Using integrated gas chimney processing, seismic attributes, and seismic facies classification to delineate oil filled reservoirs: Case studies from the Oriente Basin, Ecuador

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Abstract

The Oriente Basin of Ecuador is one of the most prolific oil producing basins in South America. Oil has been discovered in both structural and stratigraphic traps in the Cretaceous and Paleocene clastic reservoirs. However, it is often difficult to distinguish oil filled from wet sands on the 3D seismic data in this generally sand rich neritic environment. The Cretaceous to Paleocene age sand reservoirs are generally low amplitude compared to high amplitude inter-bedded carbonates. It is therefore critical to be able to delineate the extent of oil filled reservoir to predict recoverable reserves and design a development program. Subtle diffuse gas chimneys (gas clouds) have been observed over many of the producing fields in the Oriente Basin. Also reconnaissance of the 3d seismic data in the vicinity of the discovery wells showed subtle seismic waveform changes, indicating channel morphologies.

Therefore, an integrated three-part strategy was designed to highlight areas for development drilling and further exploration. 1) A horizon-based seismic waveform classification was done in a narrow window around the major producing reservoir. This process based on a neural network unsupervised vector quantification divided the seismic wavelet into eight classes. 2) Seismic attributes were evaluated which could distinguish the channel reservoirs, observed in the Pata #6 and Pata #2 wells. 3)Gas chimneys were highlighted in the seismic data using a supervised neural network approach. The results of the neural network processing showed prominent gas chimneys which charged the Basal Tena reservoirs. Recognized source rocks are in the inter-bedded shales of the Napo, which are immature in this area. Chimneys may provide a mechanism for allowing expulsion from these Zone 2 (R50-R55) source beds, by providing fractures and additional heat flow. Alternatively, chimneys may be important in moving laterally migrated hydrocarbons from the underlying continuous Hollin Fm into the more discontinuous Basal Tena reservoirs. Waveform segmentation showed the major reservoirs generally occur in low amplitude facies, which may be compartmentalized. A prospective development drilling opportunity was identified to the northwest of the Pata #6 well. Additional exploration leads were also identified on regional 2D lines.

Results of this study have implications for exploration in other foreland basins of South America. Subtle gas clouds have been observed over many producing oil fields. A comparison of gas clouds on 2D and equivalent 3D lines, indicates that 3D processing may tend to destroy much of the chaotic gas cloud signature by emphasizing mappable surfaces.

Acknowledgments

We would like to thank Petrobras for permission to show the results of this study.

References and Further Reading

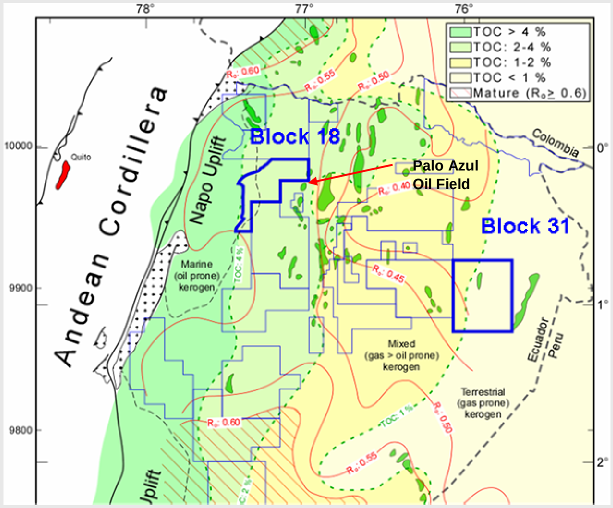
Aminzadeh, F., Connolly, and de Groot, P., 2002, Interpretation of Gas Chimney Volumes, Extended Abstracts of, Seventy Second Annual SEG Meeting, Salt Lake City.

