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A 3D Seismic Cube: What for?

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Abstract

We have already more than X hundreds wells!! ....
We do not need a seismic cube now, do we?????

Who has not heard that kind of exclamation/question while working in oil/gas field development??

Casabe oil field was not the exception. Discovered in 1941, it's been in production since 1945. It cumulated 297 MM bbl of oil (October 2008) with more than 1100 wells drilled.

Since 2004, it's been operated by an Alliance formed by Ecopetrol and Schlumberger.

A 3D seismic cube was shot during the first half of 2007. By the middle of 2008, the seismic cube had been loaded and interpreted and by October of 2008 the production had been boosted more than 50%.

The reasons….?. Two main reasons:

1. Seismic cube data
2. Selective string water injection

Of course: The second can not be properly implemented without the first.

By having a 3D seismic cube we were able to:

1. Develop a precise and reliable structural model
2. Define more accurately W/O contacts
3. Define more accurately the size of the field
4. Design more accurately well trajectories
5. Properly place injector/producer wells
6. Design more accurately the injection patterns
7. Estimate reservoir quality: Seismic Inversion data
8. Compute gas reserves: Attribute-AVO analysis
9. Incorporate undeveloped areas
10. Discover a new prospect

In other words it was possible to:

1. Get more precise reserve pictures
2. Incorporate: 10 % of the OOIP

Introduction

Casabe oil field is located 350 km north of Bogota city, Antioquia State, Colombia (Fig. 1 and 2).

Figure 1: Geographic Location.

It was discovered by Casabe-1 well in 1941 although the commercial production began in 1945 (Fig. 3), having its production peak in 1953 with 46,000 bbl/d from 414 wells.

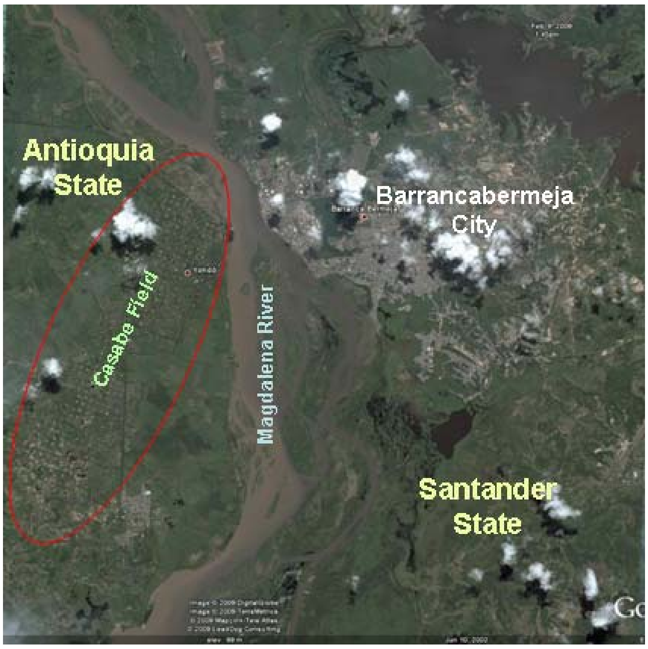

Figure 2: Detailed Geographical Location

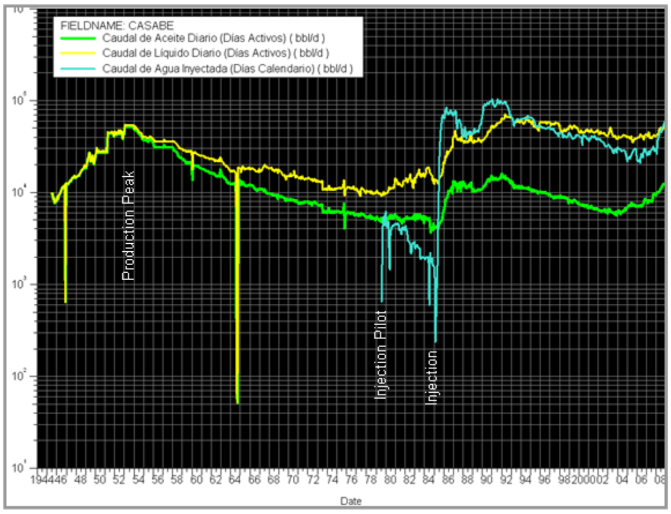

Figure 3: Production History

The field has been under a water injection program since 1985 and has cumulated (Oct. 2008) almost 297 MM bbl of oil.

A little bit of history: During 1937 a gravimetric survey was taken (Fig. 4), which only showed an east diping homoclinal. In 1938 a sparse 2D seismic survey was shot with poor and inconclusive results. A new one was shot during 1939 and 1940.

This last 2D seismic survey confirmed the gravimetric anomaly but also helped to define the position of the main west boundary fault. Based upon this seismic data, Casabe-1 well was located slightly down dip to the apex of the structure on the east side of the fault.

