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SEISMIC DETECTION OF THE DEWATERING OF DEEP BASINAL SHALES

Examination of multichannel seismic data from offshore basins with deep-water shales often shows a complex mosaic of faults which affect the continuity of the seismic reflectors. The faults are restricted to certain stratigraphic units; a tectonic origin can be excluded because of the reflection continuity of the units above and beneath. The faults are interpreted to result from fluid expulsion and volumetric reduction during the compaction of the shales. Sediments deposited in 1500 meters of water during the Plio-Pleistocene in the Porcupine Basin, offshore Ireland, have over 20 meters of offset. The faults converge down section to point sources, producing an inverted keystone effect. In the Lower Tertiary shales of the Norwegian sector of the North Sea, mapping of the fault patterns in a 3-D grid of data shows two dip directions which are antithetic. Sediments in the continental rise (over 2500 meters), offshore Georges Bank, are disrupted approximately every kilometer by faults caused by dewatering. Similar disruptions occur in deep-water sediments beneath the Outer Blake Ridge, Hatteras Abyssal Plain, and southern Gulf of Mexico.

Interactive investigation of the fault patterns of deep-water shales on multichannel seismic data contributes to understanding their diagenetic history, the amount of and timing of compaction, determining slope stability, and estimating the distribution of coarser-grained sandy sediments within the shale lithosome.

INTRODUCTION

When fine-grained sediments are initially deposited, a considerable volume of fluids are incorporated into them. During compaction, most of the fluids are expelled. What effect does this have upon the sediments themselves? Outcrop studies show normal faults which vertically offset the strata; Davison (1987) documented the formation of mesoscale examples of these at shallow depths (less than 200m) in some Lower Cretaceous turbidites in Brazil. Throws were less than 0.5m. Further dewatering of these interbedded sands and shales changed the geometry of the fault surfaces due to differing amounts of compaction in the sands and shales. A later phase of faulting at greater depth (greater than 1km) was recorded; fault planes were steeper. Displacements were greater than 0.3m.

We have observed a series of closely spaced normal faults in seismic data recorded from several deep water settings. We suggest these were produced by dewatering; they are macroscale features. In the exhibits that follow, a variety of examples are presented for examination and comment.

PORCUPINE BASIN, OFFSHORE IRELAND

The uppermost megasequence (Plio-Pleistocene) of Porcupine Basin is comprised of an 800ms (900m) interval which is divisible into six seismic sequences. Most of the sequences are associated with deposition from submarine fans. The top sequence of the underlying megasequence resulted from overbank deposits associated with a levee in the eastern part of the basin. In the east central portion of the basin (present water depths of approximately 1500m), a series of arcuate faults offset the reflectors. Two arcuate reflectors often converge to a common point at the top of Megasequence 2, indicated by the small dimples at the boundary. Vertical offsets are up to 20ms (45m), although most are less. We displayed four of the east-west lines on a Landmark Graphics workstation. The fault traces can be seen in the color displays. The average distance between the fault surfaces is 145m.

GEORGES BANK, UNITED STATES

There is a thick section of clastic sediments in deep-water (2500m) south of Georges Bank off New England. The uppermost megasequence is comprised of a thick interval (1 sec.; approximately 1200m) of sediments deposited in a continental rise environment. Northward, the sediments onlap against the base of the slope. A large channel-levee complex is present on the upper surface of the megasequence; the unit thins both eastward and westward over a distance of over 300km. Most of the reflectors are parallel or subparallel, suggesting deposition by traction currents which were unconfined by channels. A series of normal faults offset the reflectors; the displacement can be up to 50ms (approximately 60m). 444 faults were identified on two representative lines; the average distance between the faults is 0.6km. There is another series of vertical faults in the interval beneath the upper megasequence. These appear to be similar in origin but formed at an earlier time. They do not appear to be directly related to the uppermost set of normal faults.