Heggland, R., Meldahl, P., Bril, B., and de Groot, P., 1999, The chimney cube, an example of semi-automated detection of seismic objects by directive attributes and neural networks: Part I and Part II; interpretation, SEG 69th Annual Meeting, Houston, Expanded Abstracts

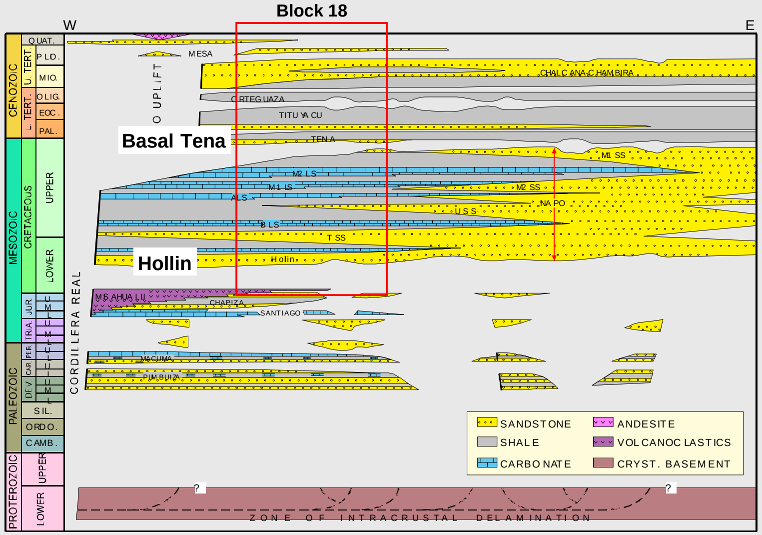
Ligtenberg, J. H., 2003. Unraveling the petroleum system by enhancing fluid migration paths in seismic data using neural network pattern recognition technique, Geofluids, Vol. 4.

Walraven, D., Aminzadeh, F. ,Connolly, D. Predicting Seal Risk and Charge Capacity using Chimney Processing: Three Gulf of Mexico Examples, SEG Extended Abstracts, 2004.

Regional Setting - Oriente Basin:

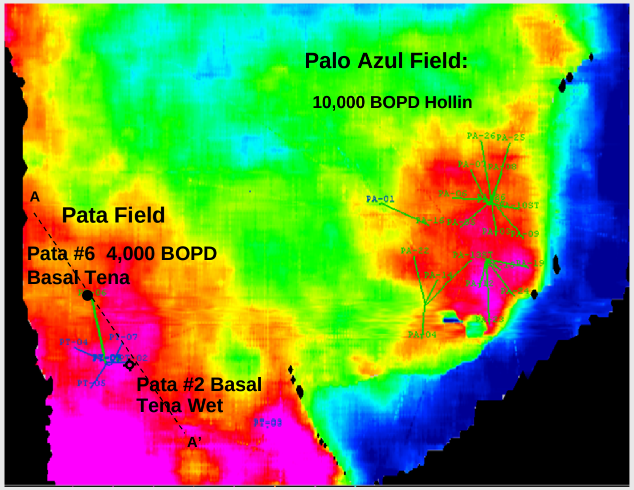


The Oriente Basin is a foreland basin on the eastern flank of the Andean Cordillera. The study area, Block 18, is located to the west of the main producing trend. The primary regional source rocks are suspected to be Upper Cretaceous shales inter–bedded with the producing Upper Cretaceous marine neritic sandstones. These shales are marginally mature (Ro 0.50-0.55) in the vicinity of Block 18. Oil is potentially generated in the source rock, but cannot be released. This would imply long range lateral migration to charge the oil fields. Oil fields are generally low gravity (14-16 deg API).

