[PS]Integrated Geomechanical Reservoir Characterization Approach to Study Migration and Accumulation of Hydrocarbons in Llanos Basin, Colombia*

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Search and Discovery Article #40871 (2012)
Posted January 16, 2012

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*Adapted from poster presentation at AAPG International Conference and Exhibition, Milan, Italy, October 23-26, 2011

Abstract

The Llanos Basin of Colombia has recently become the focus of extensive exploration due to its high resource potential. The basin itself has experienced multiple stages of trap development and failures as well as re-migration of fluids making it quite unpredictable. Many areas such as Rubiales field need long migration pathways to trap commercial quantities of hydrocarbons (HCs). Stress directions and high porosity systems provide permeability conduits for these migrations and accumulations to happen.

The study investigates relationships between stress fields and hydrocarbon migration and entrapment. HC migration has always been difficult to understand due to geological gaps in the stratigraphic column and multiple stages of consequent tectonic events which are responsible for HC expulsion. To improve our understanding, various new methods are used in the study including gas chimney analysis, paleo-stress effects and trap seal analysis.

Geomechanical reservoir characterization is a relatively new field. More recently, geomechanics are being used to find the best way to frac the subsurface to produce oil and gas (shales, CBM, tight sand, etc.). While the geomechanical correlation to permeability and porosity is established through above studies, it can also be applied to a more regional model to establish the migration pathways and movement of fluids through permeable systems within the sediments.

Neural network based chimney cube and fault seal analysis are applications of supervised Neural Networks. These technologies are applied to various seismic data sets in the Llanos Basin to better understand the regional stress field and impacts for lateral and vertical HC migration through carrier beds, fracture systems and gas chimneys.

In this study we have integrated the geo-tectonics, in-situ stress analysis, analysis of hydrocarbon chimneys, and seismic fault-seal analysis. The data included in the analysis is the geology/geophysics of the region, earthquake data, seismic and gravity.

This study provides a non-conventional process to focus exploration to a portion of a basin with the highest possibility of finding hydrocarbons.

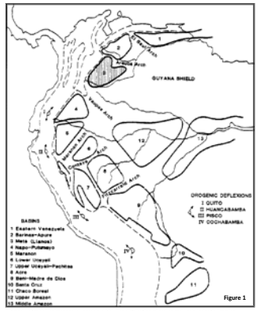


Figure 1: After Vollheimer and Musacchio, 1980. The distribution of arches and basin in South America. The major orogenic deflections cause the shear zones responsible for migration and accumulation

Llanos Basin, Colombia

Llanos basin of Colombia (Figure 1 and Figure 3) has recently became prime focus area for hydrocarbon exploration due to its high reserves potential. Recent activity includes mainly heavy and light oil. (Fig. 2)

Llanos basin is a foreland sub-Andean basin located in Colombia between Cordillera Oriental and Guyana Precambrian Shield. The sediments of the basin consist of Cretaceous and Tertiary rocks unconformably lying over basement and/or Palaeozoic rocks. The top of the Paleozoic is considered as commercial basement and not drilled by existing exploration.

The basin itself has experienced multiple stages of trap development and failures as well as re-migration of fluids which makes it quite unpredictable. Area is characterized by good coverage of data and access to it.

Many regions of the basin such as Rubiales field need long migration pathways in order to trap commercial quantities of hydrocarbon accumulations.

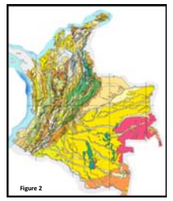


Figure 2

Region is characterized by difficult and complicated geotectonics and sedimentary history (Figure 2).
In this study we have integrated the knowledge in regional geotectonics, structural geology, in-situ stress analysis integrated with application of Chimney Cube method of Supervised Neural Network in order to find the HC migration pathways . We tried to find possible explanation of the location of HC pathways influenced by in-situ stress and strike-slip motion along meta-fault shear zone.
Stress pattern of Llanos basin (Fig. 5). To understand stress pattern of the Llanos basin the data from the World Stress Map has been utilized as well as knowledge of earthquake distribution and its focal mechanism solution where it was available.