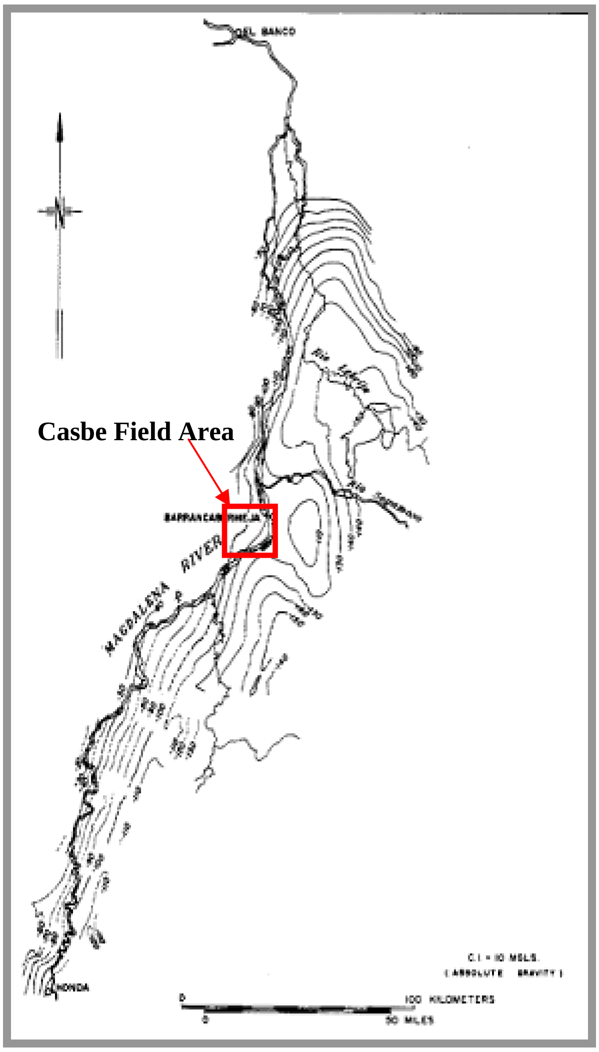

Figure 4: MMVB Gravimetric Map

Others 2D seismic surveys were shot at the end of seventies (S-1978); and during the eighties (DM1987 and DM1989), with a coarse coverage of the area.

In 2007, a 3D seismic survey was planned and shot designed for development of Casabe and Peñas Blancas fields.

The 3D seismic survey accomplished the original purposes of improving the structural model, indentifiying undeloped areas and it also played/still playing a key role in the waterflooding process.

Casabe Geological Setting

Casabe oil field is located in the Middle Magdalena Valley Basin (MMVB) (Fig. 5); a poli-history basin. Extensional, back arc basin during Triassic-Jurassic;

pericratonic basin during Cretaceous and Early Tertiary; the inner margin of a broad, east facing foreland during mid-Tertiary and at last an array of intermontaine or basins, wich sedimentary filling range from Jurassic to Neogene (Fig. 6).

Figure 5: Middle Magdalena Valley Basin Location

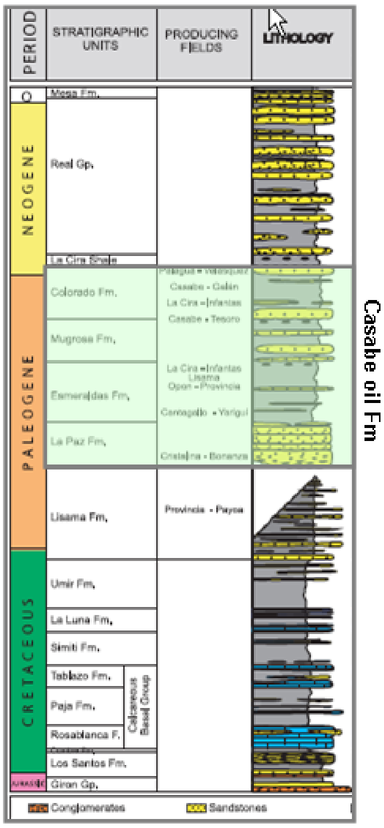

Figure 6: MMVB Stratrigraphic Column

Casabe oil field is located in the central part of MMVB (Fig. 4), and the oil bearing formations, mainly sandstones and shales of fluvial origin, are tertiary; more precisely Paleogene

From a structural stand point, the field (Fig. 7) is a three way closure anticline (although the north closure is outside de Casabe Concession) limited to the west by a main NE-SW strike slip fault and compartmentalized by several associated direct faults.