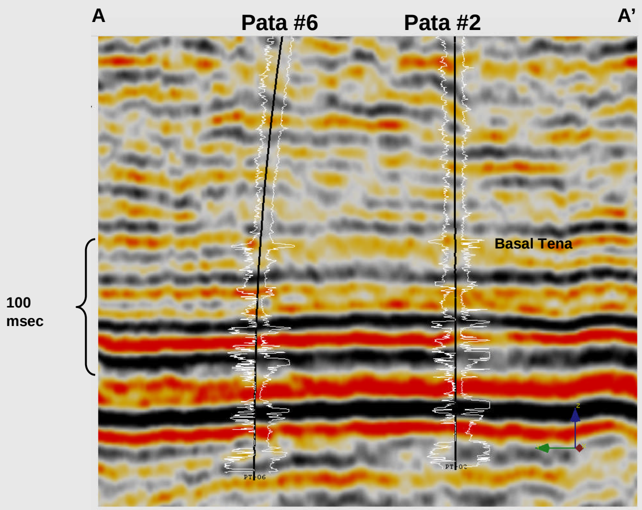


The main producing reservoirs in the vicinity of Block 18 are Lower Cretaceous neritic to fluvial sands of the Hollin formation. The Upper Cretaceous neritic marine Napo Fm is generally poorly developed. The Lower Tertiary marine Basal Tena Formation is also producing in the Pata Field in Block 18 .

The Purpose of the Study:



The Palo Azul Field produces approximately 40,000 BBls /day from the thick Cretaceous Hollin braided fluvial, meandering fluvial, and shoreface sands. In contrast the only good production (4000 BBls / day) in the Pata Field comes from the Pata -6 well which produces from the Paleocene Basal Tena interval. The Pata 2 well up dip of the Pata 6 well encountered thick Basal Tena braided fluvial sands which were wet. The purpose of the study was to understand the distribution of the Basal Tena oil filled reservoirs to guide additional development drilling and define exploration leads.

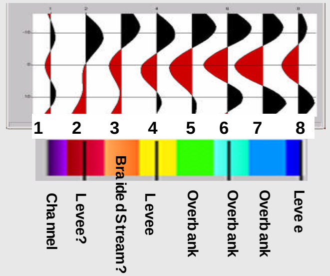


There were two main challenges: 1) to delineate the reservoir facies based on the seismic; 2) understand the distribution of oil; 3) assess potential delineation drilling and exploration drilling, based on the results of the study.

Acoustic impedance seismic volumes and AVO studies were done on the data with inconclusive results. Thus new technologies were necessary.

Observations of the seismic character through the two wells with good sand development showed a channel morphology. The reflectors showed more dip and curvature than the adjacent siltier areas. The reservoir was also lower amplitude.

Seismic Attribute and Facies Analysis: Basal Tena



Waveform Segmentation

The first step was to divide the seismic waveform into eight classes, based on its shape. The eight classes were based on neural network training for a -16 to 16 msec window around the Basal Tena horizon (a trough). The eight class centers are displayed at right. Class 1 (purple is distinguished by its low amplitude, and a generally linear morphology in map view. It is interpreted as a channel facies. Class 2 (dark red) and Class 8 (blue) are closely associated with the channel facies a may represent a levee facies. Class 3 is also a low amplitude facies and is interpreted as a braided stream facies, based on the core results of the Pata #2 well. The high amplitude Facies 5, 6, and 7 may represent over-bank sediments with higher shale or coal content. The wells in the Pata Field which encountered these facies were generally more shaly. In general the seismic waveform segmentation helped explain the distribution of litho-facies. However it was often ambiguous, and did not explain the distribution of oil.

