THE AMERICAN OIL & GAS REPORTER®
OCTOBER 2015
The "Better Business" Publication Serving the Exploration / Drilling / Production Industry

Basement Tectonics Help Locate Pay

By Corine Prieto

HOUSTON–Establishing basement tectonics should be regarded as the first step in evaluating an international frontier.

More than two decades of data correlate the relationship between oil and gas fields and discovery wells to regional structural basement characteristics in the northern Gulf of Mexico, and demonstrate the rationale for utilizing regional basement structure as a tool for evaluating exploration prospects.

Prospectivity continues to expand in the northern Gulf of Mexico as drilling technology reaches greater depths. However, the costs and risks associated with deep- and ultradeepwater exploration and drilling are increasing, and it has become apparent that using regional basement structure as an evaluation tool can help reduce both cost and risk. The position of oil and gas fields can be a vital parameter in predicting the viability of exploration sites, when the correlation between producing and projected sites can be identified.

Today's cost for acquiring seismic data over an optimum areal extent is $15 million. Completion costs for a deep-target drilling operation average $1 million per 1,000 feet, or generally a minimum of $30 million. New Wilcox and Norphlet discoveries are at depths near 30,000 feet. At these prices, cost makes a strong case for including all information, including the basement structure, in the analysis and economic assessment of prospective targets.

Based on the premise that a financial risk reduction factor can be applied when a correlation is made between the position of an oil and gas prospect and the magnetically-based basement structure map, a research study was conducted to correlate the relationship between oil and gas fields and discovery wells to regional structural basement characteristics, as well as to demonstrate the rationale for utilizing regional basement structure as an evaluation tool. The study used data amassed in the northern Gulf of Mexico over the past two decades.

The study confirms that a financial risk reduction factor can be applied when a correlation between the position of an oil and gas prospect and the magnetically-based basement structure map is made. Many operators have found the result has led to better decisions about how best to use their drilling and development budgets.

The Anticline Theory

Despite the technological explosion of recent years, the most cost effective concept defining the location of oil and gas fields arguably is still the "anticline theory," i.e., closed structural high at reservoir level. Such a structural anomaly must be located in the pathway of oil and gas, which migrates both laterally and vertically, in order to maximize its trapping potential.

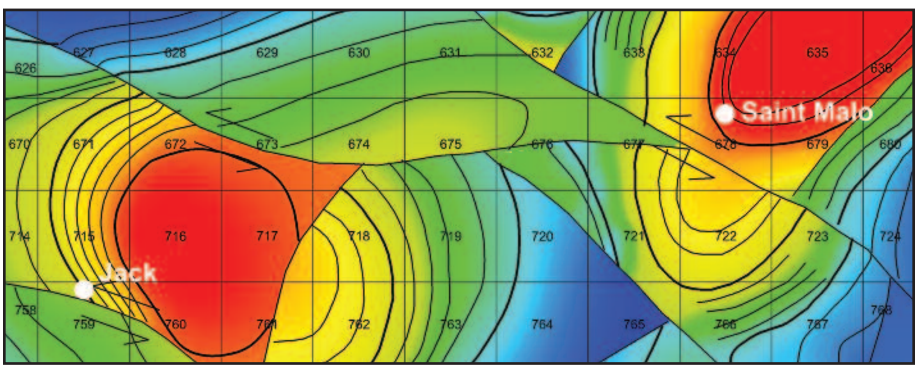
On the regional scale, a structural high must be in close proximity to a structural low (syncline, depocenter, or sub-basin). From a basinwide perspective, high structural anomalies become the focal points of migrating oil and gas.

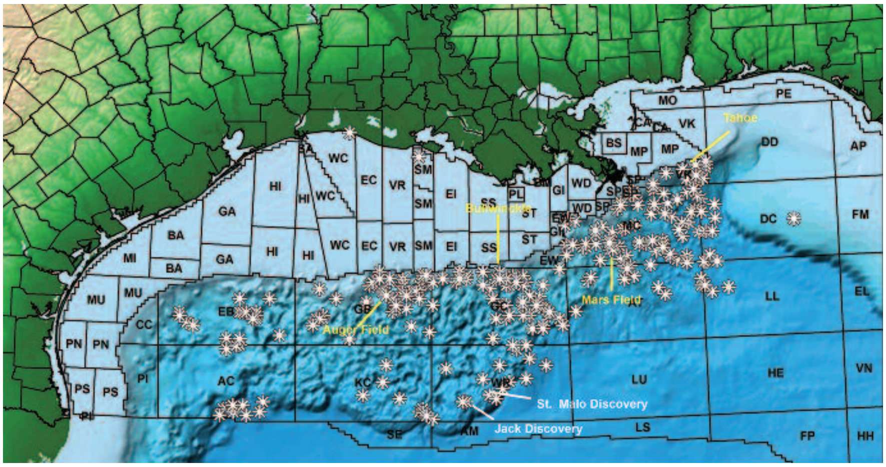
Regional (low) structural anomalies are the depocenters of generating "kitchens." In most cases, basement anomalies underlie and cause regional basinwide sedimentary structural anomalies. This is the primary rationale underlying the practical application of basement maps as exploration tools.