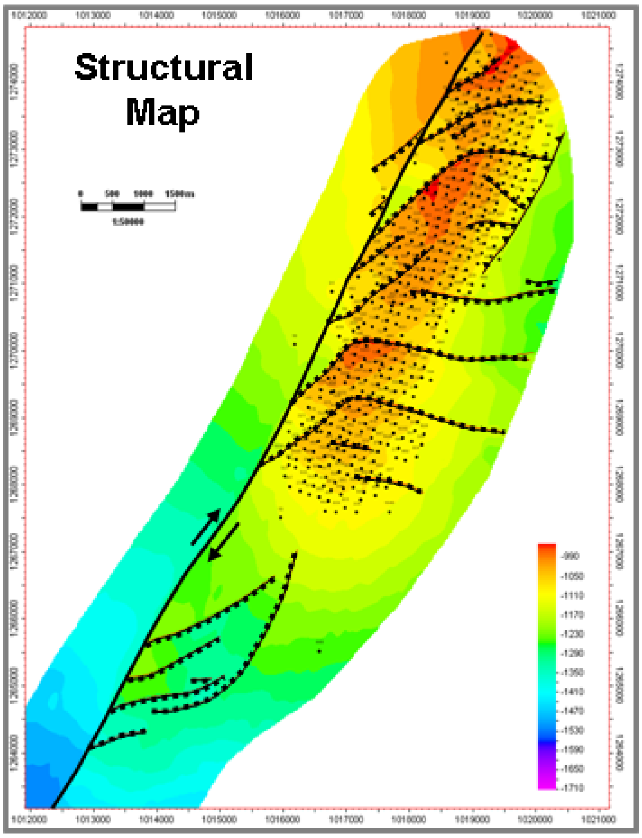

Figure 7: Structural Map

Seismic Data

During the first half of 2007 a 3D seismic cube was acquired. This cube (Fig. 8) is about one third (90 km^2) of the size of the whole Casabe Concession of 280 km^2; designed to include the two oil fields encompassed by the concession: Casabe and Peñas Blancas.

Its structural interpretation was finished by the middle of 2008 and a process of pre-stack trace inversion was performed during the second half of 2008.

A 3D Seismic Cube!!......What for??

Back to the point, let's see now why this question/exclamation is a non-sense statement by itself.

Structural Maps/ Structural Model
The first and most important product delivered from the seismic data interpretation is a structural map for a given layer/horizon (Fig. 7). Of course, it is also known that a structural map can be generated with well data (tops) as well. Since, in Casabe field, there are more than 700 wells evenly distributed (Fig. 9) in an area of 2.5 by 8 km (20 km^2 proximately); it is easy to get a reliable structural map from the well data itself.

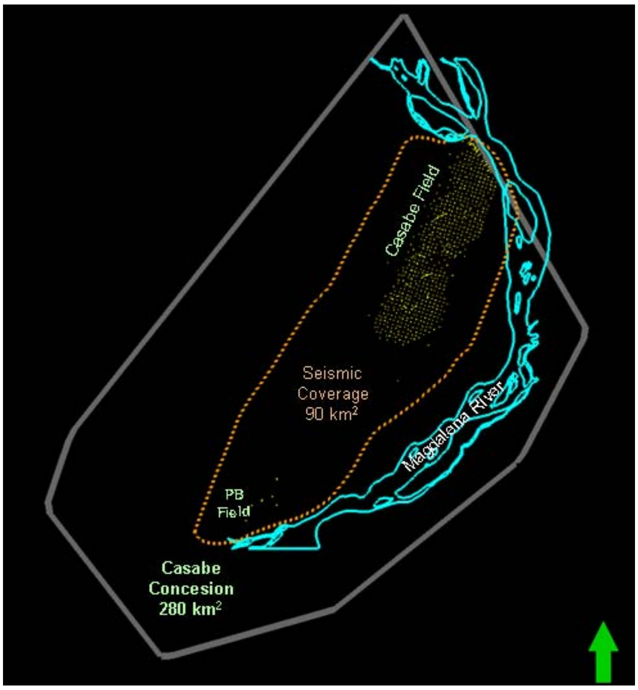

Figure 8: 3D Seismic Cube Coverage

That is correct but, even so, there will always be some areas not drilled/drained near the main NE-SW strike slip fault scared of drilling outside the trap (Fig. 9). These areas close to the main fault comes out by themselves in a seismic structural map. The area not drilled/drained is bigger than 2000 Ha.

Having at least two structural maps, the more the better, it is possible to generate a Structural Model (Fig. 10). With the structural model is easy to compute the remaining reserves.

Considering 10 reservoirs (there are actually more than 15 reservoirs), with an average thickness of 10 ft each, more than 5% of the OOIS has been added

The point here is not only the amount of reserves added but the level of uncertainty which, in fact, has been minimized by the seismic data itself.

Facies Distribution Maps/Facies Model
Either by using the conventional seismic data (amplitudes) or seismic attributes or some other product more sophisticated like Seismic Inversion it is possible to map reservoir distribution; especially when there are so many wells to calibrate the seismic data (Fig. 11). If this facies distribution map can be generated for two or more reservoirs both laterally and vertically, then a Facies Model is gotten.