NORTH SEA

The Viking Graben is a north-south Jurassic rift system in the northern part of the North Sea. During the Lower Tertiary, extensive siliciclastics prograded into the graben from uplifted areas in northern Scotland over the Shetlands. The Paleocene and Eocene progradational shelf margins are very clear on seismic sections on the western basin margin. Note the continuity of change in the reflectors when the sequences are traced into the basin. This could be a seismic facies change produced by a change in environments; e.g., mass debris flows or submarine fans. Note, however, that younger prograding units do not exhibit the same pattern. Close inspection of full scale seismic sections show that the Paleocene and Eocene stratas are intensely faulted by normal faults. The change is always observed as one goes into the basin, not at its edges. We suggest that this is due to dewatering; it may have also produced overpressurization. This faulting has a major effect on the quality of the seismic data and attempts to locate additional submarine fans similar to Alba and Emma which are recent giant field discoveries in this interval.

GULF OF MEXICO

This line is part of a line shot in the 1970's which runs from the Yucatan Pennisula over to the Mexican coast near Vera Cruz. Present water depths approach 4000m. The line is unmigrated. The uppermost reflectors are extremely continuous and unbroken. Beneath this, however, there are high angle normal faults that cut through a considerable vertical interval. Since this whole area was tilted to the southeast during a Late Tertiary disturbance, a tectonic origin could be suggested. The average distance between them is 5km, however, another feature should be noted. There are several bands of reflectors which change character upward from low amplitude to high amplitude. Note the occurrence of numerous diffractions which radiate from the upper portion of them. We believe the diffractions are coming from fault planes produced by dewatering. The average distance between them is 1.8km. Note that the lateral spacing is shorter than the other faults and the vertical offset is small.

OUTER BLAKE RIDGE, SOUTHEASTERN UNITED STATES

This section is part of a long line shot in the 1970's as part of the investigation of the Atlantic margin. The area lies east of the Blake Plateau; it is the Blake Rise. Present day water depths are about 3000m. The upper portion of the section consists of very continuous reflectors associated with the contourite deposits of the Outer Blake Ridge. Beneath this are a series of intervals which change their character vertically from low amplitude to high amplitude. The upper surface of each of these has numerous diffractions. We believe these are caused by normal faults produced by dewatering. The average distance between faults is 1.7km. The environment of these sequences is believed to be an outer fan.

SIGNIFICANCE OF MACROSCALE DEWATERING FEATURES:

1. The detection of macroscale faulting caused by dewatering offers clues to the lithofacies of the sections and their diagenetic history.

2. The horizontal spacing of the faults places a limit on horizontal stratal continuity. Determination of vertical offset provides an estimate of the degree of disruption of hydrocarbon reservoirs and their production behavoir.

3. Seismic detection of dewatering features (or their absence) may provide clues to maturation and migration and the occurrence of overpressurization.

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ABSTRACT

Seismic data shows the widespread occurance of closely spaced normal faults in some deep water sediments. Since these are in tectonically quiescent areas, dewatering is suggested to be the causative mechanism. If attributable to this process, the occurance of the faulting offers suggestions as to the lithofacies of the sediments, the limits of their horizontal stratal continuity, and clues as to sediment diagenesis and fluid migration pathways.

INTRODUCTION

Our understanding of the deposition and diagenesis of deep-water sediments (i.e. bathyal and abyssal) has increased exponentially over the last two to three decades. Part of this has been by the drilling and coring conducted under the auspices of the Deep-Sea Drilling Program and its successor, the Ocean Drilling Program. Another important contribution has come from the widespread acquisition and interpretation multifold of common depth point seismic record sections. These provide an insight into the regional and temporal variation of deep-water processes that more localized studies cannot.