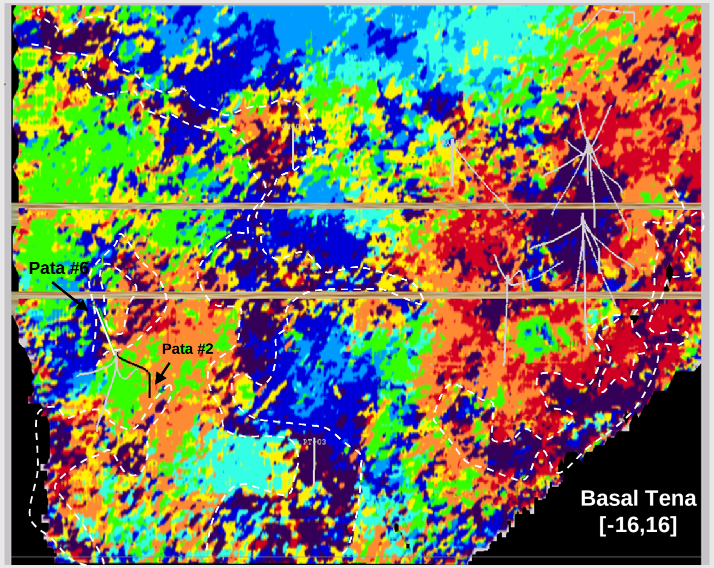
Curvedness / Energy

Since the channels were observed to have more curvature and lower amplitude, a combination attribute was thought to highlight the channels more clearly. High values of curvedness divided by energy (amplitude) would be predicted to show channels. The results do seem to show the channels (highest values in gold) more clearly than the waveform segmentation alone. Basically the Pata #6 well is in the more channel-prone area, while the Pata #2 also encountered a sand-prone facies. Still the oil- prone intervals are not distinguished.

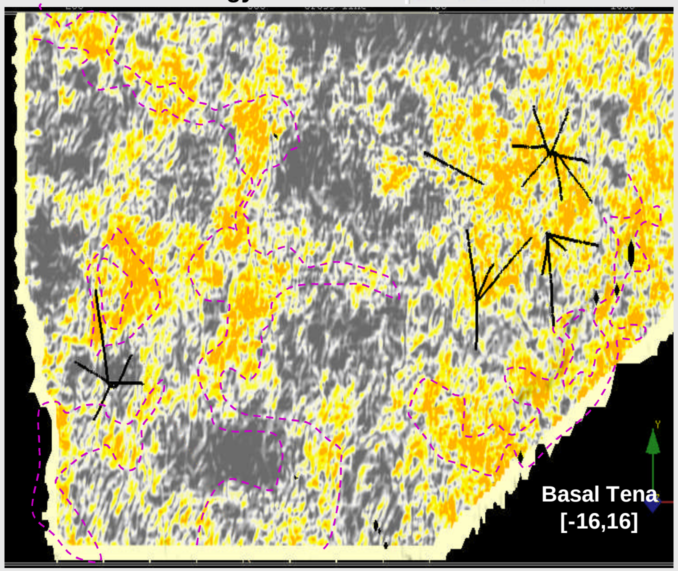
Polar Dip

Intermediate values of polar dip also show linear channel morphologies. Very high dips show circular morphologies more characteristic vertical gas chimneys. The close association of these possible chimneys with the production in Palo Azul deserves more attention.