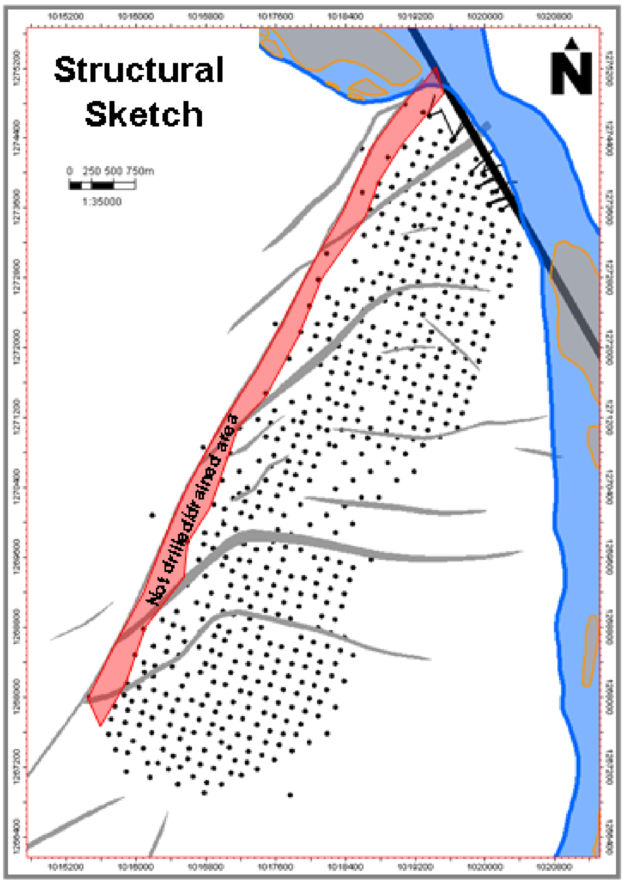

Figure 9: Not drilled/drained Area

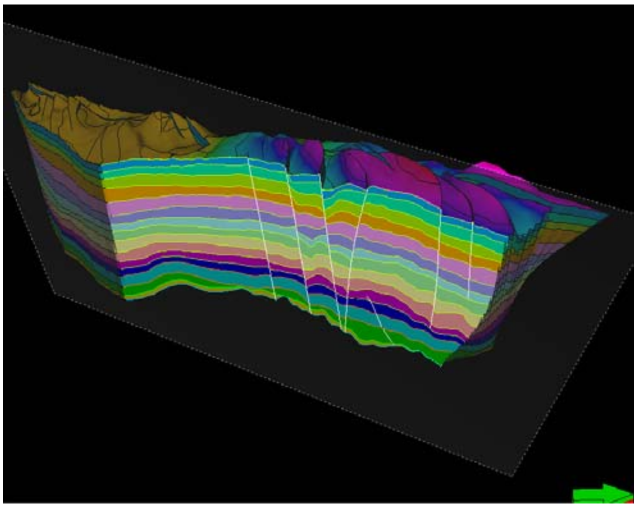

Figure 10: Structural Model

Therefore, the selection of a producer or injection well location is almost a straightforward task: just overlap the facies map distribution on to the structural map and there it is. Just one warning: do not forget the boundary given by the WOC.

The degree of uncertainty, again, has been minimized by the seismic data itself.

