PS Non-seismic Constraints in Structurally Complex Regions*

M. Soledad Velasco[1]

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[1]NEOS, Walnut Creek, California, United States (solvelasco@yahoo.com)

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

Haun, J.D., and R.J. Weimer, 1960, Cretaceous Stratigraphy of Colorado, *in* R.J. Weimer and J.D. Haun (eds.), Guide to the Geology of Colorado: Geological Society of America, Rocky Mountain Association of Geologists and Colorado Scientific Society Guidebook, p. 58-65.

Heller, P.L., S.S. Bowdler, H.P. Chambers, J.C. Coogan, E.S. Hagen, M.W. Shuster, N.S. Winslow, and T.F. Lawton, 1986, Time of Initial Thrusting in the Sevier Orogenic Belt, Idaho, Wyoming, and Utah: Geology, v. 14/5, p. 388-391.

Lindsey, D.A., B.J. Johnson, and P.A.M. Andriessen, 1983, Laramide and Neogene Structure of the Sangre de Cristo Range, South-Central Colorado, *in* J.D. Lowell (ed.), Rocky Mountain Foreland Basins and Uplifts: Rocky Mountain Association of Geologists, p. 219–228.

Popov, M., V. Nuccio, T. Dyman, T. Gognat, R. Johnson, J. Schmoker, M. Wilson, and C. Bartberger, 2001, Basin-Centered Gas Systems of the U.S.: USGS Open-File Report 01-135,version1.0., 506 p.

Sims, P.K., B. Viki, and C.A. Finn, 2001, Preliminary Precambrian Basement Map of Colorado – A Geologic Interpretation of an Aeromagnetic Anomaly Map: USGS Open-File Report 01-0364.

Talwani, M., J.L. Worzel, and M. Landisman, 1959, Rapid Gravity Computations for Two-Dimensional Bodies with Application to the Mendocino Submarine Fracture Zone: Journal of Geophysical Research, v. 64, p. 49-61.

Talwani, M., and J.R. Heirtzler, 1964, Computation of Magnetic Anomalies Caused by Two-Dimensional Bodies of Arbitrary Shape, *in* G.A. Parks (ed.), Computers in Mineral Industries, Part 1: Stanford University Publications, Geological Sciences, v. 9, p. 464-480.

Telford, W.M., L.P. Geldart, and R.E. Sheriff, 1990, Applied Geophysics, Cambridge University Press, 2 edition, 792 p.

Zamora Valcarce, G., 2006, Estructura y Cinemática de la Faja Plegada y Corrida del Agrio, Cuenca Neuquina: PhD Thesis, Universidad de Buenos Aires, p. 302.

Zapata, T.R., and A. Folguera, 2005, Tectonic Evolution of the Andean Fold and Thrust Belt of the Southern Neuquén Basin, Argentina, *in* G. Veiga, L. Spalletti, E. Schwarz, and J. Howell (eds.), The Neuquén Basin: A Case Study in Sequence Stratigraphy and Basin Dynamics: Geological Society, London, Special Publications v. 252, p. 37-56.

Non-seismic constraints in structurally complex regions

M. Soledad Velasco

NEOS, 6210 Stoneridge Mall Rd., ste. 450, Pleasanton, CA 94588

Introduction

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.

Methodology

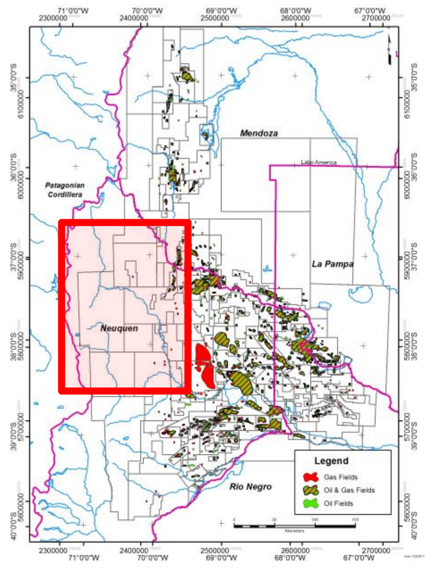
Three multi-measurement geological and geophysical programs were undertaken in complex, under-explored tectonic regions to gain better knowledge of the structure and relationship between the sedimentary basin and the economic basement. NEOS acquired gravity and magnetic data across the western side of the Neuquén Basin, in Argentina, the Sand Wash Basin, in northern Colorado, and the Sheep Mountain area of southern Colorado.