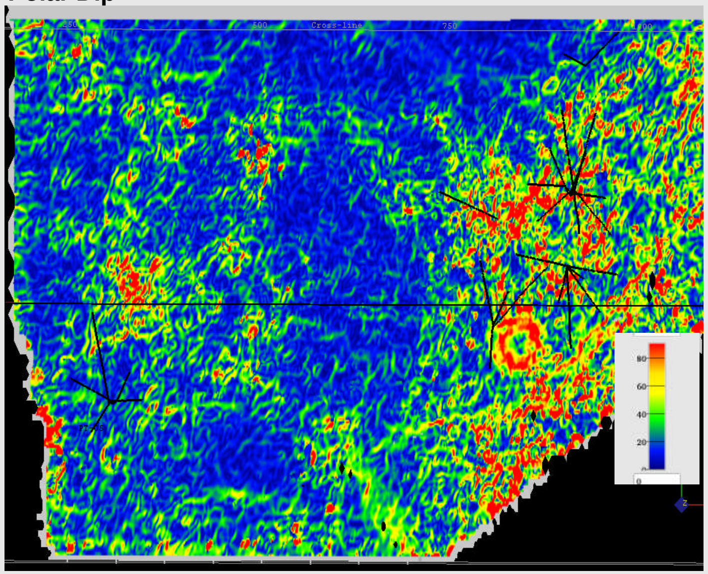
Waveform Segmentation



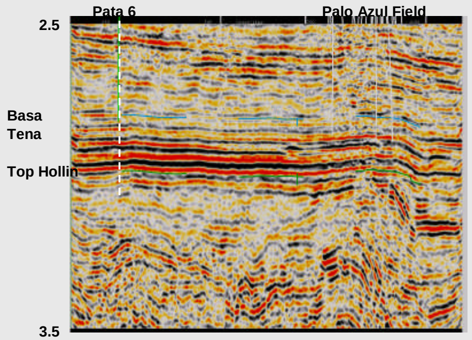
Curvedness / Energy



Polar Dip



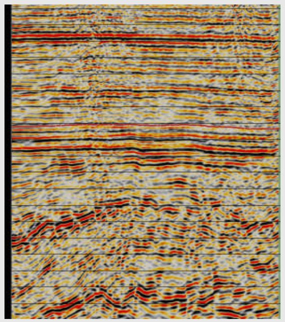
Distinguishing Oil Charged Reservoirs: Gas Chimney (Cloud) Detection



A low amplitude chaotic zone (a possible gas cloud) was observed in seismic lines through Palo Azul Field, in the interval above the Lower Cretaceous Hollin Formation. This gas cloud was apparently related to deep fracturing in the underlying Jurassic or Paleozoic section. Subtle gas clouds or chimneys were also suspected in the vicinity of the Pata #6 discovery. Detection of these gas clouds or chimneys was needed to understand their 3D morphology and aerial extent.

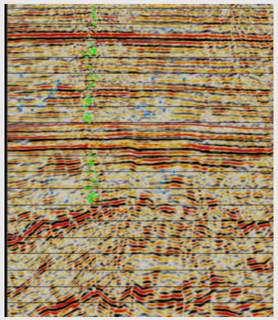
The method of highlighting these gas chimneys is described below.

Chimney Detection Methodology:



Step 1:

Scan through the seismic data, finding the most obvious zones of suspected gas chimneys.

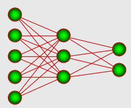


Step 2:

Pick examples of chimneys and non-chimneys on key lines and traces.

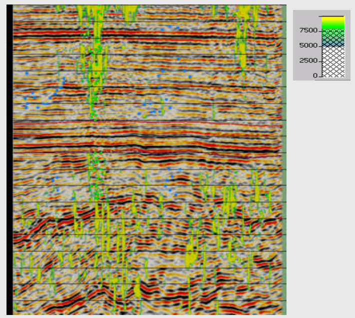
Input node relative importances:

20.0	(Reference Time)
49.2	(Polar DipVariance [-120,-40] stepout=1)
81.4	(Polar DipVariance [-40,40] stepout=1)
49.4	(Polar DipVariance [40,120] stepout=1)
46.3	(CubeSimilarity [-120,-40] stepout=1)
100.0	(CubeSimilarity [-40,40] stepout=1)
52.1	(CubeSimilarity [40,120] stepout=1)
42.6	(Similarity [-120,-40] (1,0)x(0,0) FS Min)
66.0	(Similarity [-40,40] (1,0)x(0,0) FS Min)
27.6	(Similarity [40,120] (1,0)x(0,0) FS Min)



Step 3:

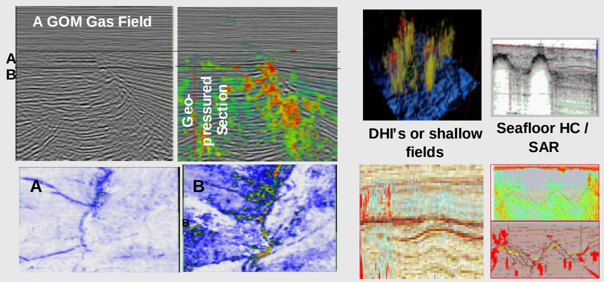
Determine a set of attributes which can highlight these chimneys. Since chimneys are vertically aligned, key attributes are chosen in windows above and below the pick sites. In this case chimneys were characterized by chaotic (high dip variance) and low trace to trace similarity. These attributes are then calculated at the picked locations, and the results are fed into a neural network. The trained neural network is then applied to the seismic volume to create a chimney probability volume.



Step 4:

The chimney probability results can then be overlain on the seismic data. Low probability chimneys are transparent.

