Geophysical tools applied in the exploration of Argentinean productive basins

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Abstract

Productive petroleum basins in Argentina present a great diversity on sedimentological and structural styles. Such a variety implies an interesting challenge at the moment of exploration and development of reservoirs. Seismic methods are intensively exploited in order to obtain maximum information of the subsurface. Seismic attributes, impedance inversion, AVO, geo-estatistics, neural networks, prestack depth migration, tomographic statics are some of the methods used along the different basins in the search of new answers for better well locations.

The aim of this work is to present a brief description of each basin and summarize some of the techniques employed to enhance the information present in the acquired data.

Introduction

Five different basins can be identified as the productive ones in Argentina. From North to South there are, the Northwest, Cuyana, Neuquen, Golfo San Jorge and Austral basins (figure 1). We will focus on the ones with more activity nowadays. For each of them we chose examples related to typical problems faced at the exploratory phase.

Figure1 Argentinian Productive basin (adapted from Shiuma et al, 2002)

NorthWest basin

This basin located in the Northwest part of the country, represents a risky area for exploration due to a very complex geology. In order to give a brief idea of the main features of this basin we will describe its regional geology, starting with its sedimentary history. Over the economic basement (Low Paleozoic-PreCambrian) there are superimposed four sedimentary cycles. There can be summarize as follows:

Siluric-Devonic, cycle: composed by lutites and sandstones deposited in marine and coastal environments. Traditionally this cycle was considered as deposited in a foreland basin. Although, lately, that origin is under discussion.

Carbonic cycle: it is a heterogeneous group of rocks. The depositional environments range from glacial to periglacial, for the basal parts, to carbonatic ramps, for the upper part. Towards south there is an erosive unconformity, which separates this one from the next cycle. In that direction there is a change of its facies to braided channels. It is considered to be deposited on an intracontinental basin with low subsidence. It has a complex stratigraphy from chaotic to sub parallel.

Cretacic cycle: this group has been deposited in an extensional basin, such as a rift, covering the provinces of Salta, Jujuy and Formosa. It has a wide variety of lithologies, from conglomerades to evaporites and from sandstones to limestone, deposited on different types of environments, but mainly continental ones.

Tertiary cycle: red beds mainly compose this cycle. There are pelites and conglomerades formed in a foreland basin due to the formation of the Andes during Upper Tertiary.

There are four main areas we can distinguish in this basin from a tectonic point of view:

Cordillera Oriental, which covers an area on the west and center part of the basin; *Sierras Subandinas*, covers North and center of the province of Salta; *Planicie Chaqueña*, located on the East of Salta; *Lomas de Olmedo*, covering from the center of Salta towards NE-SO until Formosa province and Paraguay.

From all of them, the section corresponding to Sierras Subandinas is the most attractive from the exploration point of view. This area is subdivided into *occidental* and *oriental.* The former presents chains of anticlines NNE-SSW and a complex structure, while the latter is simpler in terms of deformation. (Disalvo, 2002).

One of the major challenges imposed by this basin is due to the complex structure and the difficult task of an accurate image of the subsurface. It is well known that in the presence of very structured areas post-stack time migration fails to locate horizons in the right position. Pre-stack processing seems to be the suitable tool to deal with this kind of data. Nevertheless, for areas with structures like fold and thrust belt it is the pre-stack depth migration the most proper method to obtain the best imaging of the subsurface. As an example, to illustrate such improvement we chose a case from Sierras Subandinas, where it can be compared a pre stack time migration and a pre-stack depth migration. The former gave a poor imaging of the horizons and a blurred delineation of the faults (figure 2), due to the lack of accuracy of the velocity field used. Afterwards a Kirchoff pre-stack depth migration was performed. A layer stripping technique built the initial velocity model and its update was done by successive iterations of a global tomography until the final model was reached. The result gave a better imaging of the subsurface of interest as it is shown in figure 3.

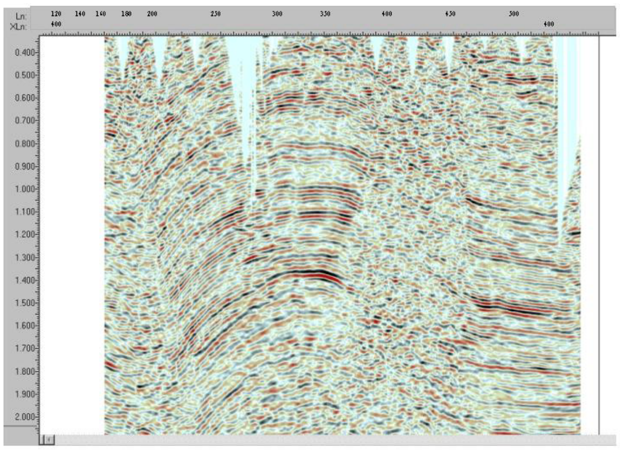

Figure2: Pre-stack time migration for an anticline in the Subandinas area.