Geomechanical Application for Regional HC Exploration

- Earthquake Fault Plane Solution
- Borehole Breakouts and Leak-off Tests
- Structural Analysis of Mega Structures
- Gravity and Magnetic Data (Basin Model)
- Depositional History (Well based Isopach Analysis)
- Regional Seismic Review
- Vertical Migration Indicators (ChimneyCube)
- Migration Pathways (Grav-Mag Inversion)
- Trap Identification (Stress Field Detection)

Regional Fault Plane Solutions for Earthquake

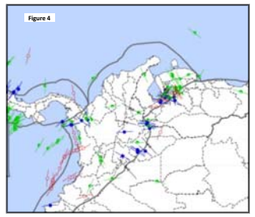


Figure 4

World Stress Map provides the regional tectonic compression direction by using various methods such as Fault plane Solutions (FPS). FPS is a P-wave first motion, using a grid search approach.

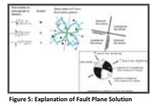


Figure 5: Explanation of Fault Plane Solution

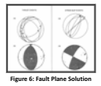


Figure 6: Fault Plane Solution

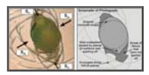
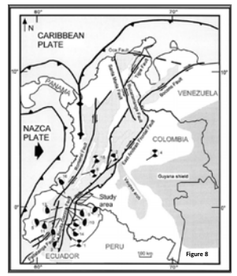


Figure 7: A schematic experiment of borehole breakouts. This is the most often used method to derive local stresses



Structural Orientation as the Stress Direction Indicator

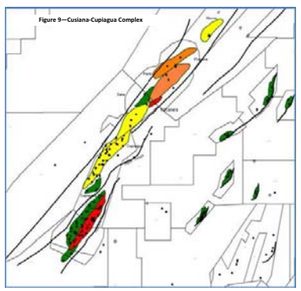


Figure 9—Cusiana-Cupiagua Complex

Numerous structures including Cusiana-Cupiagua Complex (Figure 9) and Orito anticline show a major strike slip component to the thrusts. The angle between the front end of Guyana shield and sedimentary dip and the foothills thrust axis is about 30 degrees which makes most of the anticlines plunge to the northeast.

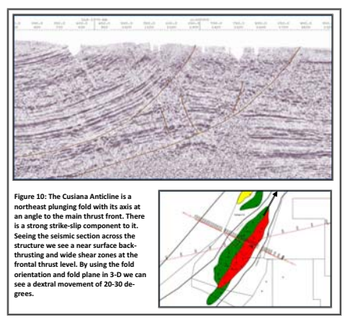


Figure 10: The Cusiana Anticline is a northeast plunging fold with its axis at an angle to the main thrust front. There is a strong strike-slip component to it. Seeing the seismic section across the structure we see a near surface back-thrusting and wide shear zones at the frontal thrust level. By using the fold orientation and fold plane in 3-D we can see a dextral movement of 20-30 degrees.

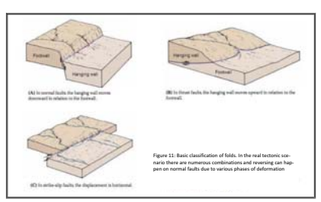


Figure 11: Basic classification of folds. In the real tectonic scenario there are numerous combinations and reversing can happen on normal faults due to various phases of deformation

As we move forward into more detailed seismic analysis of the llanos basin we see the effects of the strike slip component on the secondary migration of hydrocarbons in the Llanos basin

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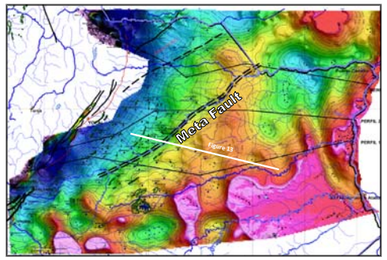
The Meta Fault Shear zone, a major dividing line and a conduit to long distance migration. Meta fault separates the Mirador and older light oil plays to the northwest to the mainly heavy oil plays of Carbonera sands to the southeast.

