PS Integrated Seismic Structure, Stratigraphy and Magnetic Basement Interpretation: Offshore Louisiana Shelf*

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Abstract

This paper presents a rationale for using an integrated interpretation of seismic and magnetic data to reduce risk for a deep play. The methodology has application not only in the Gulf of Mexico (GOM) but also in similar geologic settings.

Basement, defined here as the magnetic top of crystalline crust, may not correspond locally to "acoustic" basement identified in some GOM literature as a mid-Jurassic sequence boundary (MJS). Depth differences between basement and MJS, ranging up to thousands of feet, are significant because they infer the existence of local pre-MJS troughs with large volumes of nonmagnetic formations and deep hydrocarbon-generating "kitchens".

An example of integrated data is illustrated on a north-south seismic section from the Louisiana Shelf. It demonstrates a relationship between potential reservoirs, faults for trapping and/or migration pathways, potential "kitchens", and basement structure. The posted basement and MJS profiles cross a set of basement ridges, troughs, and faults. A strong reflector, generally coincident with the MJS depths, is conformable with the basement surface except over the basement trough. Here the reflector shows north dip and supports interpretation of an anomalously thick pre-MJS section.

Reflections marking the top of Cretaceous-Jurassic (K-J) section are conformable with dips of the underlying basement. Two complex K-J features overlying a basement trough, adjacent basement ridges, and a north-verging basement thrust are deemed attractive targets given their positive structure, proximity to potential deep pre-MJS hydrocarbon "kitchens", and adjacent faults to provide "plumbing"

for favorable hydrocarbon migration. In contrast, both basement and seismic structure to the south show a regional deep from which early-stage hydrocarbons would have migrated laterally away to more favorable locations.

An Integrated Approach

A north-south cross-section traversing part of the offshore Louisiana Shelf has been used to study a prospective hydrocarbon environment. This example provides a rationale for using an integrated approach to seismic structure/stratigraphy interpretation and magnetic basement structure interpretation. The integration incorporates use of a 2D seismic/magnetic model whose basic sedimentary geometry was established by a time-depth conversion of a simplified interpretation of a seismic profile from a 3D survey. Magnetic basement and crustal features of the model were extracted from several proprietary regional studies. Data from a seismic refraction site near the southern end of the profile provides some corroborative depths to MCU/K-T and MJS on both model and seismic profile. Bouguer and calculated gravity profiles are displayed to show that the model will fit gravity as well as the magnetics.

An important end-result of this model that fits all data sets is the visual demonstration of relationships between 1) potential reservoirs in seismically-mapped sedimentary structures, 2) their gross stratigraphy, 3) the faults required for trapping and/or providing migration pathways, 4) a potential hydrocarbon "kitchen", and 5) the magnetic basement.

Magnetic Interpretation

Magnetic basement interpretation provides a controlled bottom-up approach to an understanding of the geologic section and early-stage hydrocarbon migration pathways, or "initial plumbing". Magnetic basement is defined here as the top of crystalline or igneous crust, or less commonly, the top of extremely thick igneous intrusives/extrusives. It may or may not locally correspond with what is sometimes termed acoustic, geologic or economic basement. In the literature pertaining to the U.S. Gulf Coast there are references to an acoustic "basement" which may be better-defined as a mid-Jurassic sequence boundary (MJS). Depth differences between interpreted magnetic basement depths and the MJS surface can range up to thousands of feet. These differences are significant because they infer the existence of pre-mid Jurassic troughs containing large volumes of nonmagnetic formations which could act as "kitchens" for generation of hydrocarbons.

The basement profile for this 2D model was extracted from a proprietary regional basement surface interpretation that was based on discrete quantitative magnetic depth estimates and covers the northern Gulf of Mexico. The profile crosses a series of basement ridges, deep troughs, and a major fault zone. Equivalent magnetic depth estimates along the profile are posted as depth points (red dots) on the model and as time-converted points on the seismic profile. The time-depth conversion was based on data from a nearby offshore well velocity survey. Colored arrows identify pertinent horizons or boundaries: yellow is MCU/K-T (Mid-Cretaceous/Cretaceous-Tertiary), green is MJS, red is basement.

