EXPLORATION
LOGGING

NORSKE GULF PRODUCTION COMPANY A.S.

3/5-1 AND 3/~~5-2~~

FORMATION PRESSURE EVALUATION REPORT

CONTENTS

FORWARD

Although every effort is made to ensure the accuracy of our data, certain of our calculated values should be regarded as best estimates and any assumptions made in connection with their derivation will be more fully explained during the course of this report.

INTRODUCTION

		3/5-1		3/5-2
LOCATION	Latitude:	56° 37' 26"N		56° 32' 34"N
	Longitude:	04° 25' 12"E		04° 23' 11"E
WELL SPUDDED:		3rd May 1978		29th June 1978
REACHED T.D.:		21st June 1978		16th August 1978
DEPTHS REFERENCED TO RKB				
MEAN SEA LEVEL:		83 ft.		83 ft.
SEA BED:		292 ft.		303 ft.
MUD LINE:		287 ft.		298 ft.
DRILLERS T.D.:		11,234 ft.		12,551 ft.
GEMDAS OPERATORS:		Ian Lisseter	-	Ian Lisseter
		John Hopkins	-	John Hopkins
		Dave Law	-	Dave Law
		Colin Newton	-	Colin Newton
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LOGGING GEOLOGISTS:		Ray Burr		
		Steve Evans	-	Steve Evans
		Chris Rogowski	-	Chris Rogowski
		Brendan Arnold	-	Brendan Arnold
		Phil Houston	-	Phil Houston
				Paul Jennings
				Martin Dru

GEOLOGICAL SETTING

The wells were located on the western margins of the Fyn - Ringkobing High, adjacent to the Central Graben of the North Sea. Norske Gulf 3/5-2 is situated in a downfaulted trough, striking approximately NNW-SSE, while the 3/5-1 well lies on the uptilted block some 11 km to the North East.

SUMMARY OF MAJOR POINTS OF INTEREST

In both wells there is a broadly similar development of overpressures. The first is found in the Lower Tertiary and the pressures here are isolated from the rest of the succession by the limited permeability of the intervening Chalk formation. Below the Chalk the successions diverage in character, reflecting the positive or negative nature of the underlying blocks. However, in both cases, the second overpressure is initiated in the Lower Cretaceous Valhall Shales and continued into the underlying formations. (See figure 1).

In 3/5-1 the top of the first overpressure was identified at 5,500 ft and showed a sharp transition to 10.6 lb/gal equivalent at 6,000 ft. A further increase occurs from 6,500 ft and the formation pore pressure rises to 10.8 lb/gal equivalent by 6,800 ft.

The Tertiary succession in 3/5-2 is somewhat thicker and the top of the transition zone is first seen at 5,000 ft. The pore pressure here shows a slower rate of increase, rising to 10.3 lb/gal at 6,000 ft before levelling out. Once again here is a second increase, in this case beginning at 7,000 ft and reaching a maximum of 10.9 lb/gal at 8,000 ft.

The pattern of overpressure development in the Tertiary is most probably due to a rapid rate of sedimentation which inhibited the dewatering of the buried sediments.

The Danian and Chalk successions, being uncomformably overlain by the Tertiary and, in the absence of any contrary evidence, are assumed to be normally pressured.

The second overpressured zone of both wells can be identified in the Lower Cretaceous shales, but below these the succession in each location is markedly different and this is reflected in the patterns of overpressure development.

The upward tilting of the block underlying the 3/5-1 location has caused a truncation of the sedimentary record and Upper Jurassic sediments lie directly on the Zechstein evaporites. These form a seal between the Jurassic and Kupferscheifer/Rotliegendes formations and the pressures present in the Jurassic are therefore not transmitted to these latter formations. As a result of these influences there is a sharp rise in pore pressure from normal pressures at 8,900 ft to 11.6 lb/gal at 9,300 ft before a slower rate of increase to 11.8 lb/gal by 9,500 ft.

