Technical Service Report

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DIPMETER ANALYSIS, STATOIL 34/10-1 WELL, NORTH SEA (NORWAY)

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Reservoir Evaluation Division
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CONCLUSIONS

Major dip changes in the interval 1780-2460m of the Statoil 34/10-1 well occur around 2020m, 2080m, and 2290m, and these separate the section into four major structural units. Aside from an anomalous unit between 2020-2080m, average structural dip is steeper in the deeper units. This is interpreted to reflect the longer period of arching and tilting in the deeper strata, with levels of dip changes representing unconformities developed during a graben-filling stage (Fig. 1, top). An alternative interpretation, in which dip changes correspond to fault cuts, is less consistent with the interpreted seismic line.

The unit between 2020-2080m is termed anomalous because its internal dips are steeper than those of underlying and overlying units. Inasmuch as the steep dips are confined to a sandy unit sandwiched by marine shales, the locally high dips are believed to be sedimentary in origin. Two explanations are possible. Either the unit is a slump deposit, or it represents a marine clinoform deposit (deep-sea fan or shoreface) that prograded from east to west (Fig. 2).

Residual dips in sandstones (these appear on the GEODIP logs and were obtained by removing the structural dip component) generally are unreliable. Only in the interval from 1870-1844m are the residual dips reliable, and these suggest either shoreface progradation from north to south, or currents moving southward onto or across a shelf.