One of the features found in seismic record sections of some deep water sediments is the occurance of closely spaced faults in areas of tectonic quiescience. This was observed in seismic data imaging the sediments of the Madeira Abyssal Plain, (MAP) and the Nares Abyssal Plain (NAP) in the North Atlantic Plain by Druim et. al. (1984) and Budkley and Grant (1985). Williams (1981) further discussed this in seismic data from the MAP alone and DeLange, et. al. (1988) reported the presence of microfault-like structures in cores from the unconsolidated upper Quanternary sediments of the MAP. Druim et. al. (1984) thought the faults would be due to either mid-plate tectonic activity or differential compaction. Buckley and Grant (1985) noted that many of the faults were reverse faults. They suggested the faults were a result of dewatering processes and the reverse faults around basin highs reflect more extensive dewatering, hence greater compaction, over basement highs. Williams (1987) also suggested the faults in the MAP were a result of dewatering and caused by differential compaction over underlying basement topography. Williams examined alternate interpretations for the faults in which they were either sites of preferential dewatering or acted as seals. Overpressurized pore fluids were a feature of both models. DeLange et. al. (1988) also attributed the microfault-like structures observed in cores from the MAP to differential compaction and dewatering. Shepard, et. al. (1987) analized 21 piston cores from the NAP and characterized them as fine grained turbidites. Consolidation tests showed them to be normally consolidated to over-consolidated. DeLange, et. al. (1987) characterized the sediments of the MAP as consisting of alternations of meter-thick distal turbidites and then pelagic clays, marls and oozes.

Another place where compaction phenomena and fluid expulsion from deep-water sediments would occur is in areas where sediments are being forcifly compressed and subducted. This has been discussed in areas such as the Middle America Trench off Costa Rica by Shipley and Moore (1986), Moore and Shipley (1988), Shipley, et. al. (1990), Behrmann, et. al. (1988) and Greskes, et. al. (1989) have discussed the evolution of structures on fabric hydrogeochemistry of the Barbados accretionary complex. Mud volcanoes seaward of the Barbados accretionary complex were surveyed by submersibles by LePichon, et. al. (1990). Brown (1990) discussed the nature and significance of mud diapirs for accretionary systems. Bayer (1989) viewed the quantative aspects of modeling sediment compaction in large scale systems.

We have observed structures in seismic data from the Plio-Cleistocene sediments of the Porcupine Basin, offshore Ireland, the Lower Tertiary of the Viking Graben of the North Sea, the upper Tertiary of sediments south of Georges Bank, in the Tertiary of the southern Gulf of Mexico which we feel represent dewatering and compaction phenomena of bathyal and/or abyssal sediments. These are discussed below and their significance suggested as to the composition, diagenesis and search for hydrocarbon reservoirs in these sediments.

PORCUPINE BASIN

The Porcupine Basin is a Cretaceous-Tertiary basin which indents the continental shelf southwest of Ireland. Present day water depths range from several hundred to several thousand meters. In 1981 Merlin Geophysical acquired a speculative survey in the north-central portion of the basin. A portion of the upper 800 ms of this data was delineated as a Plio-Pleistocene megasequence and a seismic stratigraphic study suggested that the sequences in this unit were deposited by turbidity currents in submarine fans in water depths of 500 to 1500 m; these were from the north. In data from the east-central portion of the study area, we noted the occurance of opposing fine-scale arcuate faults which converged to a common focal point at the base of the unit (Fig. 1). The average distance between the faults is about 05. km and vertical offset is up to 20 ms. Using migration velocities, we calculate the offset to be up to 45 m, although most are less. The east-west lines are spaced 3.2 km apart. Because of the spacing of the faults, we could not determine with confidence their continuity from line to line. We note that their frequency decreases to the west as the reflection configuration, changes from subparallel and parallel (interpreted to be sediments deposited by unconfined sheet flow) to mounded where a submarine fan is present.

