higher energy carbonate facies development. Oil and gas accumulations are found on the crestal portions of this paleohigh in structural/stratigraphic traps.

The synthetic sonic program produces a series of synthetic sonic logs from real seismic traces. It is a powerful addition to the conventional seismic section because it monitors additional parameters of seismic continuity and rock properties in what otherwise is a relatively structureless subsurface carbonate terrain.

Detailed studies of seven regional synthetic sonic lines across the North field area indicate that significant decreases in interval velocities occur in all of the studied carbonate reservoir formations. Three factors affect the interval velocities on both a regional and local basis. These are (1) variation of carbonate facies- higher energy wackestone/packstone and possibly grainstones flanked by predominantly mudstones, (2) secondary porosity developed near the top of unconformity surfaces, and (3) the existence of hydrocarbons in the reservoir.

Many local lateral and vertical variations in interval velocities were noted on the synthetic sonic sections that would have otherwise been undetected, such as areas of tight or porous reservoir development, permeability barriers, and subtle faulting. In these studied formations, there are many examples of low interval velocity zones that are known to contain hydrocarbons whereas equivalent higher interval velocity zones on the seismic sections at other well site locations do not contain hydrocarbons. In many places, these variations are of sufficient magnitude to be mapped as intraformational permeability barriers. These variations were useful in explaining the occurrence of different oil-water and gas-water contacts within the same formation that could not be explained solely on structural criteria.

It can be concluded from this field study of the North field, Qatar, that the synthetic sonic technique is a particularly useful exploration tool in carbonate reservoir environments because it is able to delineate areas of higher exploration potential. The geologist can use these data in areas of known well control to project carbonate reservoir variation in areas where log or petrographic information is not available.

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Analysis of Hydrocarbon Potential of Outer Continental Shelf, Slope, and Rise of the Niger Delta, Nigeria, from Seismic and Geological Data

Whereas hydrocarbon potential studies of most parts of the Nigerian sedimentary regions have been documented, no similar assessment has yet been made for the outer continental shelf (OCS), slope, and rise of the Niger delta. The shelf, slope, and rise of the delta are frontier areas in which no wells have been drilled to date.

For this broad evaluation of hydrocarbon potential of the deep-water Niger delta, six published seismic sections were reviewed in conjunction with available geological information and geophysical data.

On the basis of an assumed average velocity of 2.0 km/sec, the seismic data indicate a sedimentary thickness of about 2 km (1.3 mi) in the deeper portions of the rise. This thickness increases shoreward to more than 3 km (1.9 mi) at the foot of the continental slope and 5 to 7 km (3 to 4.3 mi) beneath the outer continental shelf.

The distal relationship of the OCS, shelf, and rise to the sedimentary discharge of the Niger delta have made these areas of essentially deep-water marine sediments. With the high organic carbon content commonly associated with these areas, the thick shales in this distal deltaic environment would be very rich in kerogen. Coarse-grained clastics are identifiable on the seismic sections by their distinct and continuous reflection character. These potential reservoirs are common and widespread on the shelf and rise. The reservoir rocks occur as deep-sea fans, turbidites, canyon fills, and as onlap fills between diapiric intrusions, and are enclosed by shale, thus providing favorable conditions for the formation of stratigraphic traps. The diapirism in the slope and outer shelf provides favorable conditions for structural traps.

The tectonic origin of the Niger delta area implies a history of initially high geothermal gradients which decreased with time as the margin moved farther away from the Mid-Atlantic Ridge. The geothermal gradient map of the Niger delta indicates higher values for the OCS relative to the onshore and shallow-water areas where rapid sedimentation has depressed the geothermal gradients. The general increase of geothermal gradients toward the mid-ocean ridges would also provide gradients much higher than the 1.8°F/100 ft of the shallow shelf and probably approaching the 3.0°F/100 ft of the Anambra basin region. These gradient ranges are sufficient to mature the kerogen of the oldest shale source rocks (more than 40 m.y.) and to generate hydrocarbons within even the thinnest (2 km, 1.2 mi) sediment observed. In the areas of thin sediment, hydrocarbon potential would be appreciably increased in the vicinity of oceanic fracture zones where geothermal gradients are locally high. The hydrocarbon potential increases shoreward as sedimentary thickness increases and is very significant in the upper rise, the slope, and the OCS.