All geophysical datasets were first analyzed independently and later used to create a series of 2D models. Both gravity and magnetic data were interpreted individually using various derivatives and 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 from the gravity data helped outline basin architecture and better define sub-basins. The magnetic data was instrumental in identifying igneous intrusions at various depths.

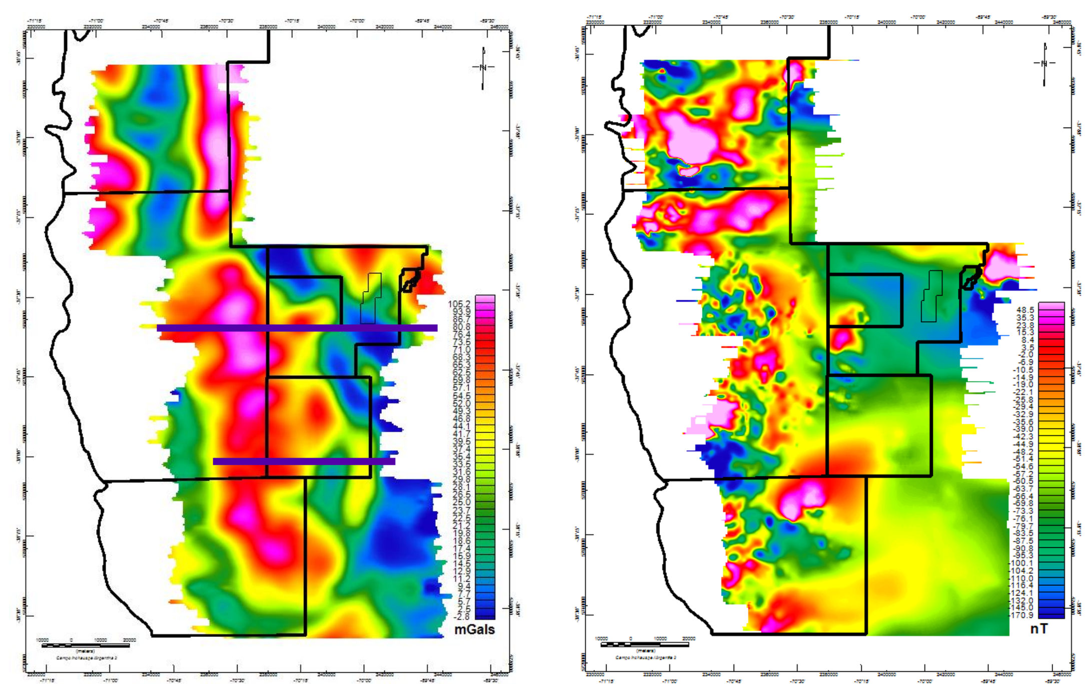
The modeled profiles were created using Geosoft GM-SYS Profile modeling v. 8.1, a gravity and magnetic modeling software, which is based primarily on the methods of Talwani et al. (1959) and Talwani and Heirtzler (1964) (more information available from http://www.geosoft.com/). This software allowed us to build geologic models with the airborne gravity and magnetic data acquired, and integrating them with surface geology, well data, magnetic susceptibility measurements and seismic interpretations. Each geologic interval was given a density and susceptibility value. Density values were determined from well logs, when available, and susceptibility values were taken from field magnetic susceptibility measurements. When data were not available, such values were estimated from a geophysical table (Telford, Geldart, and Sheriff, 1990).