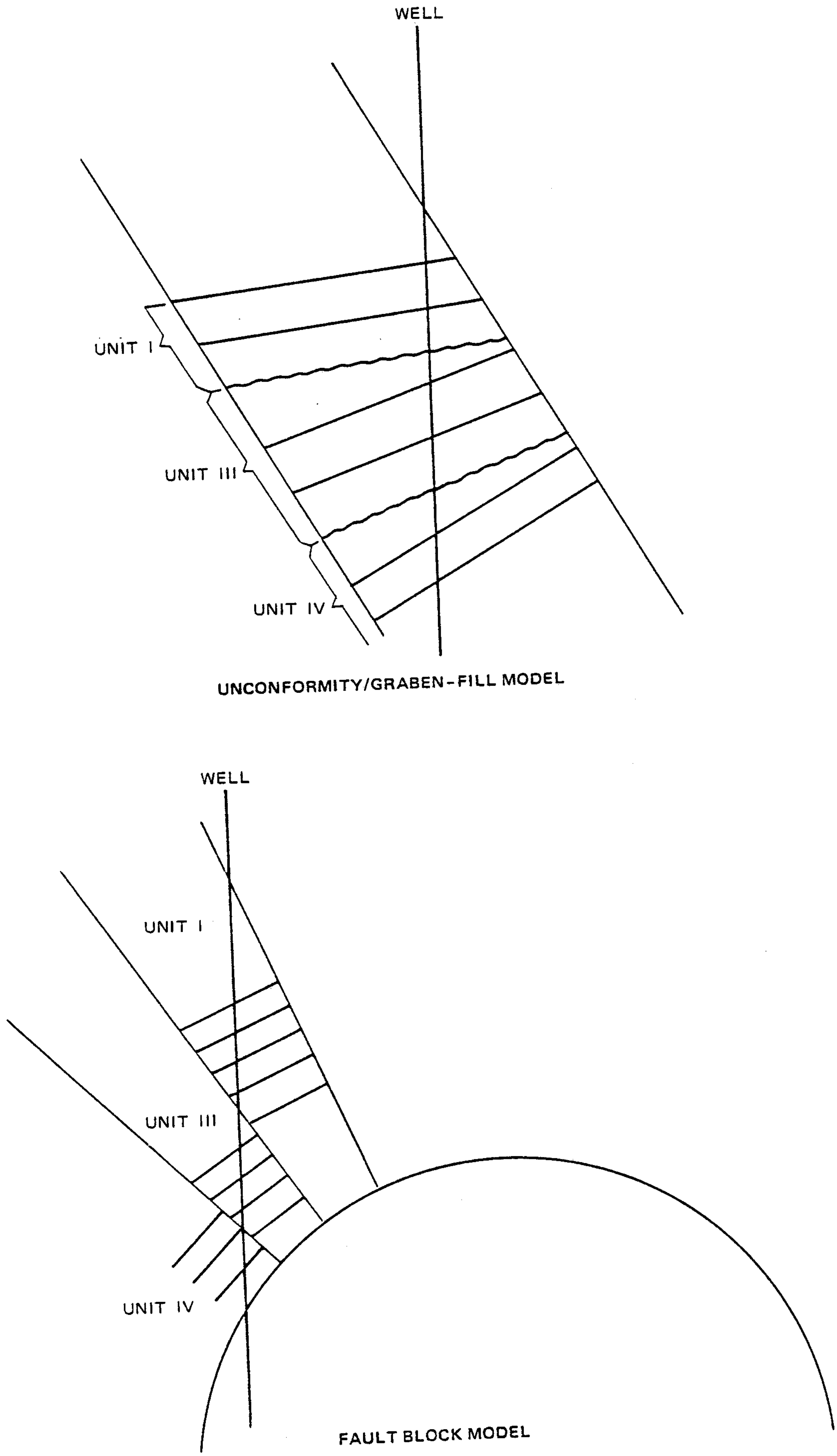
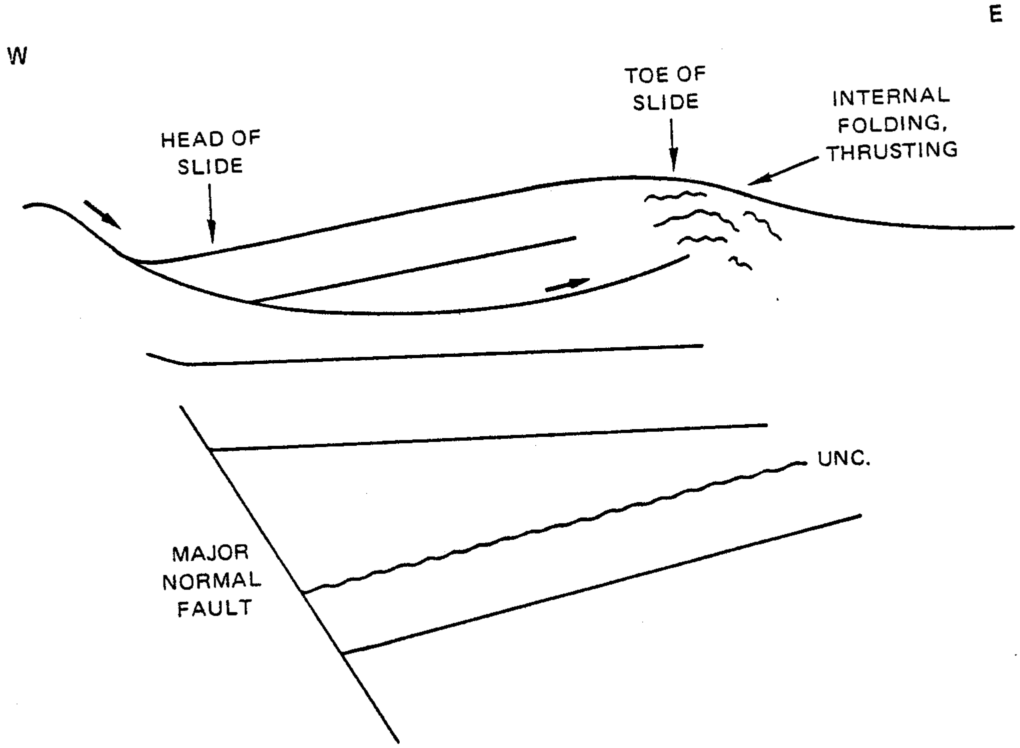
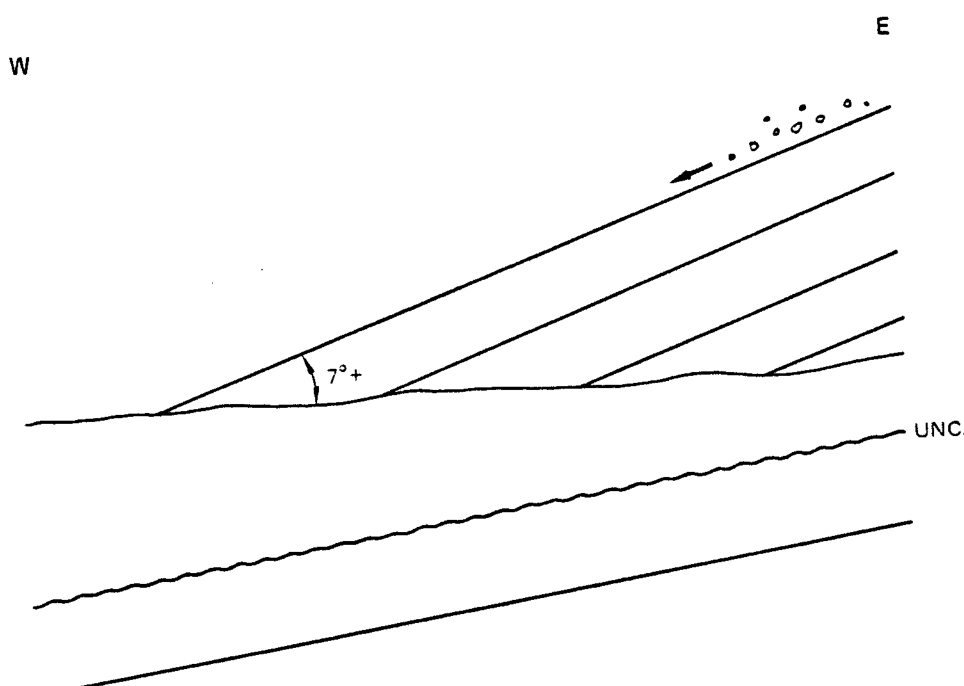