The decline in giant field discoveries in the Niger delta is a pointer to the depletion of Nigeria's onshore and shallow-water oil reserves. The continuing increase in world oil demand in the face of dwindling reserves and the steady improvement in deep-water drilling technology combine to make future petroleum exploration and production economically promising in Nigeria's high-potential deep-water frontier.

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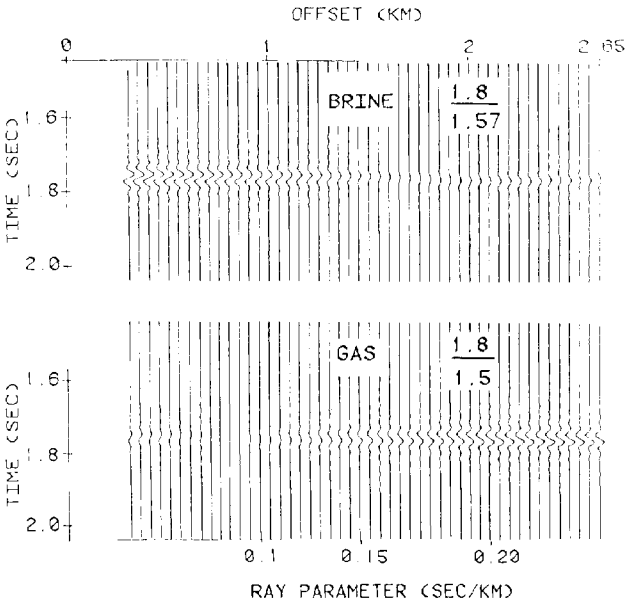
Reflection Seismogram in a Solid Layered Earth

Current approaches to seismic data processing and interpretation ignore the change in reflection coefficient with incident angle. The justification is typically based on fluid earth models or models in which the ratio of compressional velocity to shear velocity (C_p/C_s) is assumed constant. In clastic basins, normal incidence reflectivity is low, and variations in C_p/C_s can be significant. Under these conditions the change in reflection coefficient with incident angle can be very significant. Replacement of the plane wave normal incidence synthetic seismogram with the point source solid earth synthetic seismogram is likely to lead to important changes in our approach to acquisition, processing, and interpretation of seismic reflection data.

The accompanying figure shows a sample solid earth synthetic seismogram. In this example, a change from brine to gas produces a dim spot on the near traces, a bright spot on the far traces, and a polarity reversal on the stacked section. The CDP stacked trace should be different from our conventional normal incidence synthetic seismogram.

In general, in a clastic basin, we might expect to see a different set of rocks emplasized on partial stacks from different offset ranges. The sensitivity of our solid earth synthetic seismogram to changes in Poisson's ratio is such that we suggest that conventional reflection data in clastic basins should permit the extraction of band-limited shear impedance logs as well as compressional impedance logs. Attempts to work only with the CDP stacked data should yield a "hybrid impedance log;" a mix-



Synthetic seismograms after normal moveout correction for a hypothetical 20-m (66 ft) high impedance sand reservoir in shale. Ratio of compressional velocity to shear velocity in this model is 1.8 for shale, 1.57 for brine sand, and 1.5 for gas sand. Variation in reflectivity with offset in this model is a first order effect over normal recording range.

ture of the effects of compressional and shear velocity variations.

The expected variation in reflectivity with offset in clastic basins suggests that we should seriously question our conventional processing and interpretation assumptions in these areas. It also suggests that conventional seismic reflection data might yield a shear impedance image and an improved compressional impedance image rather than the currently employed hybrid impedance image.