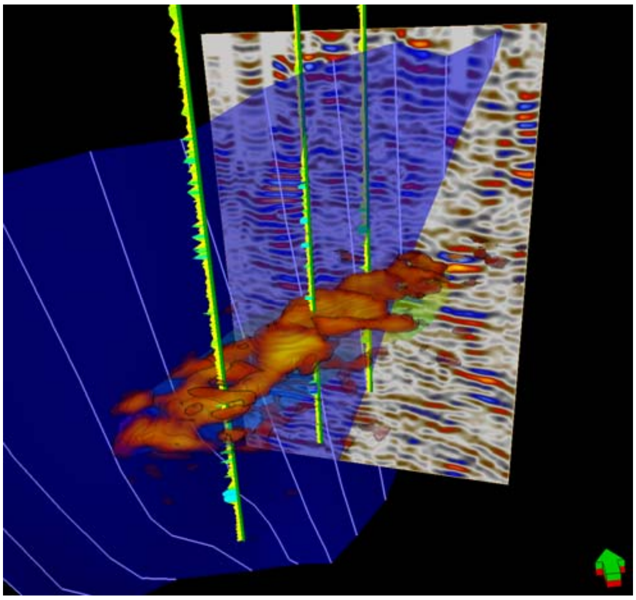

Figure 11: Facies Distribution

Well Trajectory Design

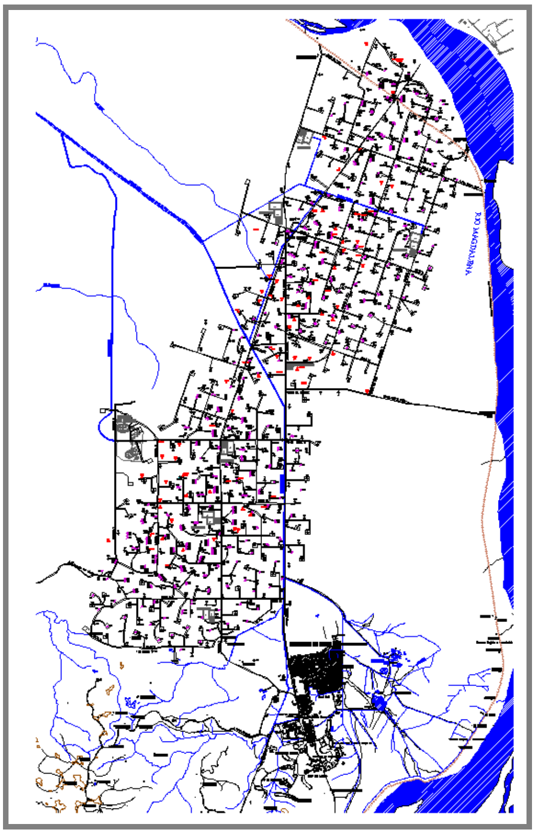

Figure 12: Surface Facilities

Casabe field is very busy on surface (Fig. 12). There are not only surface facilities as three flow stations, water injection plant, pipelines, etc; but there is also a town just on top of the field and several zones are flooded during the rainy seasons. Therefore, it is not easy to find some room on surface where to build the well locations.

From a reservoir standpoint and in order to drain those areas close to the faults, several wells are deviated. In other words, the X and Y for the final surface location is the consequence from a trade off in between the subsurface objectives and the availability of room on the surface to build the well location. As a result, most of the wells are deviated (Fig. 13); which is not an issue buy itself.

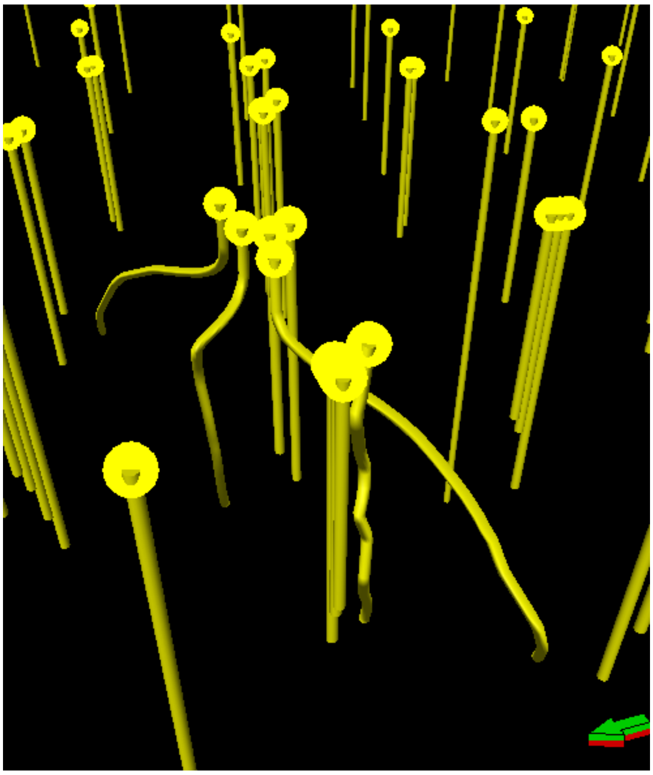

Figure 13: Well trajectory design

The subject to point out here is that without a seismic cube it would be almost impossible to properly design a well trajectory that fulfills both: reservoir and surface requirements.

Injection Patterns

It is obvious to say, for an injection pattern to be efficient there must be good connectivity in between the injector well and the producer well. Therefore they both have to be located not only in the same structural block but they also have to be connected by the same reservoir (Fig. 14).

Now, how do we know they both are in the same block and interconnected by the same reservoir?

Having a Structural Model and a Facies Model this is, again, a pretty straightforward task.

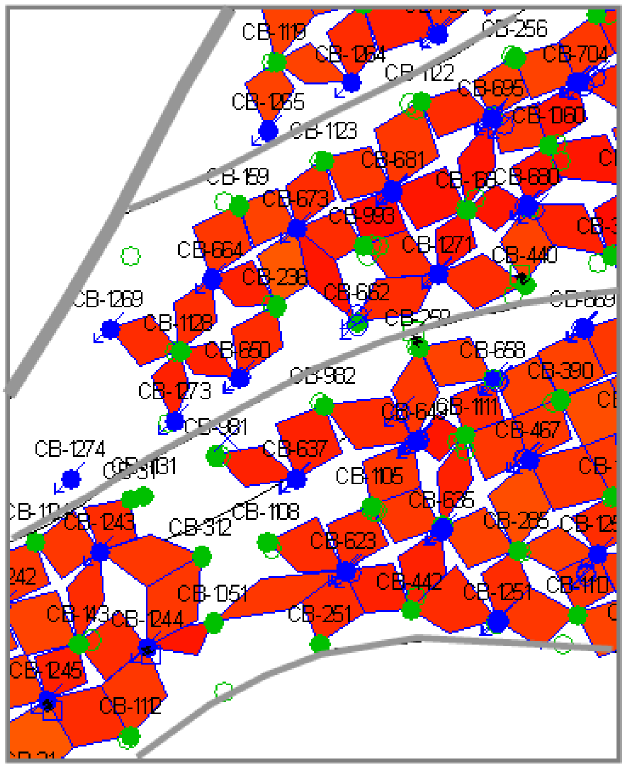

Figure 14: Water Injection Patterns

These models gotten from the 3D seismic cube plus the implementation of selective string water injection allowed sweeping the reservoirs more efficiently boosting the oil production more than 50 % in less than one year (Fig. 15).