Figure 1. Two interpretations of structural dip variations.



SLUMP ORIGIN FOR UNIT II



FOREST ORIGIN FOR UNIT II

Figure 2. Two interpretations of the anomalously high dips in unit II (2020–2080 m).

INTRODUCTION

Dipmeter data from the interval 1780-2460m in the Statoil 34/10-1 well, North Sea (Norway), were examined to identify structural and stratigraphic features of local and regional significance. Other information examined that proved helpful in the study were a section of correlated well logs, a seismic line, a mud log, and a lithologic-facies log prepared by M. T. Jervey of a core from 1782-1951m.

Interpretations involving large-scale structural features are based on major dip changes observed on the standard diplog. More subtle small-scale features of sedimentary or stratigraphic origin are less easily discerned from background "noise" and therefore are less reliably interpreted, even with the availability of the GEODIP program. This point will become more clear by referring to the brief discussions of dipmeter-error sources and problems in crossbed-dip determinations included at the end of the report.

This interpretation was requested in a letter from Jean Barrier, Esso Exploration and Production Norway Inc., to D. H. Horowitz, EPRCo, dated March 29, 1979. Charges for this work are included under project number 11450.

STRUCTURAL DIP DETERMINATIONS

Structural dip is recognized by the recurrence of comparable dips throughout intervals of several hundred meters. If more than one structural dip is recognized in a stratigraphic column, that column is divided into structural units. Three, and possibly four structural units are recognized in the interval 1800-2460 meters.

Unit I 1800-2020m. Structural dip is WNW around 9°. The dips are quite reliable from 1810-1940m, less reliable outside this interval, especially between 1980-2020m.

Unit II 2020-2080m. Apparent structural dip is W at 22°. The dip estimate is quite reliable, but whether the high dip reflects a structural or sedimentary anomaly is open to interpretation.

Unit III 2090-2285m. Structural dip is W at 15°. The dip is slightly less in the upper 40 meters, but overall is consistent and reliable.

Unit IV 2350-2460m. Structural dip is WSW at 25°. The dip estimate is considered reliable, but variation in dip magnitude (and to a lesser extent azimuth) are such that the degree of reliability is less than that for shallower units.

Intervals not included in these units because of poor dip quality or anomalous dips with limited stratigraphic range are:

1780-1800m	South dip of 11° (?).
2080-2095m	Dip magnitude changes rapidly. Deformed zone (?).
2285-2350m	Dip magnitude roughly 20° (± 10°), and dip azimuth roughly SW (± 45°). The dips in this interval more closely resemble those in the underlying than overlying unit.