As would be expected a more complete succession is preserved in the downfaulted trough in which 3/5-2 was drilled. Here the formation pore pressure rises steadily throughout the Lower Cretaceous and Jurassic sections reaching 9.5 lb/gal by 10,250 ft and continuing to increase to 11.5 lb/gal over the interval to 12,000 ft before levelling out in the Triassic.

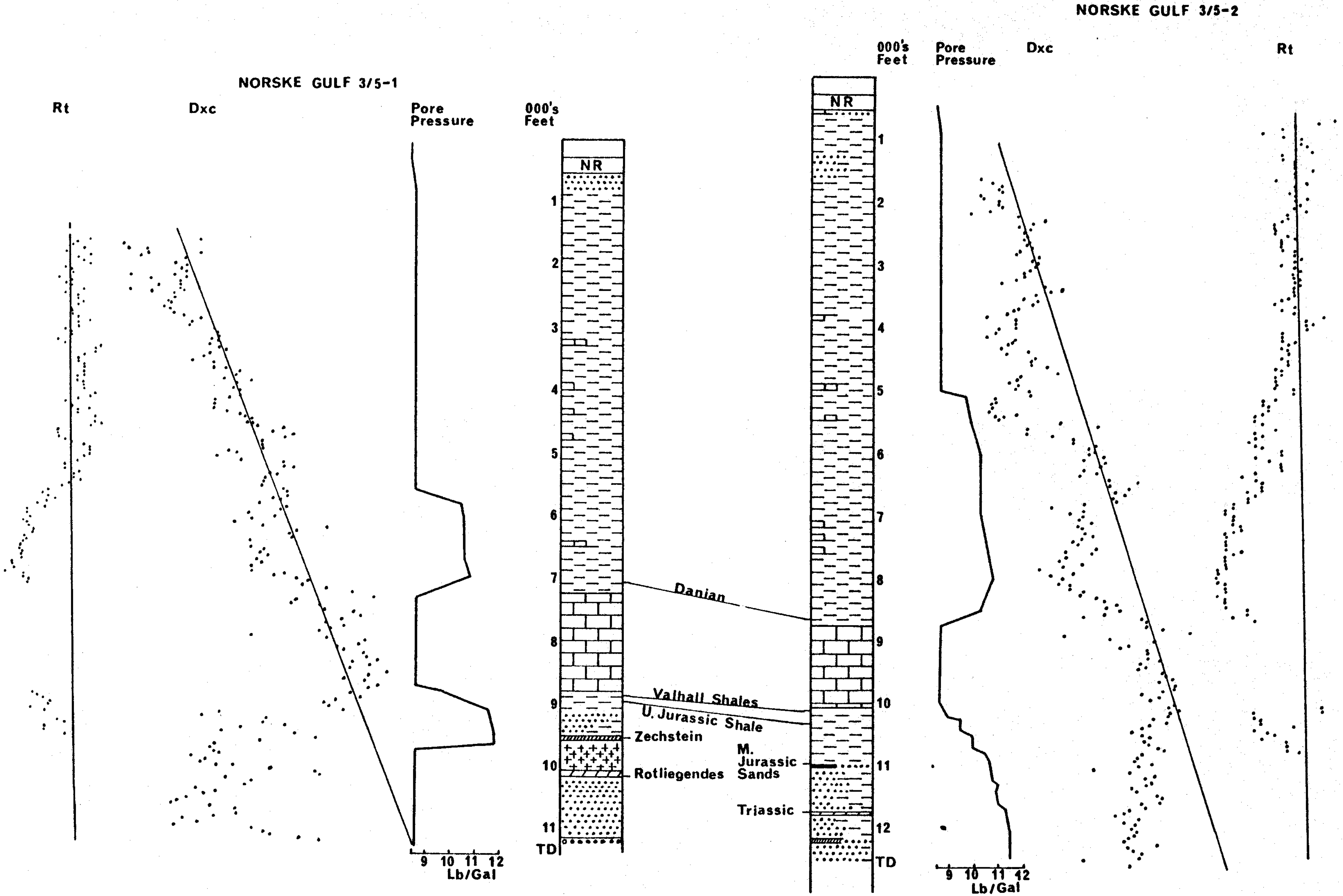
NORSKE GULF 3/5-1
Rt
Dxc
Pore Pressure
000's Feet
NR
Danian
Valhall Shales
U. Jurassic Shale
Zechstein
Rotliegendes
TD
9 10 11 12
Lb/Gal
NORSKE GULF 3/5-2
000's Feet
Pore Pressure
Dxc
Rt
M. Jurassic Sands
Triassic
TD
9 10 11 12
Lb/Gal

