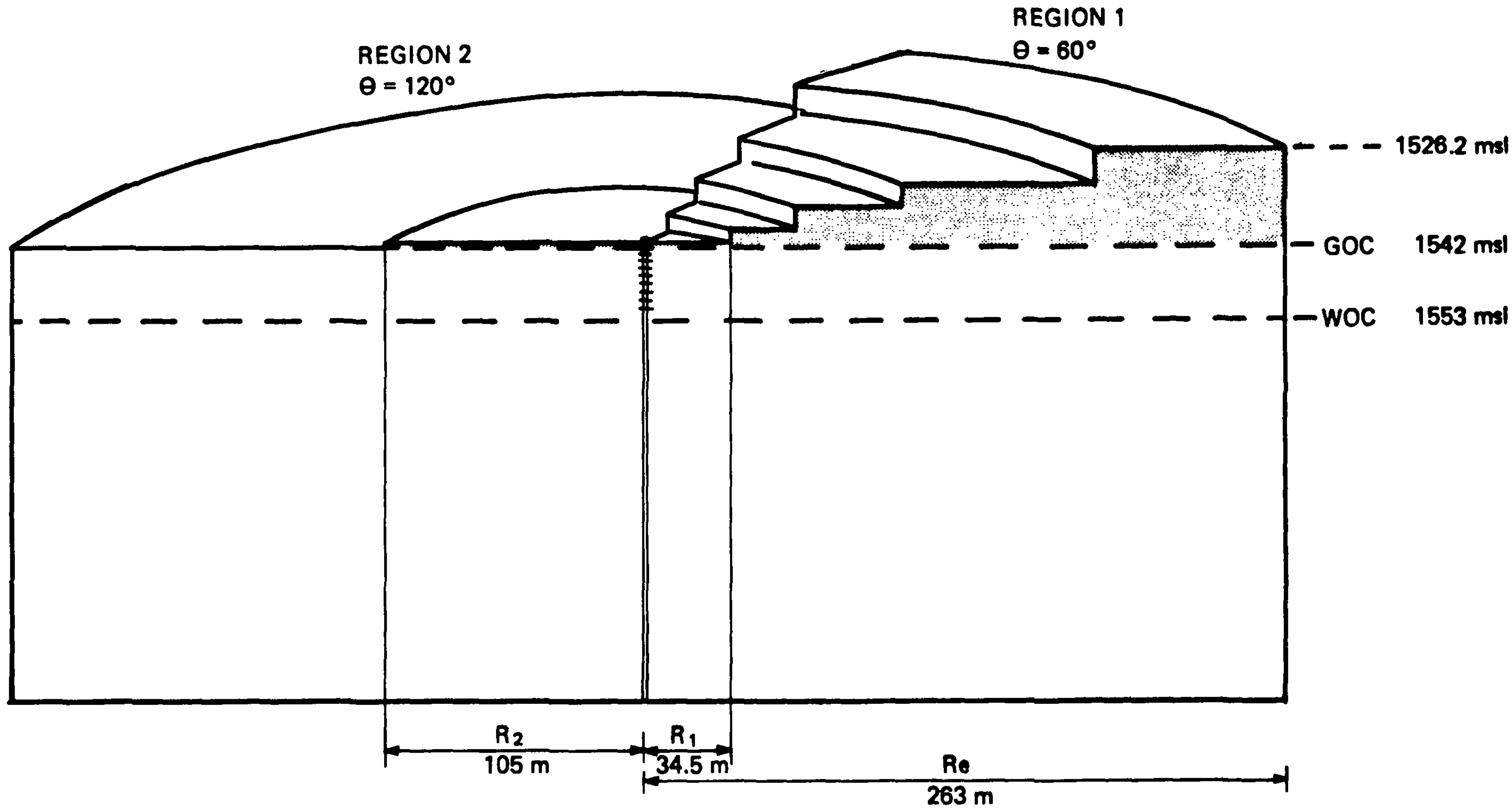
Detailed structural model based on dipmeter results :