Less accepted–or merely less known–is that in any producing basin, oil and gas are concentrated in specific areas. In fact, 75 percent or more of the oil and gas in a producing basin is contained in only 25 percent or less of the total basin

FIGURE 1

Jack & St. Malo Discovery Locations
Depth Range is 35,000 (Red) to 50,000 (Blue) Feet





Northern Gulf of Mexico deepwater discoveries correlated to basement structure are posted on a bathymetry map.

area.

Further, structural positive (high) anomalies near structural negative (low) anomalies are the preferred targets. Typical examples are the Jack (Walker Ridge Block 759) and St. Malo (Walker Ridge Block 678) discoveries, which were drilled in ±7,000 feet of water and through salt bodies greater than 8,000 feet thick. Significantly, each discovery can be correlated to a basement high block on the depth-to-basement structure map (Figure 1). The basement depth at the Jack well location is 45,000 feet; the depth at the St. Malo structure is 38,000 feet.

Methodology

The study's research objective was to correlate the relationship between oil and gas fields and discovery wells to regional structural basement characteristics, and to demonstrate the rationale for utilizing regional basement structure as an evaluation tool.

Simply stated, the position of known oil and gas fields can be a vital parameter in predicting the viability of exploration sites when the correlation between producing and projected sites can be identified. In the deepwater regime of the northern Gulf of Mexico, the availability of a reliable regional basement structure map and a documented number of oil and gas discoveries provides an opportunity to test the strategy.

Two types of databases are utilized for the statistical analysis correlation:

- A magnetically-based basement structure (depth and contours) map; and
- A tabulation of oil and gas field discoveries from several published sources.

The basement map is the product of two decades of diligent analysis of depth estimates derived from various vintages of aeromagnetic surveys. This offshore basement map has been correlated to published geology, and has been calibrated to available refraction data, onshore structural ties, and well control. Published data identify the location of more than 258 Outer Continental Shelf blocks associated with oil and gas discoveries.

The study first plotted the acreage blocks carrying the fields reported by the Bureau of Ocean Energy Management, Regulation and Enforcement, as well as the reported discoveries. The location and the geological-structural framework of these productive blocks were correlated to a magnetically-based basement structural interpretation and classified into three primary categories:

- OCS blocks on the top of basement structural highs;
- OCS blocks in steep and faulted flanks of basement structural highs; and
- OCS blocks in basement structural lows.

Furthermore, in terms of productive acreage blocks analyzed, of the 258 acreage blocks in the Gulf deepwater region publicly reported as having discovery wells or as being part of an oil/gas field development operation, the study's findings determined the following relationships to basement structure:

- 116 discoveries, or 45 percent of total samples, are located on steep and faulted flanks of basement high blocks, such as the Jack, St. Malo and Appomattox discoveries.
- 64 discoveries, or 25 percent, are located on basement structure highs, such as Vicksburg, Troika and Dawson.
- 78 discoveries, or 30 percent, are situated in basement lows, such as Zinc, Holstein, Power Play and Tahoe.

Out of the 258 northern Gulf of Mexico field discoveries cataloged, the results to date show that approximately 70 percent of the oil and gas reserves are located either on steep/faulted flanks or on top of basement structural highs. This leads to the observation that structural lows contain thicker sediment columns, and therefore thicker sections of potential oil and gas source beds.

It is established that oil and gas generated in regional lows migrate updip onto regional highs. Regional structural highs adjacent to a deep basement structural low become attractive sites for oil accumulation. Structural highs located between two adjacent basement lows offer special attraction for migration pathways from both sides. Regional low areas become the sites for increased sediment deposition with a preferred content of oil/gas source beds (depocenters).

Regional highs become the sites for reservoir development, especially on the flanks where sand units pinch out against existing topographic and structural highs. Finally, oil and gas that is generated thermally in regional structural lows migrates updip to regional structural highs.