Fig.1

3/5-1 PRESSURE EVALUATION

TERTIARY

The poorly consolidated clays and sands of Recent and Upper Tertiary ages found in the surface hole interval allowed the rate of penetration and weight on bit to range widely with consequently erratic values being derived for the drilling exponent. From around 1,700 ft the rocks began to firm up and the Dxc plot became more regular, allowing the establishment of the Trend for a normally pressured formation from which most of the estimates of formation pore pressure were derived. (See figure 1 and Appendix). The plots of sonic log Δt values and flowline temperature remains almost constant throughout this surface section, but the Resistivity Log shows a decrease from 1,100 ft which is probably the result of compaction of the clay minerals and associated dewatering causing an increase in pore fluid salinity.

Accordingly, the pore pressure gradient in this first section was taken to be 8.5 lb/gal equivalent mud weight (average sea water density) and this was gradually increased from 1,100 ft as compaction processes began to affect the density of the pore fluids. By 2,250 ft the 8.7 lb/gal gradient assumed to be the normal for the North Sea area had been attained. All subsequent pressure estimates have been derived by reference to this value.

The succession continued with a homogeneous sequence of sticky clays occasionally interbedded with thin argillaceous and dolomitic limestones. The clays become more consolidated with depth grading to claystone from 4,700 ft and eventually including some shales from 5,500 ft. The plots of Dxc and Shale Density continued to indicate normal pressures down to 5,920 ft where they both showed sharp decreases and an estimated pore pressure of 10.5-10.6 lb/gal was derived from the Dxc. This in fact turned out to be slightly low after tight hole problems and connection gases were observed following a reduction in the mud weight from 10.6 to 10.3 lb/gal at 5,850 ft. Increasing the mud weight back to 10.6 lb/gal cured the tight hole problems, but the connection gas persisted indicating a pore pressure closer to the E.C.D. of 10.6-10.7 lb/gal.

After the Electric logs were run and the values for Rt and Δt plotted it was apparent that the top of the overpressure was much higher as both Rt and Δt plots diverge suddenly from their normal trends at 5,500 ft. The pore pressure estimated using this data was higher than that shown by the Dxc plot or that derived from the hole problems previously described. However, if these estimates were true there would have been high trip gases and possibly further tight hole during tripping, but as none of these was observed the estimate taking the connection gas into account seems the better one.

The overpressure indicators continue along the 10.6 lb/gal gradient until 6,700 ft where a further increase in pore pressure is indicated. The Dxc plot provides an exception to this general scheme when it returns to the normal trend during the interval from 6,150 ft to 6,380 ft. In this case the bit was changed at 6,396 ft where it was found to be well worn and it is probable that the Dxc values were mostly influenced by the reduced efficiency of the bit.

Certainly, when the bit was replaced, drill rates increased and the Dxc plot reverted to the 10.6 lb/gal trend before showing the second increase in pore pressure mentioned above. Again, the pore pressure estimates from the E-Log data proved too high to agree with the trip gas and connection gas records and a value of 10.8 lb/gal derived from the Dxc plots is used in preference.

The sequence of claystones and shales continues until 6,900 ft where the Palaeocene tuffs and tuffaceous shales appear and the Dxc, Rt and Δt plots begin to move back towards a normal trend. These rest uncomformably on the Danian Marls at 7,090 ft and because of this relationship the marls are assumed to be normally pressured.

