Non-seismic Constraints in Structurally Complex Regions*

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Search and Discovery Article #10969 (2017)**
Posted July 3, 2017

*Adapted from poster presentation given at AAPG 2017 Annual Convention and Exhibition, Houston, Texas, April 2-5, 2017
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Abstract

Understanding structurally complex regions with a sole geophysical method can pose some challenges, especially, when coupled with extensive igneous activity. Fold belt areas which involve reactivation of basement with high angle faults, detachment folds, and out-of-sequence thin-skinned thrusts are difficult to image even with new seismic acquisition and processing techniques. The addition of non-seismic methods for exploration purposes have proven valuable in aiding interpretation, especially at deep basement levels. We present examples from structurally complex regions in Colorado and the Neuquén Basin, which combine the use of non-seismic techniques to help understand the hydrocarbon basin and its relationship with the basement. These examples integrate gravity and magnetic data with existing well and seismic data, as well as remote sensing data to help identify the shallow structure. An example from Colorado also includes airborne Electro-Magnetic (EM) data, along with ground Magnetotellurics (MT) data, which aid in identifying the overall basin architecture. The integration of these datasets are used to produce a series of 2D forward models, structural restorations are used as inputs where available, and 3D inversion models to help understand the structural complexities of the regions. This integrated interpretation approach, combining multi-physics and geological data analysis, provides a more robust understanding of the geology of a basin, especially in complex tectonic regions where seismic exploration can be challenging.

References Cited


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Introduction

Understanding structurally complex regions with a sole geophysical method can pose several challenges, which are often coupled with extensive invasive activity. Fold belt structures in Permo-Triassic rift basins typically feature high angle faults, detachment folds and out-of-sequence thrusts, making it difficult to image even with new seismic acquisition and processing techniques. The addition of non-seismic methods for exploration purposes has proven valuable in aiding integral framework and controlling the basin’s stratigraphic and lithological levels. We present examples from different basins such as the Aglio Oligocene-Zenú basin where the Neaquén Basin, which combine the use of non-seismic techniques to help understand seismic data, hydrocarbon basin and its relationship with the basement.

Methodology

These multi-measurement geological and geophysical programs were undertaken in complex, under-explored tectonic regions to gain better knowledge of the structure and relationship between the sedimentary basin and the economic basement. NEOS acquired gravity and magnetic data across the western side of the Neaquén Basin, in Argentina, the Idaho Bath Wash Basin, in northern Colorado, and the Sheep Mountain area of southern Colorado. All geophysical datasets were first analyzed independently and then integrated using a series of 2D models. Both gravity and magnetic data were interpreted individually using standard geophysical filters to produce magnetic and gravity structural interpretation maps, which yield major structural features that are well correlated with regionally mapped faults. These data were also used for deep fault interpretation, especially in areas deprived of seismic data. The structural interpretation maps of the gravity data helped outline basin architecture and better define sub-basinal and basement contacts. The magnetic data was instrumental in identifying igneous intrusions at various depths. The multidisciplinary methodological approach created using Geosoft GS/MS-Profile modeling v. 8.1, a gravity and magnetic modeling software, which is based primarily on the methods of Tewati et al. (1969) and Tewati and Huritz (1964) (more information available from http://www.geosoft.com/). This software allowed us to build geologic models with airborne gravity and magnetic data acquired, and requiring only a few geological well data, magnetic susceptibility measurements and seismic interpretations. Each geologic interval was given a density and susceptibility value. Density values were determined from published density data for the regions, and susceptibility values were taken from field magnetic susceptibility measurements. What data were not available, such values were estimated from a geological table (Tewati, Gillett, and Sheffer, 1969).

Neaquén Basin

The study area is located in the western part of the Neaquén Basin. This basin is adjacent to a retro-orogenic rift basin that is the result of a steeply dipping subduction regime marked by back-arc subduction and the expansion of marine sedimentation. The geology of the Neaquén Basin displays a complex structural evolution, with the presence of pre-Cenozoic, Cretaceous and Cenozoic formations. As a result of the Neaquén Basin and throughout the Cenozoic, the Neaquén region developed as a retro-orogenic basin with significant volcanism.