GEORGES BANK

In 1982 GECO U.S. acquired a speculative survey south of Georges Bank, New England, Macurda (198______) published an interpretation of an east-west line in this data from over 2500 m of water depth. In the upper one seond of data (approximately 1200 m) beneath the sea floor, numerous faults were observed, some with dips to the east and some to the west (Fig. 2). Their spacing, measured over two lines with a sample of over 200 faults per line, was 0.6 km apart. Offset was up to 50 ms (approximately 60 m). In the next 0.5 section of data beneath the first interval, the section is also intensely broken by faults whose spacing is slightly broader than the interval above. It is part of a different megasequence. Again faults dip in both directions; the offset is about half a reflector. We interpret these as another example of dewatering of deep basinal shales.

OUTER BLAKE RIDGE

In the 1970's a long regional line was acquired off the southeastern United States which crosses the Outer Blake Ridge (______________________, 1978). Beneath the contourites of the Ridge, there are two widespread units which are regional deposits attributed to submarine fan deposition. The data are unmigrated; each unit shows numerous diffractions from nearly vertical fault planes (Fig. 3). We suggest this is a product of dewatering prior to the deposition of the contourites.

GULF OF MEXICO

A line similar to that just described was shot across the southern Gulf of Mexico from near Tampico to the Yucatan, in the 1970's (_____________). This line again shows some parallel units to be broken by numerous faults

(Fig. 4). The only tectonic event which has affected this area is a slight regional tilting to the southeast. We suggest these faults are an expression of dewatering.

NORTH SEA

The area of the Viking Braben between Scotland and Normandy was the site of extensive deep-water Lower Tertiary siliciclastic deposition by turbidites and pelagites following renewed uplift associated with the renewal opening fo the North Atlantic. As the reflectors representing the peodelta sediments of the Eocene are traced into the basin, the data is very badly broken by numerous normal faults (Fig. 5). Younger units do not show the same breakage. We suggest that dewatering produced the observed patterns. It may also have produced overpressurization. The faulting has a major effect on the quality of the seismic data.

CONCLUSIONS

The observation of closely spaced numerous normal faults in the seismic data involving deep water sediments in tectonically quiescent areas leads to questions as to their origins. We suggest this is due to dewatering of fluid rich sediments. Some type of sliding on slopes of very low angles could contribute. The repetitive occurence of the same phenomena at different horizons vertically suggests that fluid expulsion is the more likely explanation.

If the faulting is a product of dewatering, it offers clues as to the lithofacies of the units and their diaginetic history. It also suggests limits on lateral continuity which involves the production of hydrocarbons from deep-water, thinly-bedded sediments. Detection of dewatering can also provide clues to the maturation and migration of hydrocarbons.

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SEG.PCT files

Transitional Continental Rise, SEG and Special Interpretation Issue of Geophysics

SEG 1L. Basin Location	SEG 1R. Gravity Map
SEG 2L. 5L old	SEG 2R. 5R old
SEG 3L. Flat Pair NS on MU3	H:SEG 3R. Flat Pair EW on MU3
4L. Map MU2	
5L. Map S2b	
6L. Map S2a	
7L. Map S2	
H: SEG 8L. Flat EW Top MU2 S	SEG 8R. Flat EW Top MU2 H
9L. Map MU1	
10L/R. Map S1e	
11L/R. Map S1d	
12L/R. Map S1c	
13L/R. Map S1b	
14L/R. Map S1a	
SEG 15L/R. Seismic 56.5	H:SEG 15R. Horizon 56.5 MU2
16L/R. Conclusions	16L. Acknowledgements

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GSA:

F map perspective UFS Recutting

Location map faults in plan view

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Flatten Seismic

Seismic: Georgia's Bank, Deep Gulf of Mexico, North Sea, Bahamas, Porcupine Basin.

[illegible] Porcupine Basin

GSA.PCT files
Dewatering Shallow Sediments seen on Seismic

FMAP Perspective
Location Map of faults in Plan View
Copy Lines: GSA

Upper Fan Seismic Dewatering

Flatten Seismic

Paper:
Seismic from Georgia's Bank, Deep Gulf of Mexico, North Sea, Bahamas, Porcupine Basin