Results

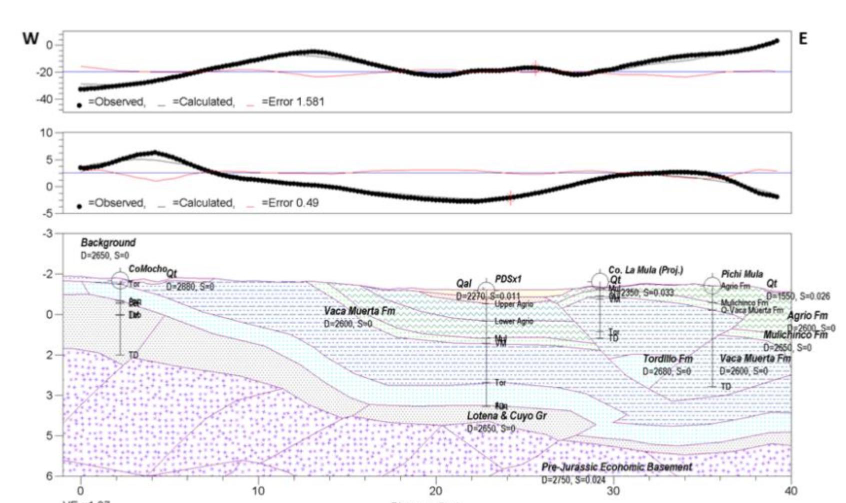
Neuquén Basin

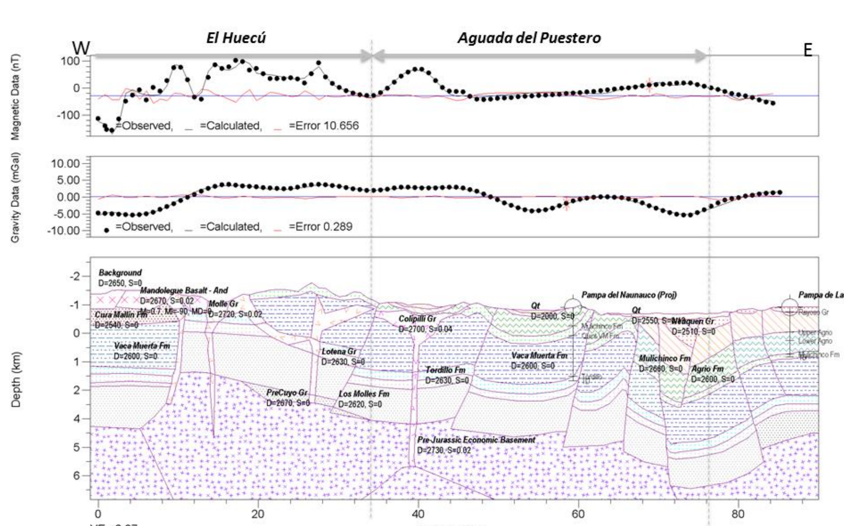


The study area is located in the western part of the Neuquén Basin. This basin initiated as a retro-arc rift-related basin in the late Triassic. During the early-middle Jurassic the onset of a steeply dipping subduction regime led to back-arc subsidence and the expansion of marine domination. Towards the end of the early Cretaceous changes in the subduction rates resulted in the development of a compressional tectonic regime that caused inversion of previous extensional structures. As a result, during the late Cretaceous and throughout the Cenozoic, the Neuquén region developed as a retro-arc foreland basin with significant volcanism.



The positive anomalies observed in the gravity data reveal basement related features close to the surface. These are also observed in the magnetic data, where volcanic plugs and intrusions are evident in the western portion of the survey. All profiles were constrained by surface geology and, where available, well log information. The average density and susceptibility values used for each interval are shown in the profile.