The Flowline Temperature and Shale Density plots were used to provide confirmation of the existance of overpressures, but only the Shale Density gave any realistic information. This parameter appears to follow the drilling exponent plot with one notable exception, the decrease in density shown at 5,580 ft which coincides with the top of the overpressure identified from the Log data. The plot of Flowline Temperature shows an increase over this general area, but this is probably coincidental following the setting of 13⅜" Casing at 5,215 ft and subsequent bit changes over the transition zone interval.

CHALK

The increase in drilling exponent values from the base of the Tertiary into the Danian Marls shows a normal pore pressure gradient by the top of the Chalk. The junction with the Danian appears to be unconformable as the initial drill rates in the Chalk were as high as 200 ft/hr and this must represent a zone affected by weathering. Below this the chalk became much harder and drill rates decreased to 15-25 ft/hr with occasional variations introduced by chert bands and fractured permeable zones. These latter were of limited extent and there is no evidence for any overpressure developing or being transmitted into the Chalk succession. No Δt or Rt values were plotted for the chalk sequence as the values cannot be compared with the shale points used above to describe a normal trend.

Towards the base, the chalk becomes increasingly argillaceous, with traces of glauconite and some chert beds, and shales appear from 8,670 ft becoming dominant from around 8,800 ft.

Although the chalk was normally pressured, the mud weight was maintained at 10.6 to 10.8 lb/gal to control the overpressures in the Tertiary, but from 8,550 ft it was increased to 11.0 lb/gal in anticipation of Jurassic overpressures.

THE SUB CHALK SECTION

The drilling exponent plot for the Lower Cretaceous shales coincides with the normal pressure trend established above the Chalk and they are therefore assured to be normally pressured. However, from 8,900 ft in the Valhall Shales, the Dxc values begin to decrease and this continues into the Upper Jurassic 'Hot' Shale where the formation pore pressure reaches 9.75 lb/gal at 9,000 ft. From 9,135 ft the shales are replaced by a silt and sand unit and the next shales do nor occur until 9,250 ft. These indicate a continues increase in pore pressure to 11.6 lb/gal at 9,300 ft. The succession becomes more variegated from here with increasing proportions of siltstone and sandstone making the drilling exponent of little use in determining the prescence and value of any further overpressures. For the same reasons, neither the Δt or Rt values were plotted after the last shale points.

During the course of this transition zone, the mud weight had been steadily raised, reaching 11.9 lb/gal at 9,300 ft, but in an attempt to increase the drilling rate, it was reduced from here to 11.4 lb/gal by 9,500 ft. At this point the sequence of siltstones and sandstones had been replaced by a limestone and at 9,520 ft a further change took place with the appearance of Zechstein anhydrite. Thus the Jurassic succession had been truncated and the Triassic was apparently absent as a result of the faulting movements associated with the development of the North Sea graben.

At 9,568 ft there was a drilling break and, although no flow was observed here, a further check at 9,574 ft showed the well to be flowing and the mud weight was increased to 11.6 lb/gal. On circulating out, the total gas reached 420 units (8.4%) and the chlorides increased from 20,000 ppm to 36,000 ppm.

A survey was made at this depth, but while pulling out to the casing shoe to retrieve the survey tool, the well again tried to flow and after circulating with 12.3 lb/gal mud, 68 barrels of salt water (maximum 110,000 ppm CL^-) were recovered with a maximum of 500 units (10%) of gas. Salt had been first identified in the samples from 9,550 ft and became the dominant lithology from 9,600 ft. From the electric log data, the top of the salt was placed at 9,588 ft and the flow of brine must have originated from the uppermost part of this suquence.

The salt continues with variable amounts of anhydrite to 10,095 ft where a medium - coarsely crystalline dolomite is followed by an interbedded sequence of anhydrite, dolomitic anhydrite and dolomites. Below this basal carbonate unit there is a thin shale marking the Kupferscheifer before the first red sandstones and siltstones appear to mark the top of the Rotliegendes at 10,179 ft. For the most part the Rotliegendes consists of sandstones with occasional stringers of anhydrite in association with red/brown claystones and siltstones. These become more frequent towards the base of this formation which is marked by a conglomerate of metamorphic, altered volcanics and indurated sedimentary rocks in a sandy matrix.