Logical Connection

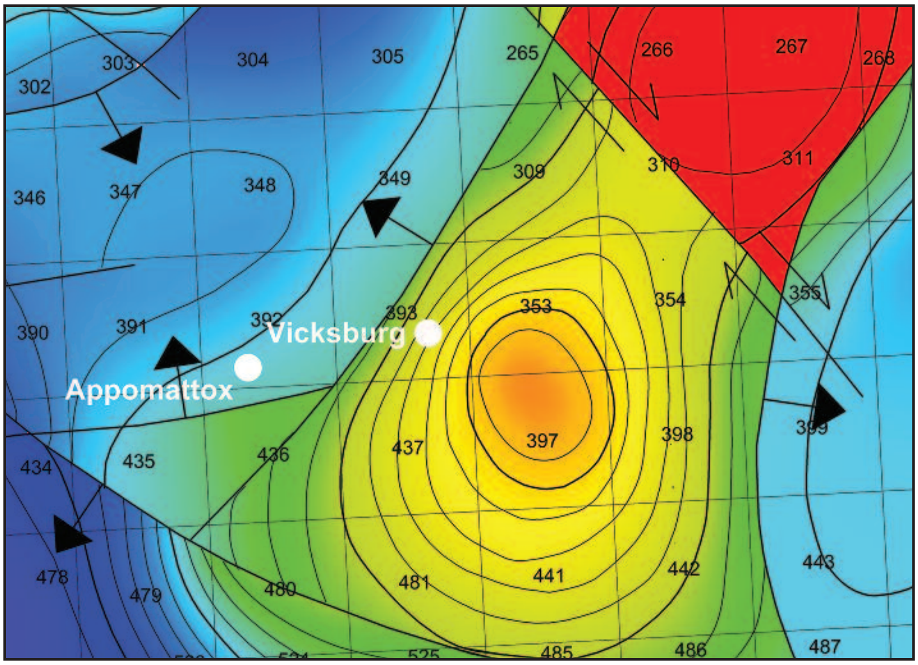
For many skeptics, the absence of a logical connection, or rather the lack of data concerning a connection between basement structure and the required structural situation at the level of deeper Jurassic, Cretaceous and Eocene source beds, is critical. Such a connection is required to assign a higher exploration value to the basement structure map.

Unfortunately, there are no maps generated with confidence from these deeper levels today. Therefore, analyzing prospective acreage blocks must be restricted to the relationships observed between the magnetically-based basement structure location and distribution of productive acreage blocks, and to discovered oil/gas reserves.

Basement structures in the northern Gulf are the result of multiple deep-seated tensional and shear faulting at the basement level. Subsequent basement motions, as well as the impact of topographical differences at the level of sedimentation during Mesozoic and Lower Tertiary times, originally led to the development of regional lows and regional

FIGURE 2

Appomattox & Vicksburg Discovery Locations
Depth Range is 40,000 (Red) to 60,000 (Blue) Feet



highs. The quality of basement structure mapping has improved continuously with higher quality data, an abundance of data, and more refined interpretation techniques.

Deepwater Gulf of Mexico discoveries have verified that the basement structure has influenced oil and gas migration. In July 2013, Shell Oil Co. announced that its deepwater Mississippi Canyon Block 393 Vicksburg discovery encountered more than 500 feet of pay at a depth of 26,385 feet (water depth was at 7,446 feet). The Vicksburg discovery was a follow-up to the Shell/Nexen Appomattox discovery (February 2012), which encountered approximately 150 feet of oil pay at a total depth of 25,851 feet.

The press release said a contingent recoverable resource of 215 million barrels of oil equivalent was identified in the Jurassic Norphlet formation in the northeast fault block of the Appomattox structure. The well is located in Mississippi Canyon Block 348 in 7,257 feet of water.

The complexity of the basement structure in the immediate area surrounding the wells is shown in Figure 2. This author has not been privy to the seismic interpretation, and can describe the basement environment only from an interpretation based on a high-resolution aeromagnetic survey and refraction velocity data. The basement depth at the Vicksburg well location is 48,000 feet. The depth at the Appomattox structure on the downthrown side of the fault is 54,000 feet.

Sequence Of Events

IGC delivered the first version of a Gulfwide basement structure in 1983. The structural configuration was based on four- by eight-mile coverage of aeromagnetic surveys.

Since we had no basement control within the Gulf, the data coverage provided an opportunity to tie to onshore structures. We interpreted that the Louisiana and Texas troughs reached depths of 65,000 feet, while the average depth across the Gulf was close to 40,000 feet below sea level. At that time, the seismic community had mapped the Gulf's basement as planar, sloping down to the abyss. The significant seismic assurance to the structural configuration did not develop until the arrival of the 14-second seismic section.