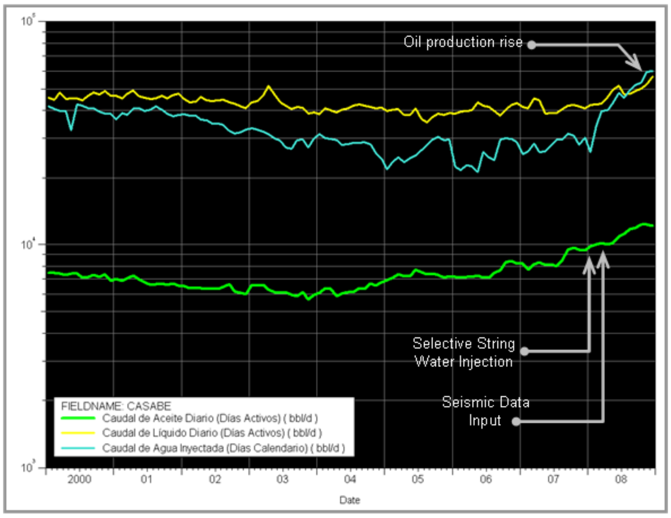

Figure 15: Water injection patterns

Attribute Analysis

Amplitude Versus Offset (AVO) Analysis

Bright spots!...., the most evident and one of the more common amplitude anomalies (Fig. 16). Everybody talks about them. Many of them have been drilled. Why so many busts?

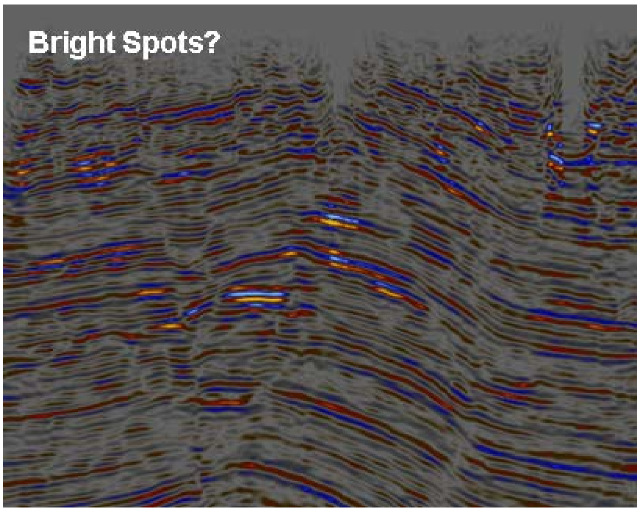

Figure 16: Bright Spots

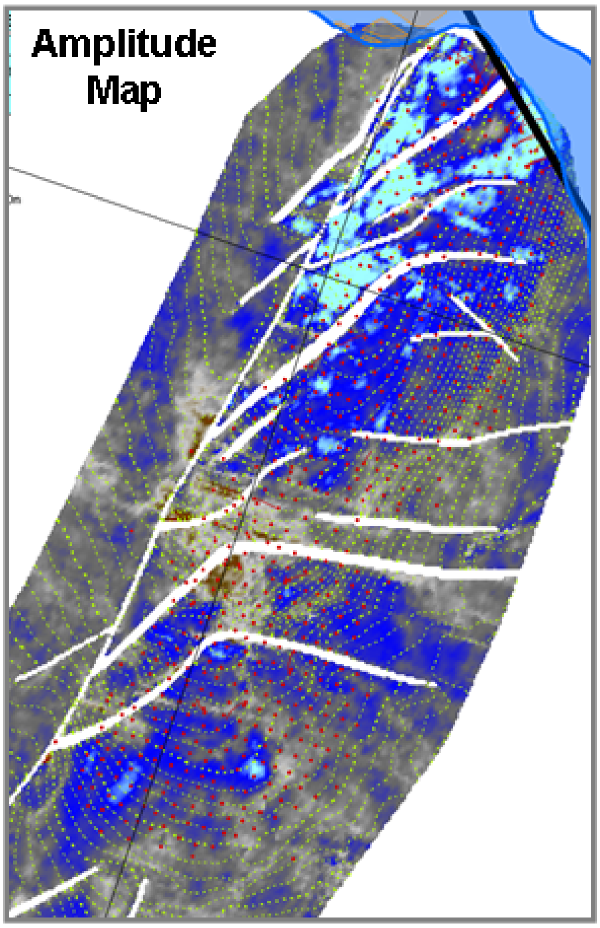

Figure 17: Amplitude Map

Let's go step by step.
Bright spots come out of seismic line by themselves. They are self evident (Fig. 15). What's next? An amplitude map (Fig. 17). Then they are drilled and a dry hole is, *frequently*, the result.