The absence of any suitable shale development below 9,300 ft has made it impossible to derive an estimate for the pore pressures within the salt and the underlying formations which can be substantiated in any way except by D.S.T. The overpressures identified down to 9,300 ft were apparently continuing to increase through the sand and silt sequences as shown by the saltwater influx at 9,574 ft. As no flow was apparent during drilling at this depth, the pore pressure is estimated to be equivalent to the E.C.D. used at the time (11.8 lb/gal). Examination of the flowline temperature plot over this section of the well reveals a rapid increase in temperature from 9,460 ft to 9,520 ft which may indicate the top of the zone of overpressure. However, this can also be corelated with the much reduced drill rate from 9,465 ft to 9,568 ft which could allow the mud to heat up at a greater rate than normal as more time was taken to drill this interval.

The Rotliegendes, Kupferscheifer and the major part of the salt are assumed to be normally pressured due to the salt forming an impermeable seal between these and the overpressures developed above although, for the reasons set out above, this is based on conjecture rather than factual information.

The well was abandoned at 11,250 ft in the Rotliegendes basal conglomerate.

3/5-2 PRESSURE EVALUATION

TERTIARY

The poorly consolidated clays and sands of Recent and Upper Tertiary origins found in the surface hole interval allowed the rate of penetration and weight on bit to range widely with erratic values for the drilling exponent being derived in consequence. From around 1,600 ft the rocks began to firm up and the Dxc plot became more regular, allowing the establishment of the trend for a normally pressured formation, and from which most of the estimates of formation pressure were derived. (See figure 1 and Appendix). The plots of Sonic Log Δt values and flowline temperature remained almost constant throughout this section, but the Resistivity Log shows a decrease to around 850 ft which reflects the increasing pore fluid salinity caused by compaction of the clay minerals and subsequent loss of sites formerly occupied by the larger cations. (Na^+, K^+, Ca^{2+}).

The pore pressure gradient starts at 8.5 lb/gal equivalent (normal sea water density) and gradually increases to 8.7 lb/gal at 850 ft as the dewatering of the clays proceeds. All subsequent pore pressure estimates use the 8.7 lb/gal gradient assumed to be normal for the North Sea area.

From 1,600 ft the succession continues with sticky clays occasionally interbedded with thin argillaceous and dolomitic limestones. The clays are characterised by their universally low shale densities (less than 2.0 gm/cc) and by their propensity for overwhelming the capacity of the flowline and shale shaker system. The normal trends for the overpressure parameters begin to develop from 2,200 ft although the shale densities remain almost constant despite the sign of apparent consolidation in the appearance of claystones and shales from 4,560 ft. At 4,900 ft the drilling exponent begins a gradual decrease simultaneous with a progressive rise in the shale density until at 5,040 ft the density drops back to levels typical of the previous 600 ft. This marks the top of the first overpressure zone and the subsequent Electric Log run confirms this as both Rt and Δt values indicate increasing formation pressures from 5,000 ft. The plots of all these parameters here form a pattern nearly identical to that of 3/5-1.

In this transition zone the pore pressure rises to 9.7 lb/gal as the clays are replaced by shales and claystones and there is a steady increase to 10.3 lb/gal at 6,000 ft. The drilling exponent and Δt return towards their normal trend values from here and no further increase in pore pressure is indicated until 6,760 ft where there are sudden changes in Dxc, Δt and Rt values analogous to those at 5,920 ft on 3/5-1. The pore pressure rises steadily from here to 10.9 lb/gal at 8,000 ft.

Throughout the Tertiary the mud weight had been progressively increased and it remained above the estimated pore pressure until 7,100 ft where it was reduced from 10.7 lb/gal to 10.2 lb/gal. Problems with bit balling and tight hole ensued and at 7,400 ft the weight was raised to 10.8-10.9 lb/gal. Additional corroboration of the pore pressure estimates can be inferred from the occurrence of connection gas from 7,900 ft to 8,200 ft where the estimated pore pressure is equivalent to the mud weight. Subsequently, while running the Electric Logs, both these intervals were found to be substantially washed out.