The complex interaction of the basement highs and the mega-shear area created the conduits for hydrocarbon migration possible to the oil-fields far away from the source rocks. This phase of secondary migration and trapping is controlled by Meta Fault and differential erosin of Paleozoic. The same Carbonera formation which acts as a vertical seal for many Llanos oil-fields northwest of Meta fault becomes a reservoir to the east of the fault



Seismic Migration Indicators and Meta Fault

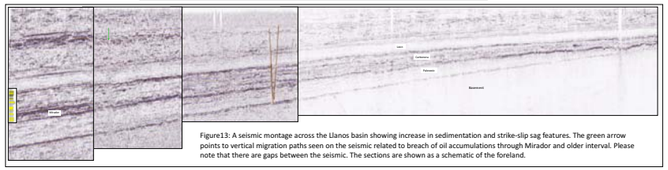


Figure13: A seismic montage across the Llanos basin showing increase in sedimentation and strike-slip sag features. The green arrow points to vertical migration paths seen on the seismic related to breach of oil accumulations through Mirador and older interval. Please note that there are gaps between the seismic. The sections are shown as a schematic of the foreland.

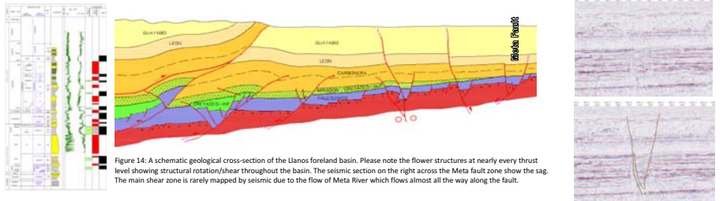


Figure 14: A schematic geological cross-section of the Llanos foreland basin. Please note the flower structures at nearly every thrust level showing structural rotation/shear throughout the basin. The seismic section on the right across the Meta fault zone show the sag. The main shear zone is rarely mapped by seismic due to the flow of Meta River which flows almost all the way along the fault.

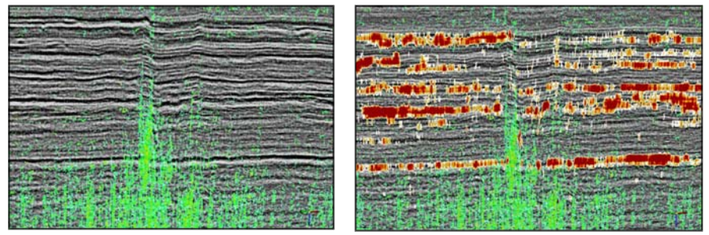


Figure 15: The Chimney Analysis, a multi-attribute Supervised Neural Network application shows the past or present vertical migration of fluids. Also note the change in Energy of the seismic marked by red patches across the faults .

Tectonic Reconstruction and HC Expulsion

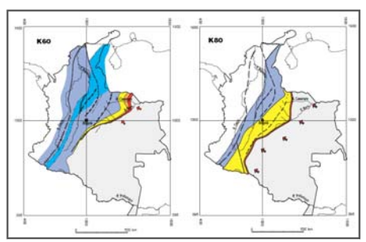


Figure 16: Based on Cooper et.al. 1995; Deposition of Cretaceous strata shows Rio Meta as the depositional edge. The Paleozoic to SE of Meta fault was eroding as seen in Figure 13 and Paleozoic inversion of Gravity data.

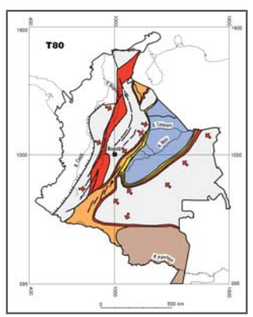


Figure 17: Cooper et.al. 1995 in their key publication on structural and stratigraphic restoration of the Eastern Cordillera show that during Oligocene to Miocene times as the Carbonera sands were depositing, the Meta area was part of a sea opening to the northeast. There is a very strong possibility that during the building of Eastern Cordillera the oil from source and reservoir rocks was pushed along the Meta Fault zone and occupied shallow unconsolidated sands.


Figure 18: One of the previous study in Llanos basin shows how the formation waters carrying the hydrocarbons from deeper and active source rocks follow the path through maximum horizontal stress.