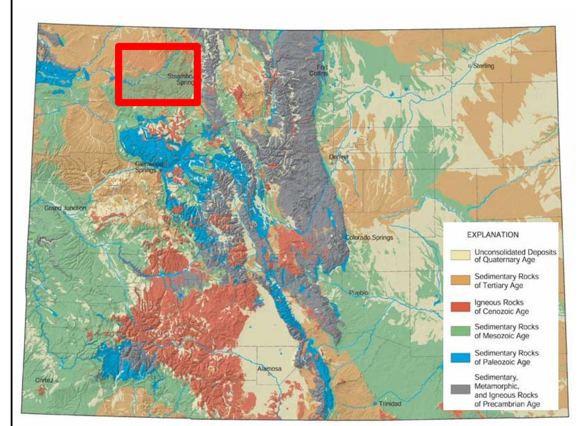




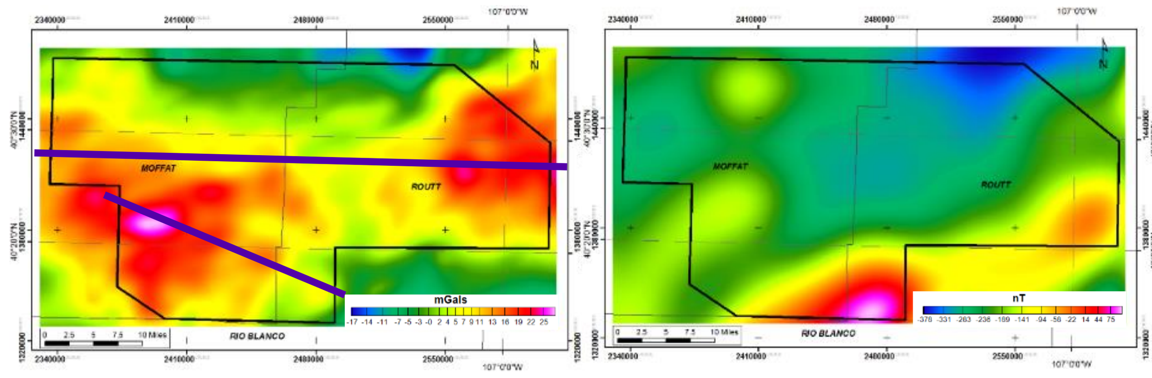
The basement is represented by pink colors, Paleozoic sediments by grays, Mesozoic by blues and greens, and Tertiary and Quaternary by beige. Igneous intrusions are shown in gray with a fill pattern. The southernmost profile is partly based on a balanced cross-section published in Zamora Valcarce (2006) and Zapata and Folguera (2005).

