

## Basement Structural Analysis Key In Deep Shelf Play

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HOUSTON—The deep gas play in the shallow-water Gulf of Mexico Shelf is defined as exploration drilling deeper than 15,000 feet below the sea floor. Although the costs and risks associated with deep drilling are high, the size of the deep Shelf prize is substantial—on the order of an estimated 10.5 trillion cubic feet of recoverable natural gas reserves.

And that gas is needed. U.S. Minerals Management Service reports indicate that gas production from the shallow-water Gulf Shelf—long the backbone of domestic supply—has declined by 29 percent since 1997. Furthermore, although a number of new wells are currently planned for deepwater regions of the Gulf of Mexico, none are expected to contribute significantly to new Gulf gas production levels before 2008. Even then, MMS projects that new gas produced from deepwater fields will not be sufficient to completely offset the decline from the conventional Shelf.

In the interim, oil and gas operators must find and develop sufficient natural gas to meet near- and mid-term demand needs. Although industry interest in the deep Shelf play has been encouraged by new deep gas royalty incentives, ultimate commercial success depends on establishing technological criteria to reduce the inherent risks of exploring at these great depths.

### Critical Factors

Some companies have made what appear to be substantial discoveries in the deep Shelf play, but overall, early drilling results have been rather mixed. The rush to produce commercially successful wells highlights the importance of reducing risk

by establishing and understanding the geological and geophysical environment of these deeper prospective targets. Critical environment factors include the structure and stratigraphy of these sediments, heat flow and its relationship to basement tectonics, hydrocarbon migration pathways, etc. All these elements must combine to support the seismically derived structural trap, which warrants the multimillion dollar cost to drill a single targeted prospect.

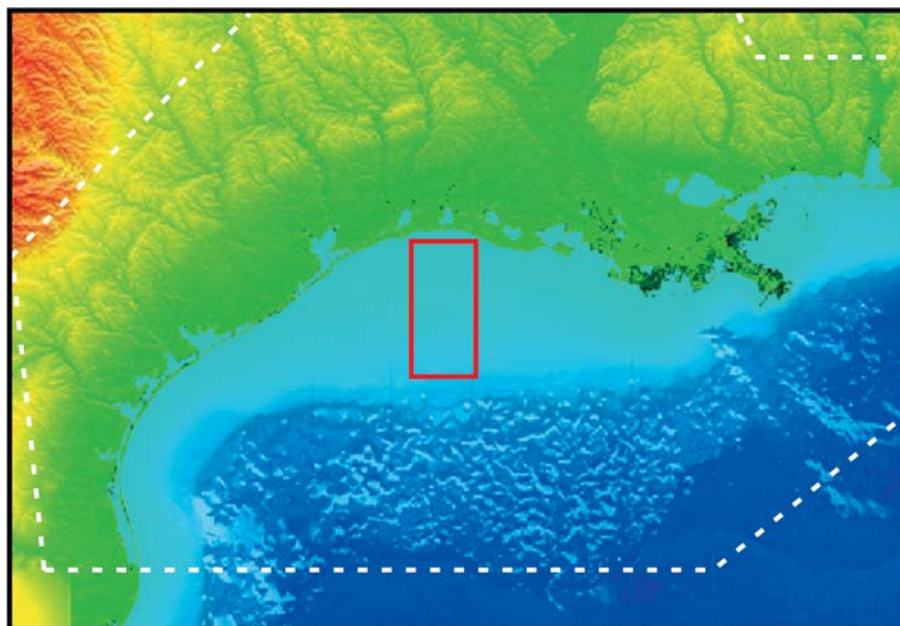
Figure 1 presents a north-to-south cross-section traversing the offshore Louisiana Shelf. Interpreting a seismic section and the magnetic basement structure along the traverse illustrates a relationship be-

tween the deep structural framework and the seismic trap, thus building geologic support for a prospective deep gas target.

The modern explorer seeks to understand the basement framework and its relationship to a producing target, even when the basement structure is known to be beyond drillable depths. One key reason is that structural analysis of the basement can advance the understanding of the overlying structures and the petroleum system for an area. Therefore, the integrated interpretation methodology starts in the deep basement, proceeds up the sedimentary section, and leads directly toward risk assessment of specific prospect sites.

FIGURE 1

Area Map



The general area of the interpreted profile traverse is shown on the western offshore Louisiana Shelf as outlined in red. The dashed white line outlines the areal extent of the magnetic basement structure interpretation.

A Northern Gulf of Mexico interpretation along the profile shown in Figure 2 utilized reflection 3-D seismic, magnetic basement structure interpretation, and a structural and stratigraphic analysis of the prospective section. The integrated interpretation demonstrates the regional relationship between seismically derived sedimentary structures, basement, and stratigraphy. The basement profile has been extracted from a Shelfwide interpretation, which was based on high-resolution magnetic data and is displayed both in two-way time and in subsea depth. Three structural levels are key: the magnetic basement structure, the intermediate Mesozoic sediment structures, and the Tertiary expanded sediments.