In addition to the depth estimates from magnetic basement, there are both supra- and sub-basement depth estimates (red dots). They were initially considered rogue values or were attributed to some form of magnetic anomaly interference. However, numerous magnetic depths in the 20,000-30,000 foot range in other areas of the Shelf suggest the possibility of a magnetized sedimentary layer. On this profile the magnetic depths correlate with a strong band (yellow) of seismic reflections and with a seismic refraction depth point (red triangle) at or near the MCU/K-T boundary. This correlation leads to the concept that the MCU/K-T is, at least locally, a magnetized layer. Sub-basement depth estimates are also present elsewhere on the Shelf and are attributed to an upper crust-lower crust magnetic boundary.

Seismic Interpretation

A prominent set of high-amplitude reflections (yellow) ranging between 4.0 and 8.0 seconds on the seismic section can be locally correlated with a horizon variously described as the MCU, K-T boundary, or top of Cretaceous-Jurassic (K-J) sediments. The MJS, as estimated from published maps, correlates with a deeper set of high-amplitude reflectors (green) between 6.0 and 9.0 seconds.

The K-T horizon is generally conformable with dips of the underlying magnetic basement time horizon. In contrast, dips in the overlying Cenozoic section appear to be controlled by possible diapiric features and/or by a series of listric, contra-regional, or extensional block faults that do not extend to basement.

In the north half of the profile (Thrust Zone Area), lateral seismic character changes and structurally complex features in the post K-T section overlie a zone of major basement faulting and structuring. Local sedimentary features are associated with a deep basement trough, its adjacent basement ridges, and with the northwest-verging thrusts. A strong energy band (green) generally coincident with time-converted depths extracted from the MJS surface is conformable with the basement surface except over the trough. Here the reflector shows some north dip, thus supporting the concept of an anomalously thick pre-MJS section which could form a deep hydrocarbon “kitchen” with adjacent faults to provide “plumbing” for early-stage migration.

To the south (Transfer Zone), an abrupt southward thinning of the pre-MJS section and dramatic expansion of the post K-T/Cenozoic section occurs over an interpreted regional left-lateral basement transform fault zone intersected by the profile. There is an evident north-to-south change in seismic character in the deep Cenozoic. Both the basement structure and seismic structure show the area to be a regional deep from which early-stage hydrocarbons would have migrated laterally to more favorable locations. As such, this would be an area of high-risk exploration.

Integrated 2D Model

The post-K-T boundary portion of the model has not been interpreted in detail, other than to post depth-converted reflector horizons and fault traces. The model's MCU/K-T horizon (yellow band) is shown as broken by significant faults to the north, but is relatively continuous to the south. Its depth at the north end was established by ties to other studies and at the south end by a tie to a refraction depth (red triangle). Both the northern and southern portions correlate with magnetic depth estimates; there are no estimates in the central portion.

One of the more important features of the model is the pre-MJS section overlying magnetic basement. Previously the MJS was thought to be not only an acoustic basement but also a geologic basement. Depth-to-top of the modeled MJS is roughly based on published data, and there is a southern tie to a refraction depth (red triangle). Use of seismic reflection bands at an approximated MJS depth provides more structural detail than the published smoothed surface. In some areas the MJS is coincident with magnetic basement but in this area it is not. In fact, as the model demonstrates, there may be thousands of feet of pre-MJS section overlying magnetic basement.

Conclusions and Questions

The coincidence of supra-basement magnetic depths and strong seismic events at MCU/K-T levels suggests that quantitative magnetic interpretation could be used to help bridge seismic interpretation data gaps. It also raises questions as to why the boundary is magnetized and if some level of magnetization is continuous over large areas of the Shelf.

The interpreted non-magnetic pre-MJS is relatively thick and may have a Paleozoic "hydrocarbon kitchen" potential. Structuring and faulting in and above the MJS would control the necessary migration pathways to conduct hydrocarbons to the overlying sediments.

A configuration of the magnetic basement surface which best fits the pattern of depth estimates and the magnetic profile requires a series of northwest-verging thrusts in the labeled Thrust Zone, and a collapsed high in the labeled Transfer Zone. These basement features are reflected by lateral and vertical changes in the overlying sediments, as evidenced by the seismic data. One of the basement thrust sheets must be modeled as highly magnetic in order to fit the observed and calculated magnetic profiles. The sheet may be an ophiolite. While this concept is speculative, it is not unique to this profile; there are other portions of the Shelf and adjacent areas that can be interpreted to have similar basement structures and composition. That should raise questions as to whether the tectonics of the Louisiana Shelf are as straightforward as often described, or whether there have been tectonic events not fully recognized. The model shows a lower crust of moderately high density, but is relatively nonmagnetic. Its top is established by deep magnetic depth estimates which relate to upper crust/lower crust magnetic contrasts.