Criteria for Validation of Processing Results



Chimney slice above reservoir target

Chimney slice below reservoir target

DHI's or shallow fields

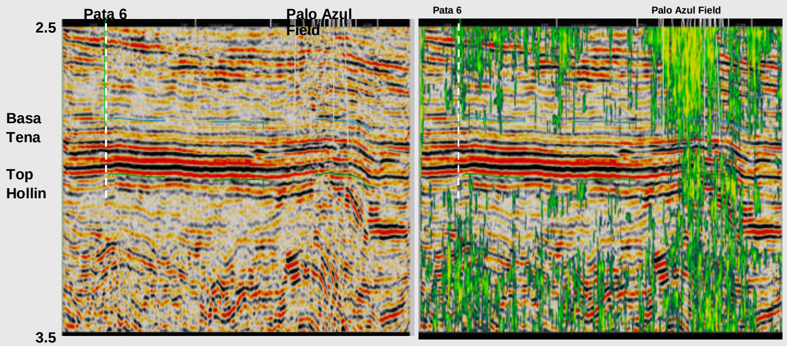
Seafloor HC / SAR

Link to Deep HC Kitchens

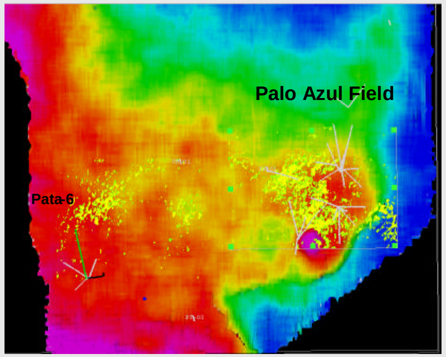
Basin Modeling

Low energy vertical discontinuities in seismic data can be caused by other factors than vertical HC migration. Thus, the processing results need to be validated. True migration can be distinguished from fault shadow imaging problems by a characteristic pockmarked morphology. Chimneys can be tied to shallow DHI's, fields, seafloor gas anomalies, remote imaging seeps, or piston core seeps. Also, true geothermal HC migration can be distinguished from de-watering of shales, biogenic gas, or mass transport deposits by their link to deep HC kitchens. Basin modeling can also validate chimney results and vice versa.

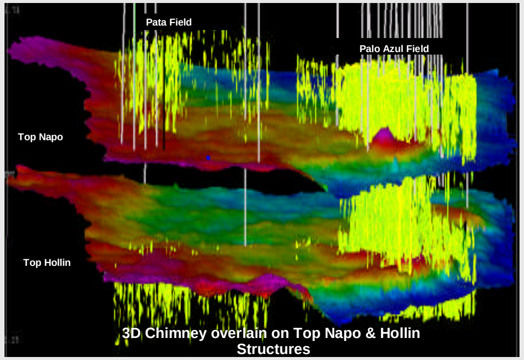
Results of Chimney Processing: Block 18



3D Views of Chimney Processing Results:

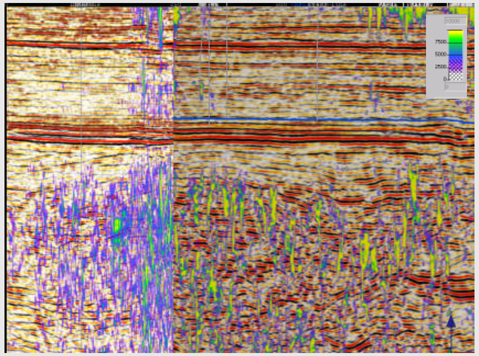


3Dview of high probability chimneys (yellow) is overlain on Basal Tena (Top Napo) horizon. Pata #6



Gas clouds occur over the producing Hollin Fm in the Palo Azul Field. Minor gas clouds occur on the NE flank of the Pata #6 well over the producing Basal Tena reservoir.