INTERPRETATION OF STRUCTURAL-DIP VARIATIONS

Two interpretations consistent with the interpreted seismic line submitted for the study are shown in Figure 1. The unconformity/graben-fill model (top of the figure) is the favored interpretation because it accords more closely with the interpreted seismic line provided by Esso Exploration and Production Norway Inc. In this model dip changes reflect major unconformities developed during periods of arching and normal faulting. Judging from the relatively abrupt dip changes between units, periods of structural movement were short and relatively violent. The progressively steeper dips of deeper structural units (ignoring for the moment Unit II) result because the deeper units were subject to more episodes of arching and tilting. A fault-block model (bottom of Figure 1) is also consistent with the observed dip changes but does not accord with the interpreted seismic line. In this model dip changes occur when crossing normal faults.

ORIGIN OF ANOMALOUS DIPS IN UNIT II (2020-2080m)

Unit II is considered anomalous because dips of overlying and underlying strata are more gentle. For this reason, and because Unit II is a sandstone sandwiched by marine shale (Units I and III), the high dips are believed to be sedimentary in origin. Less likely is the possibility that Unit II is a tilted wedge between closely spaced faults, a possibility that becomes more likely, however, if the fault block model (Figure 1) is adopted.

Pursuing the more likely sedimentary origin of the high dips, two possibilities are suggested: slumping and foresets (Fig. 2). The slumping origin implies that a large block of nearshore sand slid intact into deeper water, as suggested in the upper diagram of the figure. Because of the uniform dips, the portion penetrated by the well should correspond to the head of the slide. For the classical slide, dips of this portion should be directed toward the topographic high from whence the slide originated. After removal of structural dip (9° WNW in overlying unit, 15° W in underlying unit) a residual westerly dip of at least 7° remains, indicating a westerly source of the sand. In the figure, the topographic feature fostering the slide is the high side of a major normal fault, but this is speculative. An alternate interpretation, in which the slide originated from the east cannot, however, be ruled out. Some recently reported slides have apparently "plowed" into their downslope substrates and now dip more steeply in the direction of transport.

The foreset origin attributes the high dips to the westerly progradation of a submarine fan or shoreface sand wedge, as shown in the bottom of Figure 2. Although appealing, this interpretation should be accepted with reservation because a more-or-less constant sedimentary foreset dip of at least 7° in a 60-meter interval is indicated (remove the 15° W structural dip of Unit III from the 22° W dip of Unit II; the residual 7° W dip is minimal, because it is not clear whether the steeper structural dip of Unit III or the more gentle dip of Unit I should be used for Unit II). A 7° dip is unusually high. The alluvial fans on the west side of Death Valley, for example, have slopes of about 4°. If the foreset origin is valid, the sands were derived from the east.

LOCAL SEDIMENTARY DIPS (GEODIP RESULTS)

Residual dips that remain after removal of the structural dip component **are** presumably of sedimentary origin and may reflect cross-bedding, foresets, drape, loading, or soft-sediment deformation. The GEODIP program is designed to calculate the internal, residual dips in sandstones and therefore may reveal some of these sedimentary dips. An interval by interval analysis of the GEODIP log follows:

1792-1798m General southeasterly dip around 10° but locally as high as 30°. These residual dips are probably invalid because an incorrect structural dip (8° at 310° azimuth), valid for deeper strata, was used in this shallower interval. The correct structural dip in this interval is closer to 11° south.

1800-1836m Residual dips are typically less than 5° and statistically point west, although there is much scatter. This result could be produced if the structural dip was underestimated for the GEODIP calculations. Indeed, I would have selected a magnitude of at least 9° and possibly 10° instead of the 8° used in the calculations. I suspect the preferred westerly dips would vanish if the higher structural dip magnitude is used.

1836-1838m High dips (20°-40°) are believed to be spurious and do not reflect crossbedding. The most compelling evidence for the statement is the core description by Jervey: beach sands with parallel to low inclined laminae are present. Moreover, examination of the field-recorded resistivity curves (right-hand margin of the GEODIP log) fails to reveal reliably correlated excursions.

1838-1870m   Generally low dips (<10°) with no preferred statistical orientation. Clusters of higher magnitude dips are all based on questionable correlations. Core examined by Jervey exhibits parallel lamination or gently inclined lamination.

1870-1894m   Dips are generally less than 10° and statistically point south, correlations are excellent (therefore dip reliability is high) in horizons at 1876m, 1882m, 1890m, and 1893m. This unit corresponds to the upper shoreface environment, according to Jervey. The southerly dips might therefore represent clinoforms indicating progradation from north to south. Alternatively, the dips might represent low-angle crossbeds formed by currents moving southward onto or across a shelf.