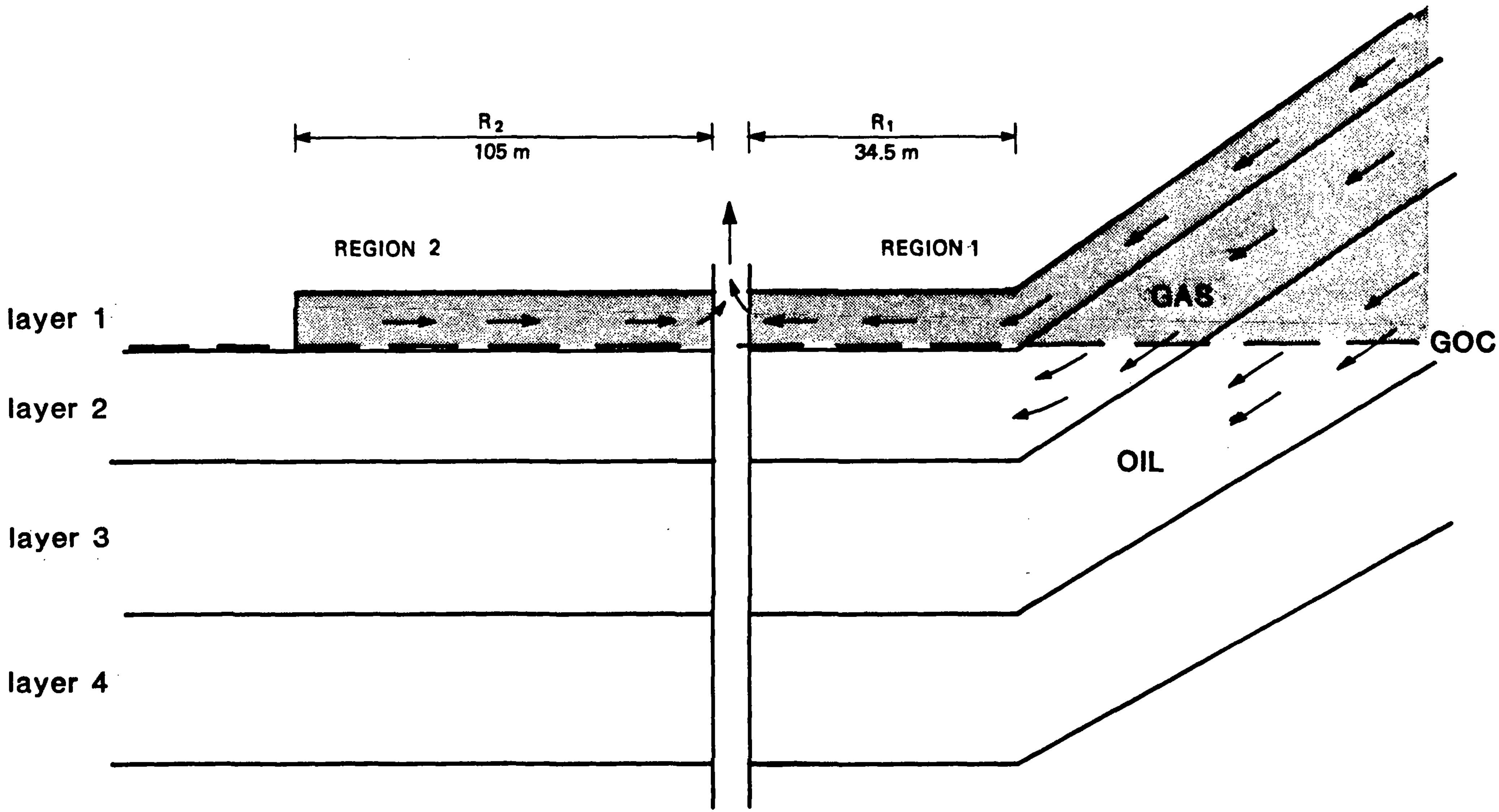


Location of grid
(SG's depth map)