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

Sand Wash Basin

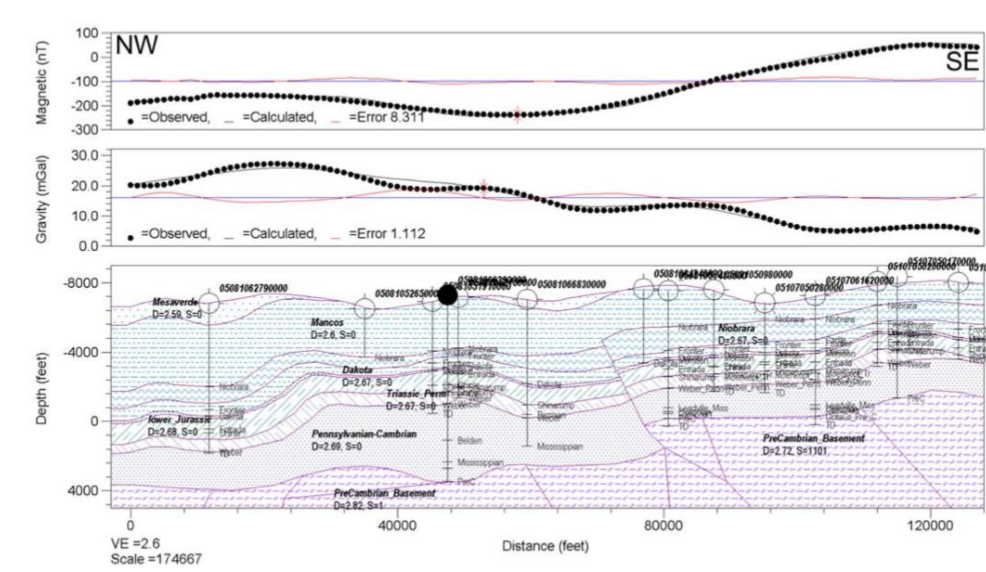


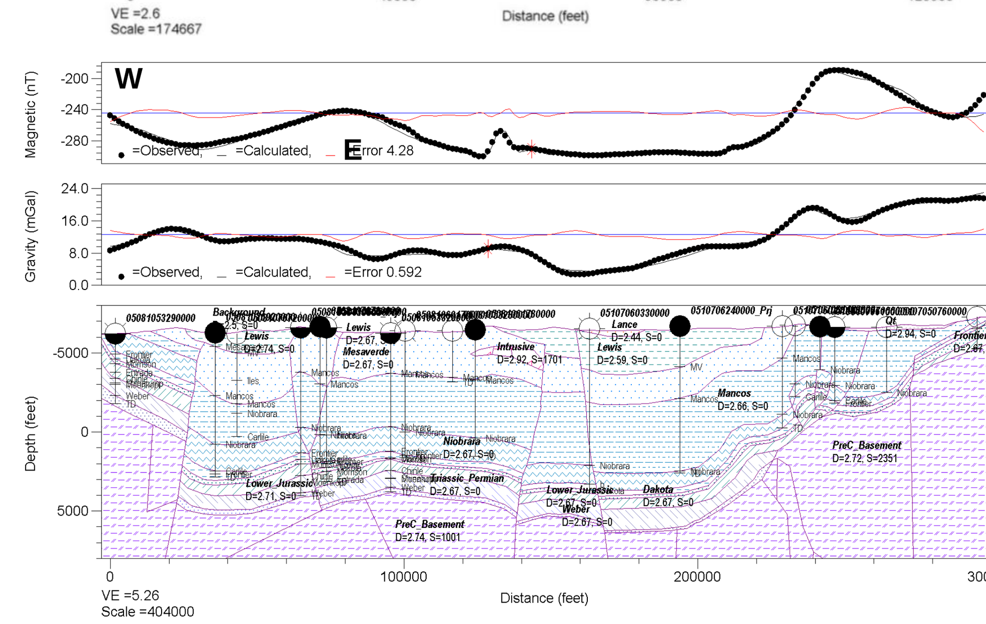
The complex geology of the Sand Wash Basin was primarily driven by Cretaceous deposition and subsequent tectonic deformation. During the Cretaceous, this basin was on or near the western margin of the Western Interior Seaway, an inundated foreland basin that developed in response to the Sevier orogeny. Deformation of the thrust belt coincided with a major episode of subsidence: as the cordilleran moved eastward and the foreland basin subsequently underwent flexural loading, the foreland basin subsided (Heller, et al. 1986). As much as 11,000 feet of clastic sediments were deposited during the Cretaceous (Haun and Weimer, 1960).



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 involved structures that extend throughout the entire study area. In this model, 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.

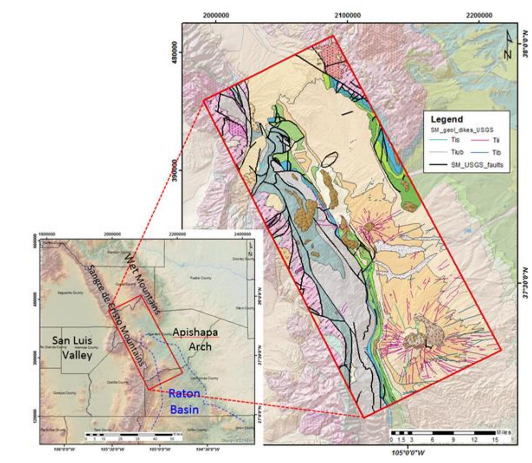
The wide range of lithologies observed in outcrop, along with mafic and intermediate dikes, consisting of andesite, basalt, and dacite, are suggested in the lateral and vertical variation of the basement's density and magnetic susceptibility. Therefore, the gravity results illustrating a lateral basement 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.