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Airborne Methods: Structure and Stress Fields

Aero-gravity and Aero-mag

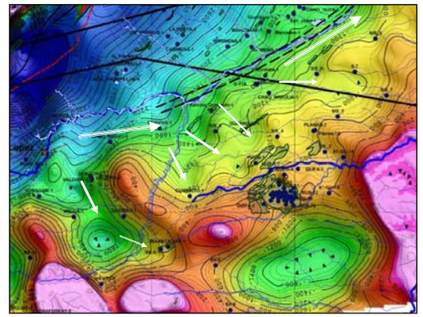
Basin Architecture and Structural Lineaments

Aeromag and Aerogravity data provides the basin architecture.

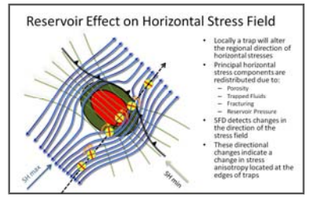
The map shown in the figure across is the inverted Paleozoic structure from Aero-mag and Aero-gravity survey by Carson. The location of Rubiales field can clearly be explained by its down-dip access to the Meta shear zone through a series of Paleozoic lows. Downdip occurrence of oil and up-dip wet zones within Quifa block also explain the same migration paths

One critical part missing in wide aero-mag and aero-gravity surveys is the information about the possible fluid traps.

Remote stress field detection explained below adds an extra layer of trap indicators.


Possible Migration Pathways: The gravity lows within Paleozoic act as estuaries for Lower Carbonera sand and are excellent reservoirs. The gravity data shows the stress paths due to interaction of shear along Meta Fault and basement lineaments.

SFD: Stress Field Detection

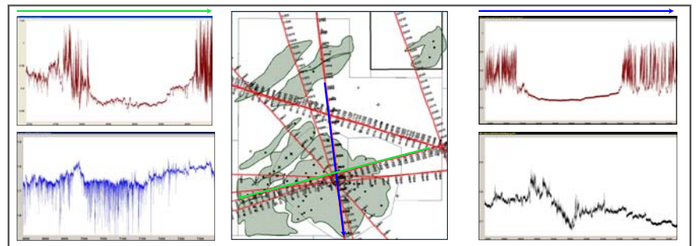


Finding the Traps with Airborne SFD

A new method for remote detection of stress anomalies in the subsurface.

The method is passive detection of minor perturbations in the gravity field caused by trap-related stress anomalies.

The SFD technology is successfully applied in Llanos, Putumayo and many other basins in Colombia in addition to its development and application in Western Canada, US, and around the world.



SFD Data: Rubiales Field

Various flights over the Rubiales Field clearly show the trap indicators. Using various SFD sensors the degree of error is minimized by looking at signature over multiple signals at the same time. Although Rubiales field and Quifa block are complex trapping mechanism, the SFD technology could point to these potential areas with high confidence

Conclusions and Future Work

- Finding oil and gas in a new basin needs understanding of all the components of structure and stratigraphy
- Regional tectonics plays a major role in oil generation, migration and accumulation
- Stress directions, especially horizontal stresses, have a very stark association to fluid trapping
- Airborne tools like gravity and stress field surveys when integrated with basin history could lead to areas of significant discoveries
- Further seismic analysis could lead to possibilities of Paleozoic source rocks contribution and could open up some other plays farther away from the basin center.

This Joint Study was made possible by:

1 - Petro-Explorers Inc. 2 - NXT Energy Solutions 3 - dGB Earth Sciences

References

Baranova, V., Mustaqeem, A., and Bell, J.S., 1999, A new model of induced seismicity in Western Canada Sedimentary Basin, Canadian Journal of Earth Sciences
Chengxuan, T., Zhijun, J., Mingli, Z., Liangjie, T., Chengzao, J., Shuping, C., Meiling, Y., Lianbo, Z., 2001, An approach to the present-day three-dimensional (3D) stress field and its application in hydrocarbon migration and accumulation in the Zhangqiang depression, Liaohe field, China, Marine and Petroleum Geology, Volume 18, Issue 9, November 2001, Pages 983-994
Zoback, M. L., 2008, World Stress Map
Zoback, M.D., 2007, Reservoir Geomechanics: Earth Stress and Rock Mechanics Applied to Exploration, Production and Wellbore Stability, Cambridge Press, Cambridge Press, 449 pp.