The shales and claystones are succeeded by the Palaeocene tuffs and tuffaceous shales from 8,400 ft and there is an associated decrease in rates of penetration which continues into the Danian at 8,621 ft. The Dxc returns towards the normal pressure gradient trend and the pore pressures are assumed to decrease as it is unlikely that these tuffaceous sediments were laid down as part of the same sedimentary cycle which produced the overpressured shales and claystones found above. The unconformable junction between the Palaeocene and the Danian is taken to isolate the latter from the overpressures above and the marls and limestones are therefore normally pressured.

CHALK

The normal pore pressure gradient continues from the Danian Marls and Limestones into the main Chalk formation. Immediately upon entering the chalk the bit was changed for a turbine/diamond bit assembly, but this only managed 4-8 ft/hr through the topmost cherty interval which drilled so quickly in 3/5-1. Conventional bits were used to drill the rest of the chalk and, in contrast to 3/5-1, the drill rates remained fairly regular throughout at 10-20 ft/hr. No Rt or Δt values were plotted for the chalk sequence as the values cannot be compared with the shale points used above to describe the normal trend.

Towards the base the Chalk becomes increasingly argillaceous, containing traces of glauconite, and chert reappears from 9,900 ft in association with shales and siltstones. These become more important with depth and at the base of the chalk, around 10,080 ft, they include traces of coal.

The mud weight had been raised through the chalk succession and was 11.5 lb/gal at the base in anticipation of overpressures below the chalk.

THE SUB CHALK SECTION

As with the Tertiary, the pattern of overpressure development here is quite slow and steady. Beginning at the base of the Chalk, the drilling exponent decreases through the Valhall shales into the Upper Jurassic 'Hot' shale where the pore pressure is estimated to be 9.5 lb/gal at 10,400 ft. There are further decreases in the Dxc, through the succeeding shales and dolomites below the Upper Jurassic sand, and by 10,900 ft the pore pressure has risen to 10.7 lb/gal. The mud weight had been maintained at 11.6-11.4 lb/gal over this interval so that the background gas and trip gas level was generally low and no connection gas was recorded at all. The shale density values in the Lower Cretaceous are lower than expected, (approximately equivalent to those found in the Palaeocene) confirming the existance of the overpressures here, but at 10,400 they rise suddenly to about 2.55 gm/cc and remain around this value until T.D. The wireline log data plotted down to this point is inconclusive as although the Rt and bulk density are lower than the normal trends the Δt plot shows the reverse situation. The flowline temperature shows a slight decrease over the interval from 10,000 ft to 10,400 ft followed by a rapid increase to 10,500 ft where the normal gradient is re-established, but this also coincides with the setting of the $9\frac{5}{8}$" Casing and subsequent slow drilling on junk which casts some doubt on the validity of the flowline temperature at this point. Taking all the information into account it appears most likely that the Dxc derived indicators of overpressure are the correct ones and this viewpoint has been used to evaluate the rest of the succession.

At 10,974 ft the shale and limestone sequence is replaced by a sequence of coal, siltstone and sandstone of Middle Jurassic age although the major part of this unit comprises on interbedded sequence of shale, claystone, siltstone and sandstone. At 11,730 ft a dolomitic limestone marks the top of the Triassic red bed formation which comprises a succession of red siltstones, sands and claystones with occasional dolomites down to 12,150 ft where massive anhydrite appears and the succession continues with increased proportions of siltstone and sandstone and only minor quantities of claystone.

The plot of the drilling exponent follows a slightly negative trend throughout the whole sequence and this is taken to indicate a constant increase in pore pressure. The use of the Dxc plot is theoretically limited to a single lithology, usually a shale, and that comparisons with Dxc values for other lithologies, for the purposes of overpressure identification and the estimation of the pore pressures, is not viable. However, in this case, consisting of a variegated sequence of clastics including a large amount of argillaceous material, it appears to work and the constant shale density readings for the Jurassic and Triassic provide some confirmation of the continuance of the overpressures.