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Lacustrine and Paludine Facies: Cretaceous Baum Limestone, South-Central Oklahoma

The Lower Cretaceous Baum Limestone in the Arbuckle Mountains of south-central Oklahoma was deposited in lacustrine and paludine settings near the Cretaceous shoreline. The unit rests unconformably on folded Pennsylvanian rocks and is overlain by and grades into the Paluxy Formation, a sandstone deposit with numerous *Ophiomorpha* burrows. The lacustrine lithofacies include the following: (1) massive micrite containing charophyte fragments and ostracodes; (2) intraformational conglomerate composed of rounded micrite clasts in a micritic matrix; (3) rounded peloids and coated peloids; (4) laminated micrite; and (5) conglomerate composed of clasts derived from Paleozoic rocks within a micritic matrix. Disintegration of charophytes that grew in the littoral zone of the lake produced the massive micrite. Intraformational conglomerates and peloids represent reworking of massive micrite whereas the other conglomerates represent fluvial influx. The coated peloids and laminated micrite probably formed as a result of algal activity in the shallow margins of the lake.

Features found within the paludine facies include: (1) brecciated micritic limestone that probably formed as a result of shrinking and swelling due to an oscillating phreatic water table; (2) subspherical nodules of micrite (peds) separated by red shale (plasma) that represent pedogenic alteration of exposed lacustrine mud; and (3) subcylindrical columns composed of micritic limestone representing root-casts. These paludine features formed as a result of pedogenic processes in a marsh that rimmed the shallow lake where the lacustrine facies accumulated.

The lacustrine and paludine facies are not grouped into sequences similar to those reported from some modern and ancient lacustrine carbonate deposits, but alternate in an apparently random pattern. Comparison with modern carbonate-dominated lacustrine systems indicates that the facies in the Baum Limestone have no precise counterparts, although they are most similar to facies in temperate-region marl lakes.

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Seismic Expression of Carbonate to Terrigenous Clastic Sediment Facies Transitions of Western Florida Shelf

Transitions from carbonate to terrigenous clastic sedimentary deposits are commonplace in the Mesozoic-Cenozoic section of the northwestern Florida shelf. On a regional scale, these transitions are responsible for a large seismic velocity variation between the areas of the Destin dome and the Middle Ground arch. In the Destin region, clayey shales and sands are more prevalent, interspersed with carbonates and evaporites, with the result that seismic transmission velocities are relatively low. Toward the south on the Middle Ground arch, the increased carbonate-evaporite content of the section results in much higher velocities. An example of this variation is that a reflection two-way travel time of 2 sec corresponds to a depth from 2.5 to 2.8 km (1.5 to 1.7 mi) in the Destin area while this same reflection time corresponds to a depth of 4 km (2.5 mi) in the vicinity of the Texaco 2516 well on the Middle Ground arch. Analyses of stacking velocities indicate that the transition is a gradual one to the north and west of Middle Ground arch.

On a local scale, transitions or terminations related to facies changes, erosion, or sediment body geometries are a potentially important factor in prediction of reservoir rock on the as yet uncondemned, 12 km(7.4 mi) broad, deep structural culmination west of the Destin tests and on the untested, 9 km (5.5 mi) broad, deep structure 20 km (12.4 mi) south of the Destin dome. The deep Exxon test on the Destin dome encountered 20 m (66 ft) of Norphlet quartz sand with porosity ranging from 20 to 30% and permeability of 1 darcy. This potentially excellent reservoir bed at a depth of 5,224 m (17,138 ft) is more than 150 m (492 ft) below the deep structural crest on the Destin dome. The Sun test, 25 km (15.5 mi) east of the Exxon well, penetrated 6 m (19.6 ft) of Smackover oomoldic dolomite with porosities of 13 to 15% and failed to find any Norphlet sand as it bottomed in Louann salt immediately below the Smackover. A study of a combination of velocity analyses, density and velocity logs, and synthetic seismograms allows speculations that the deep Destin dome and the structure on its south flank are still viable exploration prospects.

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Significance of Limestone-Shale, Rock-Stratigraphic Contacts—The Connecting Links Between Areas of Contemporaneous Carbonate and Terrigenous Detritus Sedimentation

In undisturbed depositional sequences one rarely, if ever, observes lateral change directly from mud-supported carbonate