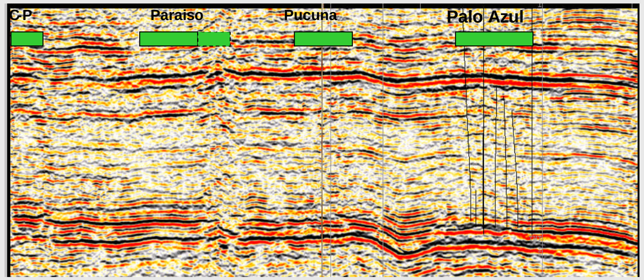
Comparison of 2D & 3D Data: Pata Field

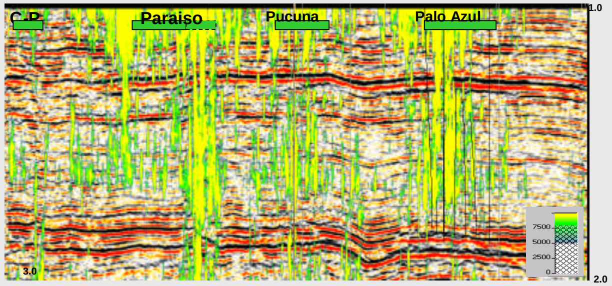


2D data seems to indicate gas clouds over the Pata Field more clearly than the 3D data over the same area. Processing of 3D data, in an effort to image horizons more clearly, may eliminate the noise in the data, which is evidence of gas clouds.

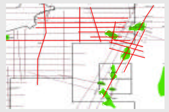
Gas Clouds Over Other Foreland Basin Fields of South America:

Paraiso, Pucuna, & C-P Oil Fields Oriente Basin

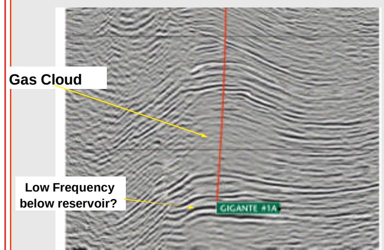




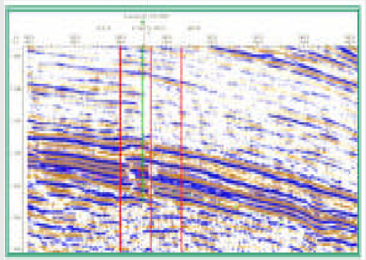
Seismic + Chimney

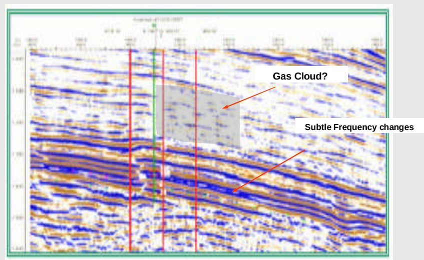


Gigante Oil Discovery (800-900 BOPD)
Upper Magdalena Valley



Guayuyaco Oil Discovery (850 BOPD):
Putumayo Basin, Southern Colombia





Discussion: Significance of Gas Clouds in Predicting Oil Filled Reservoirs

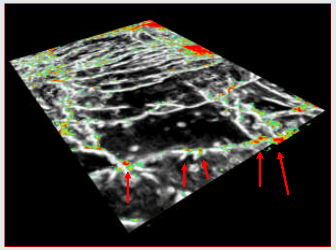
A strong correlation of gas clouds and over (low gravity) oil fields of the Oriente Basin, in the vicinity of Block 18, is observed. However regional basin models indicate that the probable source rocks providing oil to the overlying Basal Tena and underlying Hollin reservoirs are the marine shales of the Napo Fm. These shales are immature in the immediate vicinity of these fields, and large scale lateral migration has always been assumed.

How can we explain these observations?

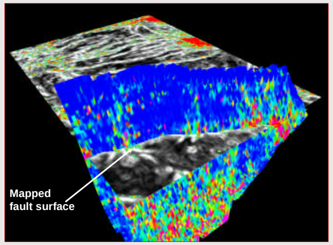
First, the source rock is in Zone 2--the onset of liquid generation. Normally in this zone, oil is difficult to expel (Bissada; personal communication). However, fracturing, related to underlying movement, may provide the mechanism for oil expulsion. These deep seated fractures may also provide additional heat flow to aid in expulsion. The second possibility is that the primary migration pathway is, indeed, lateral via the massive Hollin Fm. Gas clouds are related to diffusion or fracturing, as pressures in the reservoir exceed the seal strength of the overlying sediments.