Conclusion: a bright spot by itself does not guaranty the presence of hydrocarbons.

What follows is an AVO analysis. Let's see the bases.

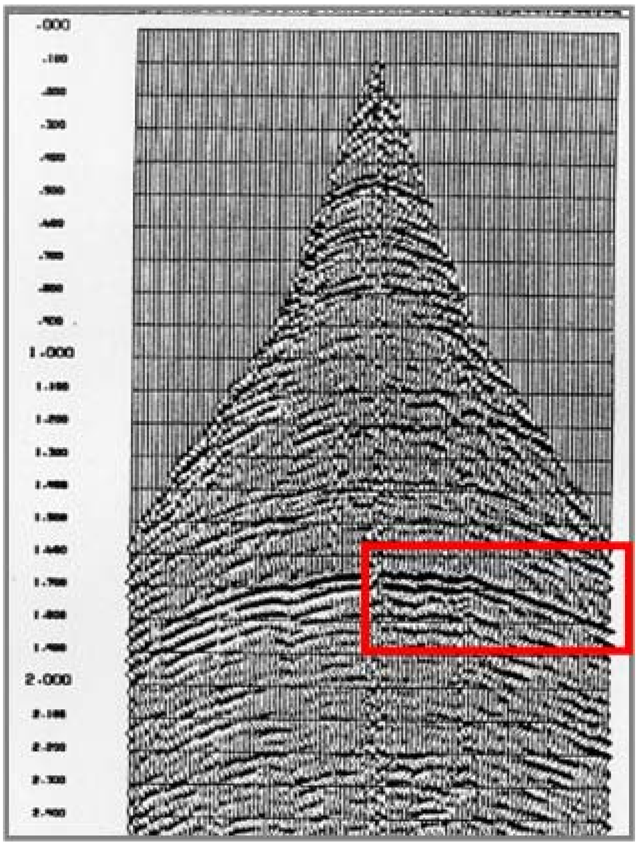

Figure 18: Uncorrected common Depth point gather

In a Common Midpoint Gather (Fig. 18), it means before stacking, the amplitude either at the top or at the bottom of a wet reservoir **decreases** with offset (Fig. 19a). In other words: amplitude decreases with the distance to the source.

In the presence of a **small** amount of gas this relationship in between amplitude and offset is altered: sometimes amplitude **increases** with offset (Fig. 19b) and sometimes it does not only increases but also change polarity. Then we are in the presence of an AVO anomaly: ***Amplitude increases with offset***.

The degree of uncertainty has been minimized. The probability of having a good well is much higher. This is the logical sequence that we have to stick to.

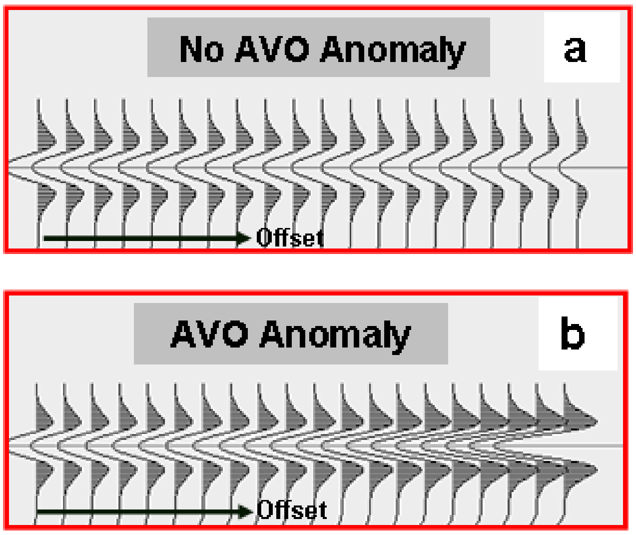

Figure 19: Common Depth Point Gather

Undeveloped Areas
The water oil contacts previously defined, where modified and extended to the east by mean of the seismic structural maps (Fig. 20).