### Magnetic Basement

Magnetic basement is defined as the top of crystalline or igneous crust. It may or may not locally correspond with what is often termed acoustic, geologic or economic basement. In Gulf Coast geology, there have been references to a “Buller basement,” which is actually a mid-Jurassic sequence (MJS) boundary interpreted from seismic reflection and/or refraction data. It is important to recognize that this Buller basement or MJS may lie close to or be identical with crystalline basement in places, but be thousands of feet shallower than igneous basement in other places.

The basement surface in the Northwestern Louisiana Shelf area forms a series of northeast-trending ridges and deep troughs. Within the troughs, magnetic basement is significantly deeper than the premid-Jurassic sequence boundary (pre-

MJS) shown on published maps, suggesting that these troughs could contain potentially thick preJurassic sediments. Magnetic anomaly shapes and anomaly offsets indicate zones of north-verging basement thrusting, south-dipping normal faulting, and wrench faulting.

The basic basement configuration shown in Figure 2 is derived from Integrated Geophysics Corp.’s original 1997 magnetic interpretation, subsequently verified and detailed by a new interpretation of high-resolution aeromagnetic data. The depth-to-time conversion utilized velocity data from an offshore Louisiana checkshot database.

The two north-verging thrusts (brown) and associated structural highs in the northern half of the profile are part of northeast-trending basement features. A deep northeast-trending basement trough separates the two highs. Basement in the southern half of the profile is relatively deep and flat, but begins rising toward a large, deep structure immediately south of the profile. The left-lateral fault (green) is part of a series of regional northwest-trending wrench or transfer zones interpreted crossing the Louisiana Shelf.

Shallow magnetic depth estimates (shown as blue triangles) overlaid onto the seismic section may indicate salt bodies. The sand and shales in the Gulf exhibit low magnetic susceptibility values, which would be in contrast with any salt body; therefore, the contrast generates an associated magnetic signature from which the depth estimate is derived.

### Mesozoic, Tertiary Sections

The yellow horizon in Figure 2 is

shown delineating the top of a series of high-amplitude seismic reflections, and is interpreted to mark the top of Cretaceous to Jurassic sediments deposited above magnetic basement. This horizon generally matches the dip of the basement time horizon shown in blue. Structural interpretation of the mid- to upper Mesozoic section shows a series of extensional block faults (in black). A prominent basement syncline and large northward-verging basement thrust fault are correlated to a similar feature in the Mesozoic section. The seismic line shows the yellow horizon cut by a compressional fault (in brown) that lines up favorably with the thrust in the basement, and an interpreted transform motion (green fault) is positioned at the same place as the transform in the basement.

In addition, the thicknesses across the brown thrust fault do not look consistent. The northward-thrusted block displays seismic reflection patterns that indicate a thinner Mesozoic section compared to the northern-most block. The brown fault looks similar to those in graben systems like the southern North Sea that have experienced younger compressional events, incompletely reversing motion on extension faults. Compressional forces operating in the post-rift section of the Gulf of Mexico would be a new observation needing further study.

Salt movement would certainly affect the structure of the yellow horizon. But salt starting to move upward would take advantage of the oldest fault zones of weakness. The faults shown in Figure 2 are seen as the most likely pathways for salt to make its way into the Tertiary section.

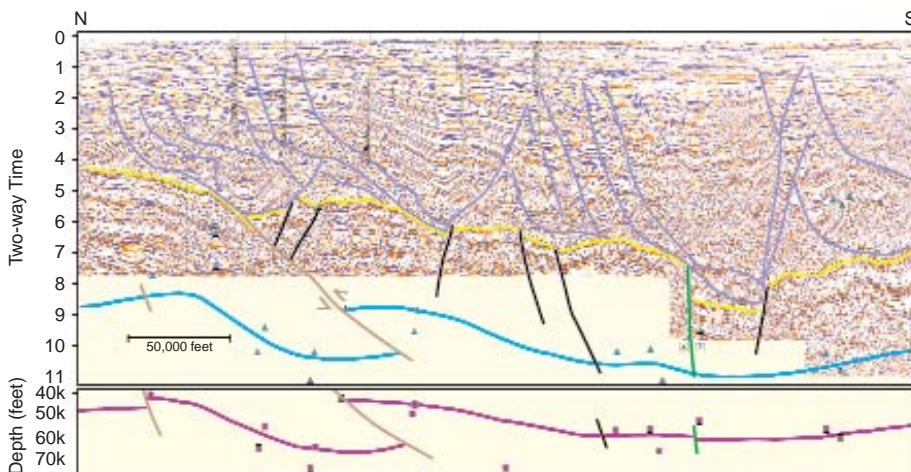
The seismic section shows the Tertiary sediments greatly expanding into a complex series of down-to-the-south, listric slide faults that sole out onto the interpreted yellow horizon. These faults seem to have greater expansion into the lows formed at the yellow horizon. The stratigraphy of the mid to lower Tertiary in this area is controlled by the expansion faults, as well log gamma curves show thick units of sand-prone sediments developing on the downthrown sides. Several contra-regional faults are interpreted in the Tertiary section and have a correlation with down-to-the-north faults cutting the yellow horizon. The green transform fault in the basement and Mesozoic marks a change of structural style in the Tertiary south of this zone. Shallow decollement surfaces form, with the deposition of thick sediments into highly rotated fault blocks.