Scale 1 : 6250



The simulation model



Gas advancement towards the well

Fig. 14

Geo-section and fluid contacts ST8007-405

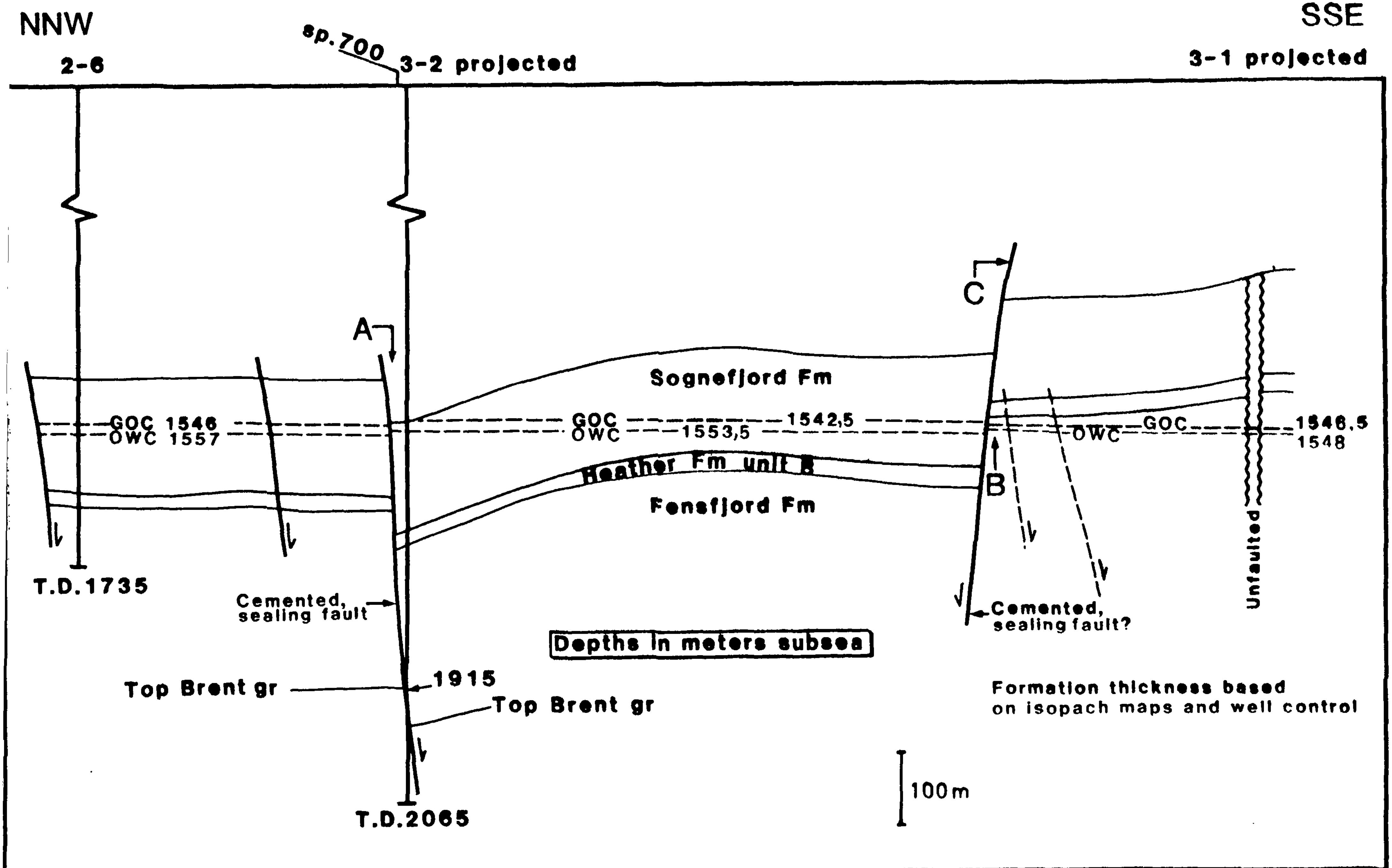


Fig. 16