It was then that serious interest developed in the structural framework of the Gulf of Mexico. New, high-resolution aeromagnetic data were acquired from 1992 to 2009, such that today, the northern Gulf is covered with 0.5- to 0.25-mile by 1.0-mile surveys.

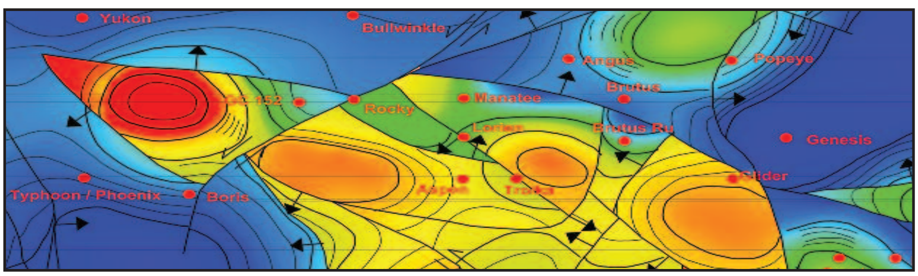
The correlation between magnetically-based basement structure and oil/gas production has been demonstrated in many basins around the world. A few examples are Argentina, the Austrian Vienna Basin, China (onshore/offshore), Ecuador, the Hungarian Plains, India (western/eastern offshore), Peru, Sumatra (northwestern), former Soviet Union, and Yugoslavia.

The statistics we started to gather in 2000 indicate the Gulf of Mexico can be added to the list. The 2015 analysis indicates that approximately 70 percent of the Gulf's oil- and gas-field discovery reserves can be related to structure described as either steep/faulted flanks or drape-over of basement highs. Early discoveries in the deepwater Gulf of Mexico–Tahoe (Viosca Knoll Block 783 in 1984), Bullwinkle (Green Canyon Block 65 in 1983), Auger in 1987, and Mars in 1989–led to an awareness of its prospectivity by a vast majority of pioneer companies (Figure 3).

These initial discoveries flanked our interpretation of a ridge complex of structural highs with an average depth of 44,000 feet and an average water depth of 5,200 feet paralleling the Louisiana Coastline, which I called the "first buttress" into the deepwater region. There are more examples, such as ExxonMobil's Hadrian discoveries in Keathley Canyon. The Davy Jones discovery on the Louisiana Shelf lies on what I interpret as a basement

FIGURE 3

"First Buttress" Northern Gulf Deepwater Discoveries
Depth Range is 35,000 (Red) to 60,000 (Blue) Feet



embayment, as do the Lower Tertiary discoveries in Alaminos Canyon.

This started our collection of discovery statistics published in various industry sources. The 15-year collection is evidence that the Gulf of Mexico's structural framework is a critical and integral part of the hydrocarbon evaluation process. We are aware that the oil and gas play within the sedimentary section differs with each discovery, yet 70 percent correlate to basement structure.

Basement structure is defined as the topography and structural fabric (shear zones and fault zones) within the crystalline basement. These deepwater and Shelf structures in the Gulf of Mexico are the result of uplifts, platforms, or multiple deep-seated tensional and shear faulting.

The process of delineating regional uplifted blocks (horsts) and depocenters associated with faults/fracture zones, enables companies to locate hydrocarbon prospects (migration pathways). The Wilcox and Norphlet plays appear to correlate to basement embayments (platforms).

Structural framework controls alternating extensional and compressional dynamics of the Louann Salt. The rate of sedimentation and the rate of subsidence are controlled by the structural configuration and tectonics of the basement; i.e., sedimentary regression and transgression through channels and fan systems. Understanding the structural fabrics of the basement and overlying sedimentary sections can unravel areas of identical structural developments in less well-explored sectors of the Gulf of Mexico. ❒

Editor's Note: Many have contributed to the IGC basement structural interpretation and findings discussed in this article, notably Michael Alexander, associate geophysicist; J.C. Pratsch, consulting geologist; and Karim Aimadeddine, geophysicist. CGG (formally Fugro Airborne of Canada) provided the aeromagnetic database utilized in this undertaking. Worldwide areas and basins discussed are from publications that described the concentration of oil and gas.

CORINE PRIETO

Corine Prieto is founder and president of Integrated Geophysics Corp. in Houston. She has 40 years of integrated geophysical and geological experience in the Gulf of Mexico, onshore North American basins, the North Sea, Africa, the Middle East, the Far East, and the West Indies. Before founding IGC in 1981, Prieto served five years as exploration supervisor at Superior Oil Company and eight years as a geophysicist at Mobil Oil. She holds a B.S. in physics and math from the University of Texas at El Paso, and an M.S. in applied physics from the University of Toronto.