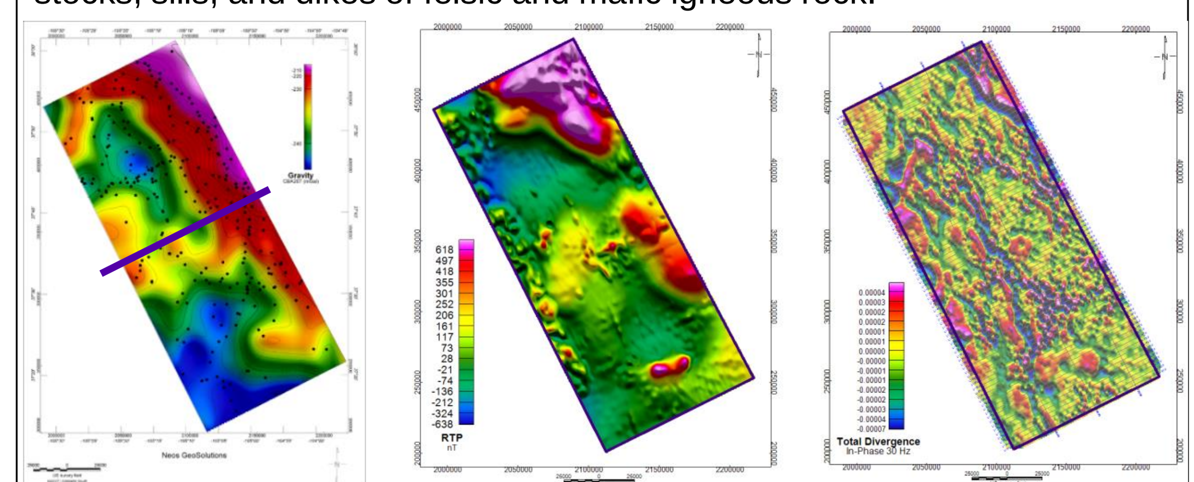


The magnetic and gravity data reveal, not only irregular topography of the basement, but also lithology contrast, as observed in outcrop.

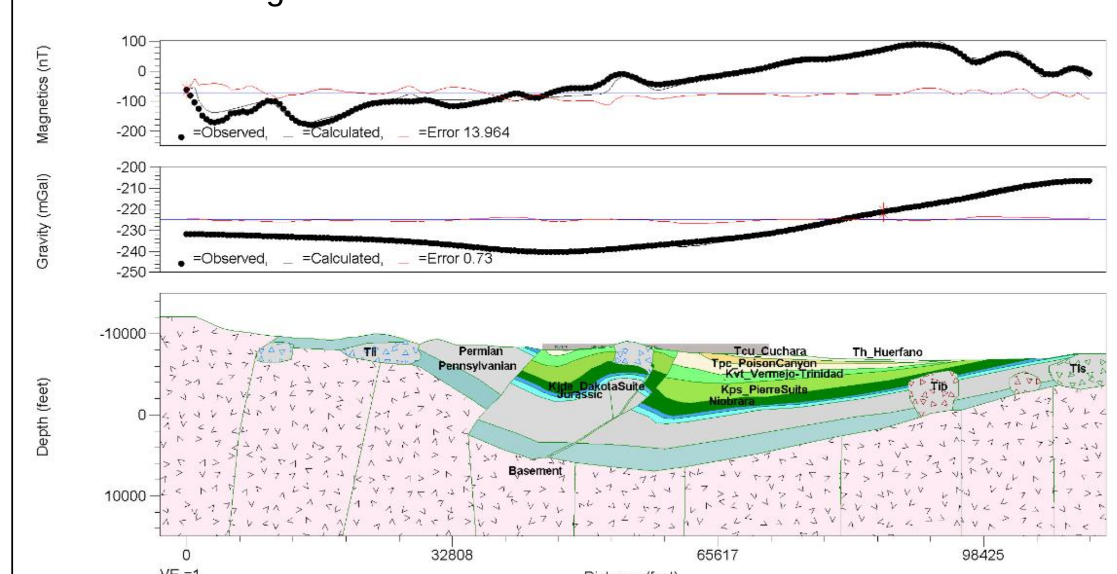
Sheep Mountain

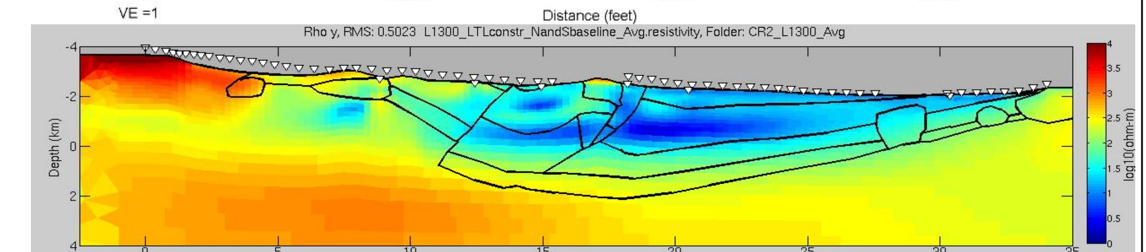


The study area is located on the northern edge of the Raton basin. It is the southernmost Laramide foreland basin associated with the development of the ancestral Rocky Mountains. It is steeply dipping to overturned along the western flank and gently dipping on the eastern flank. During the Laramide Orogeny in the late Cretaceous through early Tertiary, this basin deepened dramatically, resulting in a stratigraphic column of over 20,000 ft of lower Paleozoic through Tertiary sedimentary rocks in the deepest part of the basin (Sims et al., 2001; Popov et al., 2001). From late Oligocene to the present, the Sangre de Cristo Range was uplifted and the adjoining San Luis and Wet Mountain Valleys were downdropped by Rio Grande rifting (Lindsey et al., 1983). Rifting accompanied and followed intrusion of stocks, sills, and dikes of felsic and mafic igneous rock.