1894-1906m   Dips generally under 10° with little to no preferred orientation are believed to represent the random fluctuations about the average structural dip.

1944-1970m   Few dips were calculated in this interval because it consists largely of shale. Dips in slightly sandy zone from 1964-1968m are randomly oriented.

2020-2080m   Northerly residual dips in the upper 20 meters of the interval signify that the upper portion of the unit probably has an overall dip azimuth of about 280° instead of 270°; the latter value applies for most of the interval and was used as the structural dip azimuth for calculation of residual dips. Residual dips throughout the rest of the unit are more random, indicating the 270° is probably a correct choice for the local structural dip azimuth.

2095-2105m   Easterly dips are consistent but of unknown origin, possibly related to emplacement of overlying sandstone unit in interval 2020-2080m.

2105-2285m   Generally random dips reveal no anomalies and suggest that structural dip selected (15°W) is a good estimate of the true structural dip.

2285-2460m   Dip variability on the standard diplog is sufficiently great that it is difficult to define a precise structural dip, and consequently the validity of residual dips calculated using one selected structural dip is questionable. Generally, northerly residual dips prevail on the intervals 2285-2307m and 2350-2450m, and easterly dips prevail from 2307-2350m. These dips are typically about 10° or more in magnitude, for the most part too low to represent crossbedding (moreover, many occur in a shaly section) and probably too high to reflect the paleoslope of fan systems. Perhaps these changing residual dips reflect minor structural tilting during horst and graben development.

ORIGIN OF RANDOM DIP VARIATIONS

Borehole irregularities and variations in tool velocity during logging are probably two of the most important factors causing random scatter about a mean dip, even where strata are strictly parallel. Unless the borehole is very smooth, the dipmeter electrodes will traverse depressions or mini-washouts that are generally reflected by lower resistivity values compared to mud-covered rock. Accordingly, these irregularities create spurious excursions on the resistivity traces, and this could lead to improper correlations and therefore invalid dips. Resistivity profiles across homogeneous units are most affected by borehole irregularities, and this is one reason why some dip scatter must be tolerated when dipmeter dips within clean sandstones (or shales) are examined. This is one of the problems we face with the GEODIP logs.

Variations in uphole tool velocity also create scatter in the computed dips. To use an extreme example, if a tool temporarily lodged in a constriction, then snapped loose and surged uphole several meters, the resistivity profile would be compressed on the surface recorder which moves in synchroneity with the hoisting cable (the cable obviously stretches during the period of lodgement). Compression of the record reduces displacements of correlative excursions and results in a lower computed dip. From the example it is understandable that erroneously low dips will be calculated when tool velocity is high, and erroneously high dips will be calculated when the tool moves more slowly. These errors will, of course, amount to only a few degrees unless movement is quite erratic.

Aside from instrumental errors, geologic factors also may be responsible for random dip variations. To begin with, strata often are not strictly parallel - at least across the borehole - because of local scouring and lateral variations in thickness. Other factors to be considered are nodules, differential cementation, or coarse components like pebbles. These create local resistivity changes that may not be correlatable across a borehole.

PROBLEMS IN CROSSBED-DIP DETERMINATIONS

The GEODIP program attempts to calculate sedimentary dips in sandstones (i.e., structural-dip component is removed), and this includes crossbed dips. Only under special conditions will crossbed dips be revealed by the dipmeter, however. The most important requirement is that the crossbed laminae are sufficiently contrasting in electrical resistivity to give rise to correlatable excursions on a resistivity profile. Most cross-bed laminae do not meet this requirement. A second requirement is that the crossbed sets be sufficiently thick that they give rise to several correlatable excursions, otherwise a valid correlation could be overlooked because the excursions are likely to be quite subtle. Moreover, more dips can be calculated in thicker sets and this increases the confidence level because greater reliability is placed on a string of similar high dips than just one isolated high dip.

In my experience North Sea Rotliegende and western U. S. Nugget dune deposits are the only facies that have yielded reliable crossbed dips. Certainly the great thickness of crossbed sets contributed to the success, but more importantly the avalanche laminae of dune deposits are typically relatively thick (about a centimeter) and texturally contrasting, so that resistivity profiles carried many valid excursions. Differential cementation in the texturally contrasting laminae also enhanced the resistivity variations.