In summary, integration of seismic and magnetic interpretations can lower the risk inherent in exploring deep targets in an offshore shelf environment. Magnetic interpretation can locate the deep depocenters, high blocks, and major sediment fairways, thus highlighting the most promising deep hydrocarbon generation, migration, and accumulation areas. Seismic interpretation can then be concentrated on detailing the sedimentary structure and stratigraphy of the highgraded areas.

Acknowledgements

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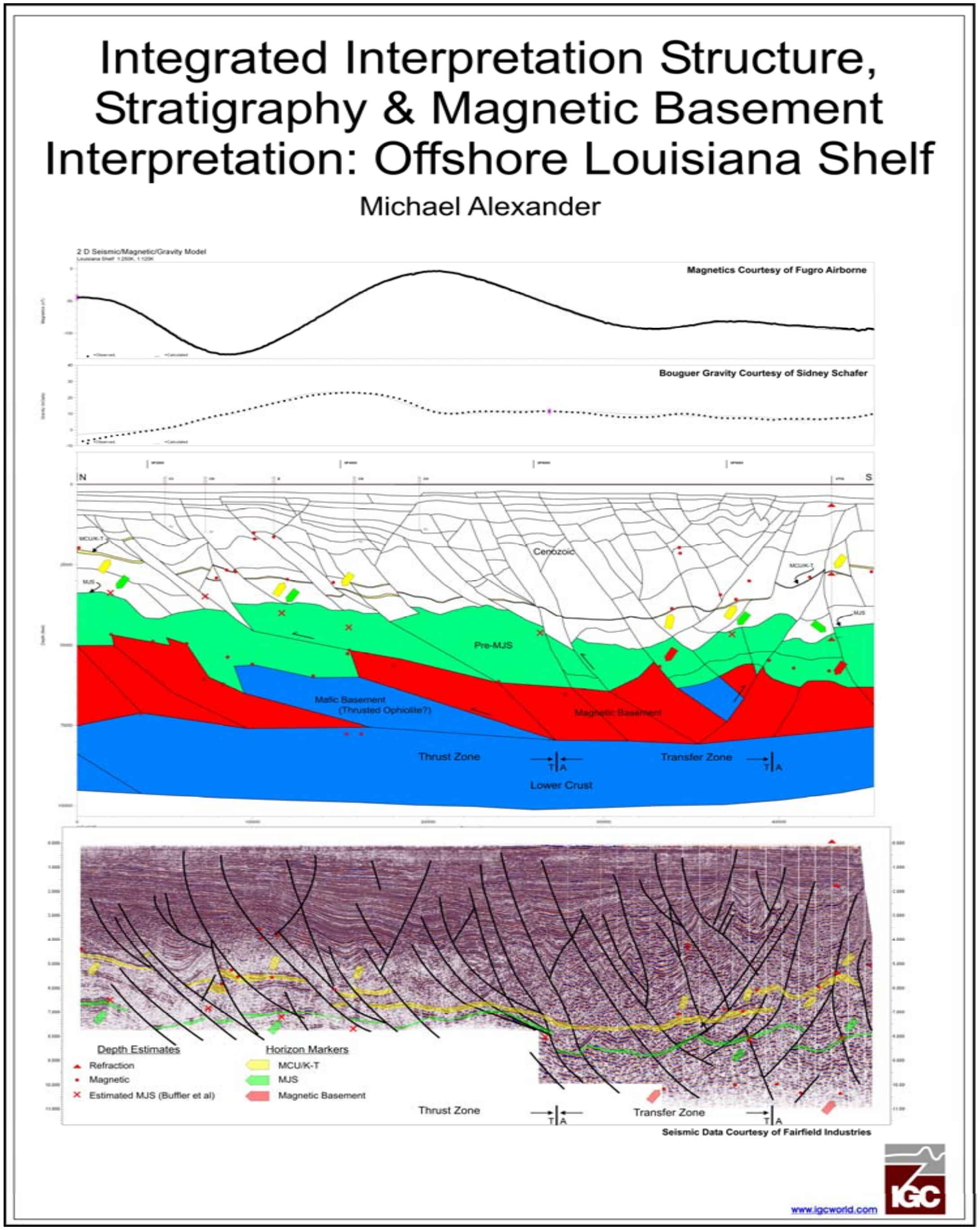

North-south seismic section across Louisiana Gulf Of Mexico Shelf, with integrated interpretation of structure, stratigraphy and magnetic basement.

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