Results

Neaquén Basin

The magnetic and gravity data reveal NE-SW deep basement structure suggesting varied lithology as observed in igneous and metamorphic rocks in outcrop. In the profile below, the deepest layer represents the base of the sedimentary basin, which suggests an irregular topography with basement structures that extend through the entire study area. The Precambrian basement is as shallow as ~3,500 ft above sea-level towards the east, and as deep as ~10,000 ft below sea-level towards the southeast. The wide range of lithologies observed in outcrop, along with mafic and intermediate dikes, consisting of andesite, basalt, and dacite, are suggested in the lateral and vertical variation of the basement’s density and magnetic susceptibility. Therefore, the gravity results illustrating a lateral basement density variation is most likely representing lateral differences in mineralogy within the gneiss and the Uinta Mountains Group; and the magnetic results for the basement, showing lateral susceptibility variations, are most likely due to larger lithological changes.

Sand Wash Basin

The magnetic and gravity data reveal the NE-SW deep basement structure with a transition in magnetic and gravity susceptibility. This transition is related to major volcanism, the Neaquén Basin, and the associated NE-SW NEP, perpendicularly to major structural trend and parallel to interpreted faults at the surface. The basement appears to be intruded by younger, higher susceptibility igneous rocks, not all of which are observed in the surface. This study also included the collection of Electromagnetic (EM) data. These data also reveal the major structural trends and confirm the location of igneous intrusions and basement related features.

Sheep Mountain

The magnetic and gravity data reveal the major NW-SE structural trend and a dramatic increase in magnetic susceptibility related to the Precambrian suture zone. The data also reveal two sub-basins divided by high density and high magnetic susceptibility material likely related to igneous intrusions. The magnetic data helped recognize major dikes orientations, radially related to major volcanism. NW-SE domes were identified along the NE-SW NEP, perpendicularly to major structural trend and parallel to interpreted suture zones at depth and E-W. The intrusions mapped at the surface appear to continue at depth in most cases. The magnetic bodies mapped at depth and not observed at the surface are likely sources of the isolated E-W high magnetic bodies and swarms of dikes mapped perpendicularly on the surface eastern part of the basin. The basement appears to be intruded by younger, higher susceptibility igneous rocks, not all of which are observed at the surface. This study also included the collection of Electromagnetic (EM) data. These data also reveal the major structural trends and confirm the location of igneous intrusions and basement related features.

Conclusions

The combination of all available datasets was successful in outlining basin architecture. Potential for future work include possible fold belts involved tectonics and thicker sections of repeated strata associated with basin. Identification of small-scale faults and magnetic data, as well as remote sensing data to help identify the shallow structures. An example from Colorado also includes Electro-Magnetic (EM) data, which aid in better identifying the overall basin architecture.

In all profiles, the contact between the Precambrian basement and the Neaquén Basin strata above denotes a large magnetic susceptibility contrast across the entire reef, compared to the magnetic data observed in the magnetic data, and these anomalies are interpreted to represent shallow intrusions of Tertiary age. Similarly, the gravity data suggest the highest density contrasts to be located across the boundary between the sedimentary basin and basement. The integration of these datasets is used to produce a series of 2D forward models to help understand the structural complexities of the regions. This integrated interpretation approach, combining multiphysics and geological data analysis, provides a more robust understanding of the geology of a basin, especially in complex tectonic regions where seismic exploration can be challenging.

Acknowledgments

The author would like to thank NEOS for the financial support and funding for the production of the data. I would also like to thank the entire NEOS team for the acquisition and processing of the presented data.

References


Endnote

The interpretation of the EM data are derived from the modeled profile above the Neaquén Basin. It shows the interpolated values in low magnetic areas (blue) and sedimentary basin and higher susceptibility zones (red and yellow) in agreement with igneous intrusions and basement related features.

The black circles in the panels above the section represent the real magnetic and gravity data profiles, respectively. The black lines in the top two panels represent the data calculated from the profile, whereas the red line represents the error between the two. This caption is applicable to all profiles.