Other Exploration Applications of Gas Chimney Processing:

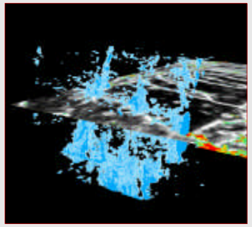
Detecting HC Migration Related to Faulting



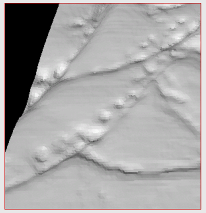
'Pockmarked' character of fluid flow along fault



HC migration related to shear along faults.

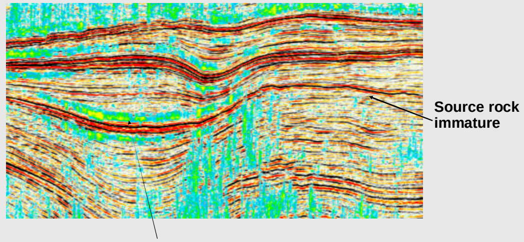


3D visualization of hydrocarbon flow along fault.



Linked to pockmarks at seabed

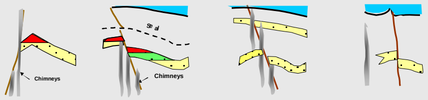
Detecting Expulsion from Source Rock



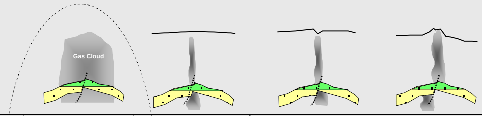
Local fluid migration activity in source rocks

Assumed to be related to active hydrocarbon expulsion

Assess HC Charge and Vertical Seal Risk



Trap Type	Non-fault Seal Trap (HIT)	Fault Seal Trap (HIT)	Fault Leak Trap (MIT-LIT)	Non-chimney Trap
Chimney Character	No chimney over structure	Fault related: With vertical seal; Poss Lateral leak	Fault related: venting to shallow reservoirs or surface	Chimney has no clear link to trap
Mechanism	Vertical fracturing & lateral flow	Fracturing	Fracturing / Sediment Flow	Lateral / Uncertain
Geologic Discoveries	94% N=18	93% N=30	27% N=19	57% N=14
Necessary Supporting Technologies	Basin modeling to understand timing	SGR for possible lateral fault leak, Basin Modeling to understand timing	Fault strain analysis, Basin Modeling to understand timing	



Trap Type	Gas Cloud Trap (Oil-prone MIT)	Seepage Pipe Trap	Blowout Pipe Trap	Mud Volcano Trap
Chimney Character	Gas Cloud over Accumulation	Pipe with no obvious pock mark	Pipe with evidence of pock mark	Pipe with evidence of sediment flow
Mechanism	Diffusion / Micro-fracturing	Micro-fracturing	Fracturing	Sediment Flow
Geologic Discoveries	97% N=42	Expected to not be a significant seal risk	Expected significant seal risk if near surface	Expected significant seal risk if near surface. Can be good seal if buried
Necessary Supporting Technologies			Basin Modeling, Pore Pressure	Basin Modeling, Pore Pressure

We performed chimney analyses over 125 fields and dry holes to assess risk for HC charge and vertical seal. The selected dry holes tested valid structures with good reservoir. Thus, the reservoirs failed for lack of charge or seal.

Case studies were primarily from the GOM, North Sea, South Atlantic, Caspian.

Conclusions:

1. Seismic waveform segmentation, and combination seismic attributes can delineate reservoir prone fairways.

2. Gas clouds are associated with many low gravity oil fields in the Oriente Basin and other foreland basins throughout South America.

3. Processing of 3D seismic data can potentially destroy the noise associated with gas clouds which is present in 2D data.

4. Gas chimney processing is a critical tool for delineating subtle gas clouds over oil and gas fields. It can also be used to highlight fault related hydrocarbon migration pathways, detect expulsion from source rock, and assess HC charge and vertical seal risk for prospects.