Using these Dxc values the estimated pore pressures rose from 10.7 lb/gal at 11,200 ft to 11.0 lb/gal at 11,300 ft and there was a further rise from 11,560 ft, reaching 11.5 lb/gal in the Triassic at 12,000 ft. The pore pressure remained at 11.5 lb/gal until the well was abandoned in the Triassic at 12,550 ft.

CONCLUSION

Both wells show two main overpressures, the first occurring in the Tertiary claystones and shales, and the second starting in the Lower Cretaceous and continuing into the Jurassic. The Tertiary overpressures are most clearly shown by the plots of Sonic Log Δt and the deep resistivity Rt values, the drilling exponent and shale density plots being adversely affected by the relative softness of the claystone. However, the pore pressure estimates using the Dxc plot gave the results in closest agreement with the observed hole conditions and these values are therefore used as the best guide to the formation pore pressures in both wells.

Below the Chalk the second zone of overpressure can be identified although, due to the truncation of the succession in 3/5-1, there are pronounced differences between the wells in the pattern of overpressure development. The Dxc plot is the prime indicator of overpressure here as the values obtained from the shale below this formation are therefore more difficult to relate to those values obtained higher up the succession.

Overall the drilling exponent has been the best parameter to use for the identification and quantification of the overpressures and the shale density appears to be viable as confirmation of their existance. The Electric Log Δt and Rt parameters are the most accurate for identifying the overpressured zones, but the pore pressure estimates derived from them tend to be too high and their advantages are to some extent overshadowed by their usually being run after the overpressure has been drilled.

APPENDIX 1

3/5-1 OVERPRESSURE DATA

Dxc Normal Trend = 1.09 at 4,000 ft; 1.43 at 7,000 ft

At 6,000'	Dxc_N	=	1.305	Dxc_O	=	1.07	From 8.7 x Dxc_N/Dxc_O =	10.6
6,500'			1.37			1.15		10.36
6,900'			1.42			1.15		10.74
9,000'			1.60			1.51		9.22
9,400'			1.75			1.30		11.70

Sonic Δt Normal Trend = 180 at 2,000 ft; 126 at 6,000 ft

At 6,000'	Δt_N	=	122	Δt_O	=	148	From 8.7 x $\Delta t_O / \Delta t_N$ PPG=	10.55
6,500'			117			139		10.34
6,900'			112			155		12.04
9,000'			107			115		9.6

Using Reynolds (1974) Curve for North Sea data the estimates increase to 11.3, 10.7, and 13.5 respectively.

Rt Normal trend = 1.3 at 5,000 ft; 1.32 at 7,000 ft

At 6,000'	Rt_N	=	1.29	Rt_O	=	0.67	Using Timko (1971 PPG =	10.85
6,500'			1.31			0.60		11.4
6,900'			1.32			0.47		12.6
9,000'			1.34			1.0		9.5
9,400'			2.2			0.9		11.8

APPENDIX 2

3/5-2 OVERPRESSURE DATA

Dxc Normal Trend = 1.10 at 3,600 ft; 2.00 at 11,700 ft

Depth	Dxc_N	Dxc_O	From $8.7 \times Dxc_N/Dxc_O$ PPG
At 7,000'	1.414	1.22	10.1
8,000'	1.522	1.13	11.7
10,400'	1.80	1.56	10.0
11,000'	1.899	1.57	10.5
11,700'	2.0	1.48	11.8

Sonic Δt Normal Trend = 162 at 2,000 ft; 112 at 10,000 ft

Depth	Δt_N	Δt_O	From $8.7 \times \Delta t_O/\Delta t_N$ PPG
At 7,000'	129	155	10.5
8,000'	123	162	11.5
10,400'	110	110	8.7

Rt Normal Trend = 1.5 at 1,000 ft; 1.6 at 5,000 ft

These values are very approximate and no pore pressure estimates were made using the Rt data.