The magnetic and gravity data reveal the major NW-SE structural trend and a perpendicular trend likely associated with Precambrian suture zones. 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 dike orientations: radial, related to major volcanoes; NW-SE, parallel to the major structural trend; SW-NE, perpendicular 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 shallow igneous bodies and swarms of dikes especially observed on the eastern part of the block. 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 Electro-Magnetic (EM) data. These data also reveal the major structural trends and confirm the location of igneous intrusions and basement related features.





The interpretation over the EM data are derived from the modeled profile above. Note the agreement in low resistivity areas (blue) and sedimentary basin and higher resistivity zones (red and yellow) in agreement with igneous intrusions and basement related features.

Conclusions

The combination of all available datasets was successful at outlining basin architecture. Potential fields modeling suggests Basement involved tectonics and thicker sections of repeated strata associated with thrusting.

The examples shown 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 Electro-Magnetic (EM) data, which aid in better identifying the overall basin architecture.

In all profiles, the contact between the Precambrian basement and the sediments above denotes a large magnetic susceptibility contrast across the entire area, represented by long-wavelength, high-amplitude responses. Short-wavelength responses are also 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 are used to produce a series of 2D forward 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.

Acknowledgments

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References

Haun, J. D., and Weimer, R. J., 1960, Cretaceous stratigraphy of Colorado, in Weimer R. J., and Haun, J. D., eds., Guide to the geology of Colorado: Geological Society of America, Rocky Mountain Association of Geologists and Colorado Scientific Society Guidebook, p. 58-65.

Heller, P. L., Bowdler, S. S., Chambers, H. P., Coogan, J. C , Hagen, E. S., Shuster, M. W., Winslow, N. S., and Lawton, T. F., 1986, Time of initial thrusting in the Sevier orogenic belt, Idaho, Wyoming, and Utah: Geology, v. 14, no. 5, p. 388-391.

Lindsey, D.A., Johnson, B.J., and Andriessen, P.A.M., 1983, Laramide and Neogene structure of the Sangre de Cristo Range, south-central Colorado, in Lowell, J.D., ed., Rocky Mountain foreland basins and uplifts: Rocky Mountain Association of Geologists, p. 219–228.

Popov, M., Nuccio, V., Dyman, T., Gognat, T., Johnson, R., Schmoker, J., Wilson, M., and Bartberger, C., 2001, Basin-centered gas systems of the U.S., USGS open-file report 01-135, version 1.0

Sims, P.K., Viki, B., and Finn, C.A., 2001, Preliminary Precambrian basement map of Colorado-A geologic interpretation of an aeromagnetic anomaly map, U.S. Geological Survey Open File Report 01-0364.

Talwani, M., Worzel, J.L., and Landisman, M., 1959, Rapid Gravity Computations for Two-Dimensional Bodies with Application to the Mendocino Submarine Fracture Zone, Journal of Geophysical Research, 64:49-61.

Talwani, M. and Heirtzler, J.R., 1964, Computation of magnetic anomalies caused by two-dimensional bodies of arbitrary shape, in Parks, G.A., Ed., Computers in mineral industries, Part 1: Stanford Univ. Publ., Geological Sciences, 9, 464-480. 17. Telford, W.M., Geldart, L.P., and Sheriff, R.E., 1990, Applied Geophysics, Cambridge University Press; 2 edition, p.792.

Zamora Valcarce, 2006, Estructure y Cinemática de la Faja Plegada y Corrida del Agrio, Cuenca Neuquina. Universidad de Buenos Aires, Thesis, p. 302.

Zapata, T. R. and Folguera, A., 2005, Tectonic evolution of the Andean fold and thrust belt of the southern Neuquén Basin, Argentina. In Veiga, G., Spalletti, L., Schwarz, E. y Howell, J. (eds.) The Neuquén Basin: A case study in sequence stratigraphy and basin dynamics, Geological Society, Special Publications 252: 3756, London.