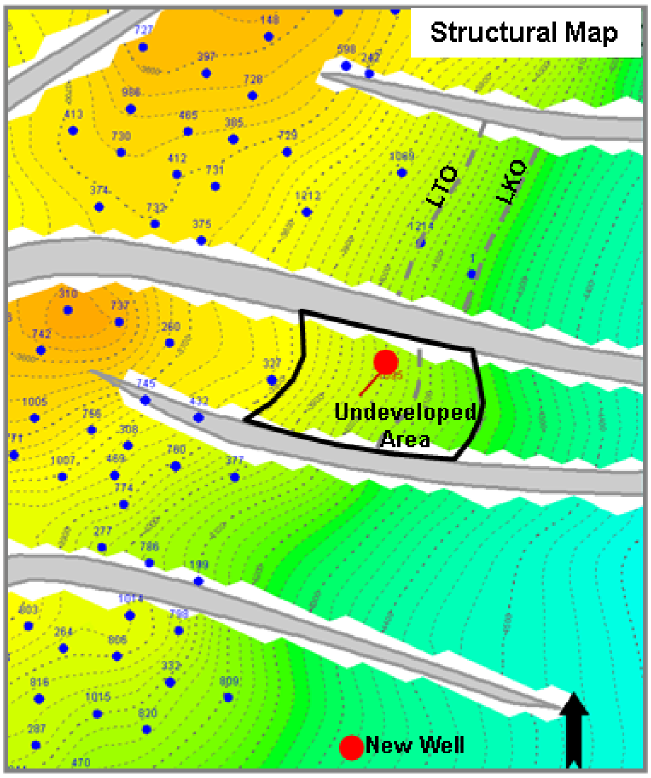

Figure 20: Undeveloped Areas

These undeveloped areas were later drilled (Fig. 21) proven oil saturation and consequently increasing reserves and oil production.

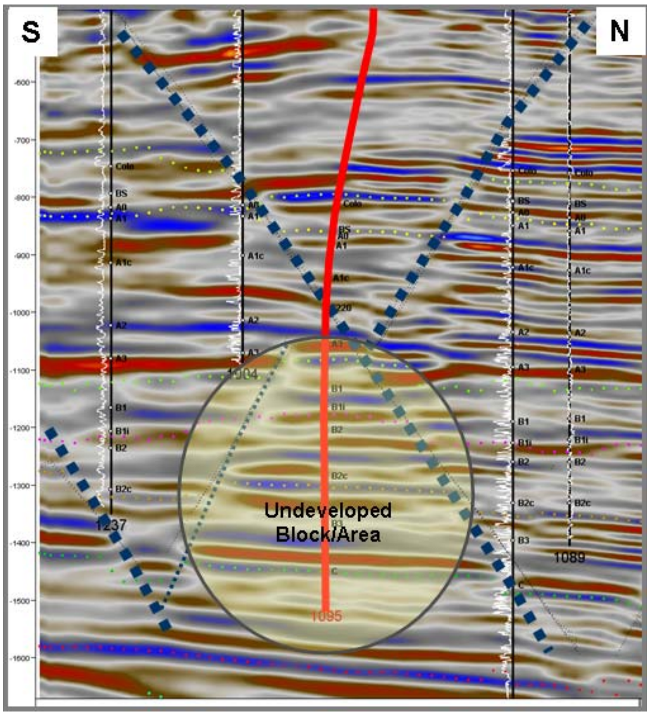

Figure 21: N-S Seismic Cross Section

New Prospect

In a flat area like this (Fig.2) covered with quaternary sediments, there is not other way of finding new prospects but with indirect methods (geophysical methods) and of course, seismic is one of them.

The Casabe 3D seismic cube extends 90 km^2 in subsurface (Fig. 8), covering Casabe and Peñas Blancas fields 7 km away. Halfway between the two fields a new prospect showed up (Fig. 22).

This new prospect, with an estimated resource of 50 MM bbl OOIP, has not been drilled yet.

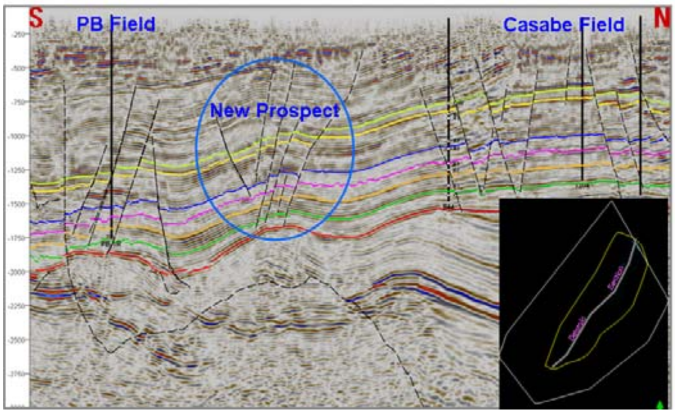

Figure 22: N-S Seismic cross section

Again, the same question: Would have it been detected without seismic data? NO, it wouldn't.

Wrap Up

In 2004, when the Alliance formed by Ecopetrol and Schlumberger took over the operation of the field; it had been in production for almost 60 years. More than one thousands wells had been drilled and more than 280 MM bbl of oil had been produced.

In a mature field like Casabe, there is not any doubt regarding petroleum system. What left then?

What left can be summarized in two statements:

1. Keep looking for traps/undeveloped areas
2. Continue injecting water

Conclusion

It is never late to shoot a 3D seismic cube.

The value added by the 3D Seismic Cube has been much larger than the investment performed in its acquisition, processing and interpretation as it is clearly demonstrated by a Profitability Index (PI) higher than 2 (two).

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