### Migration Pathways

An analysis of hydrocarbon migration pathways is enhanced significantly by the integration of magnetics-derived basement

FIGURE 2

### Regional 3-D Seismic Line



The correlation of the seismic structural interpretation of the Tertiary and Mesozoic section to the high-resolution aeromagnetic-derived basement structure is shown on this regional 3-D seismic line from the Gulf of Mexico Shelf. The top of the Cretaceous is interpreted as the yellow horizon. The extension faults are colored black, thrust faults are colored brown, and the transfer fault is green. The time basement horizon is in blue, and the depth (subsea) basement horizon is purple. Discrete magnetic depth estimates, both basement and intrasedimentary, are displayed as blue and purple symbols.

with the results from interpretation of seismic data. Upper Jurassic to early Cretaceous-age source rock sediment thickness and facies would be affected by the basement configuration. Prominent basement synclines are viewed as favorable sites for source rock development. Prominent highs may cause thinner source rock development, but would also become collecting areas for early hydrocarbon migration.

The basement structure derived from the high-resolution aeromagnetic data gives the explorer the capability of interpreting the "initial plumbing" of a basin area. This initial plumbing is described as the migration pathway direction based on the structural configuration of the depocenter before any salt tectonism has occurred. Early hydrocarbon migration would take advantage of the most connected fault routes to the younger sediments. The most through-going faults—from the basement level, to the Mesozoic level, to the Tertiary level—are viewed as primary routes of hydrocarbon migration.

Several features on the Shelf seismic line in Figure 2 illustrate these points. The Mesozoic fault block above the prominent basement syncline does seem to exhibit a thicker section than the Mesozoic block atop the high thrust basement block. The thrust fault would be a major migration route to the Tertiary. Several listric faults and contra-regional faults in the Tertiary section connect to the posi-

tion of the deeper fault patterns.

Mathematical basin models, whether one- or two-dimensional, are of interest to geologists because heat flow, the thermal history of a sedimentary basin, influences the hydrocarbon maturation process. These basin models are mainly concerned with the heat budget of a sedimentary section over time. The depth to basement, as well as lithology and structure, contribute to basin model results. The more accurate models include the heat loss due to the basement from a quantitative depth estimate rather than from a speculated level plane, especially in the marine basins along Gulf of Mexico continental margins where rapid sedimentation reduces the heat budget.

#### Nonexclusive Data

This integrated interpretation utilized two databases (seismic and aeromagnetic) and three interpretation techniques (stratigraphy, magnetic depth estimation and structural geology). All the data were subsets from extensive nonexclusive data surveys and interpretation packages. The seismic section is a line extracted from the Shelf and deep Shelf 3-D seismic surveys acquired and processed by Fairfield Industries Inc. The detailed basement structure interpretation by Integrated Geophysics Corporation is based on the regional and high-resolution aeromagnetic databases acquired by Fugro Airborne Surveys.

The authors are now involved in the interpretation of detailed basement structure and intrasedimentary magnetic features for the offshore Texas and Louisiana Shelf utilizing Fugro Airborne Surveys' 1992 and 1998 high-resolution aeromagnetic (HRAM) surveys. The Shelf areas have been generally traversed by the HRAM 0.25 x 0.25-kilometer survey grid. The basement structural profile shown was extracted from a 1997 regional version, and then augmented by this current interpretation, which consists of a profile-by-profile analysis of the HRAM data. The results are finalized as a hand-contoured magnetic basement structure map that delineates basement depths and faults.

The example line is intended to outline the integrated interpretation methodology, which starts with the determination of the basement structure. The basement framework ultimately determines presalt depocenters, sediment fairways, delineations and extrapolations of basement transforms and fault lineations, reservoir constraints, and the "initial plumbing" of a basin. The interpretation proceeds up the sedimentary section, where stratigraphic analysis correlates with seismic attributes, sedimentary faults, basement faults (structure), and favorable hydrocarbon migration pathways.

All of these elements lead directly toward the final risk assessment and ranking of the specific prospects targeted. □



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