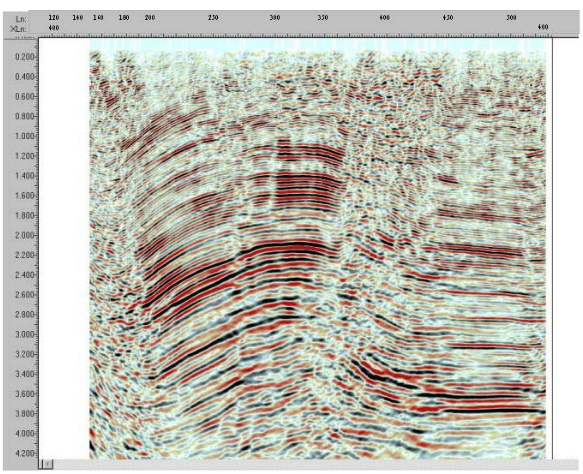

Figure3: Pre-stack depth migration for an anticline in the Subandinas area.

Neuquen Basin

This basin is one of the most important basins of Argentina in terms of oil and gas reserves. It covers Neuquen Province and the west portion of the provinces of Rio Negro and La Pampa, and the southwest part of the province of Mendoza.

From the tectonic point of view, the basin began its evolution during late Triassic and early Jurassic, as a result of the extensional collapse of the Permian Triassic Orogenic Belt. During the Triassic and Late Jurassic, the basin was affected by northeast oriented extension and during the Late Jurassic to Cretaceous by NW extension related to Gondwana break-up. During the Kimmeridgian, the inversion of an earlier depocenter created the Huincul dorsal. During Tertiary, the western part of the basin was affected by Andean tectonics (Vergani et al., 1995).

The wide geological diversity and the existence of four proved petroleum systems make this basin extremely attractive from the exploration point of view. This characteristic encourages geophysicists to improve acquisition and processing techniques in order to take advantage of all possible seismic attributes at the interpretation step. This basin presents different types of reservoir and not only structural but also stratigraphic and combined traps. From the seismic point of view there are many challenging areas, like the western thrust belt and "La Dorsal" in the center of the basin (a right lateral wrench fault, with a W-E direction), for such cases pre-stack processing is the option mostly used.

In the eastern area of the basin, where most of the oil and gas fields are located, seismic attributes are extensively used, as well as impedance inversion in many cases with very positive results. As an example, studies with RMS amplitude work satisfactory well in some areas like Sierra Chata, one of the important discoveries of hydrocarbons in the 90's.

Another example is one applied to the less explored reservoir in the basin, the Precuyano. For some productive fields this reservoir, is represented as hemigrabens infill, associated to acid volcanic rocks linked to effusive events with a strong activity of piroclastics flows, therefore reservoir development is associated to alteration, and fractures. In the Field of Medanito 25 de mayo- Medanito SE it was found that the best seismic attribute to characterize this reservoir was the Reflection Strength. Correlation of this attribute with the accumulated well production revealed an inverse relation, the higher the production the lowest the Reflection Strength. Such a relation makes sense if we take into account that this reservoir is characterized by fractures where energy will be dissipated, implying low values of Reflection Strength. Based on this concept, it was defined a possible boundary of a productive zone for this reservoir (figures 4-5) (Pangaro et al., 2002).

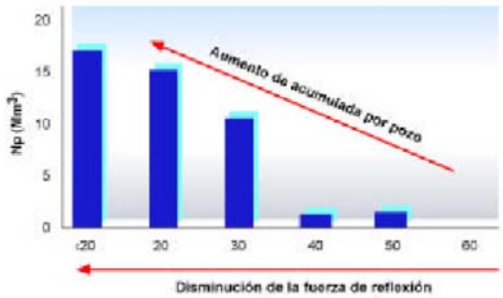

Figure 4: Accumulated production vs. Reflection Strength attribute (adapted from Pangaro et al., 2002)

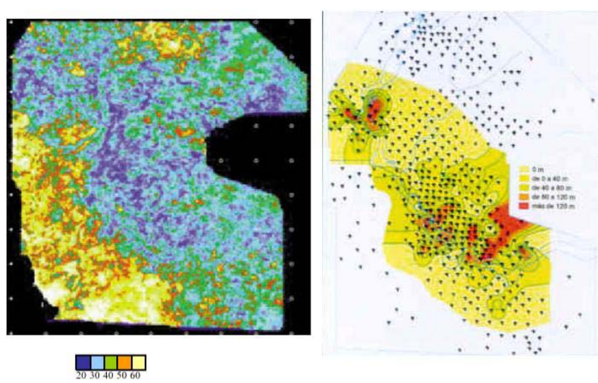

Figure 5: Left: reflection strength attribute between Top Precuyano + 120 ms below it. Right: Isopach map of the reservoir (adapted from Pangaro et al., 2002)

So far, conventional post-stack attributes seem to work fine in the eastern part of the basin. However there are cases where seismic amplitudes are not representatives of the properties of the reservoir or hydrocarbon content, mainly because of signal attenuation caused by surface features, which generally act as a low-pass filter. This is to say, the signal applied to the field during acquisition turn out to be distorted and studies of amplitude related attributes might be useless, unless careful processing is done.

In this sense, one of the most challenging problems in the Neuquen basin is the presence of surface basalt flows. In those cases, the seismic signal traveling through the basaltic layer loose its high frequency content. This kind of layer acts as a low-pass filter and distorts the signal as it travels through it.

Basalt layers are characterized by a wide velocity spectrum, from very low, 300m/s for non-consolidated material, up to very high velocities, 6000m/s for massive and consolidated bodies. From the processing point of view, a proper static correction becomes a critical point. Conventional refraction method is not able to handle such a velocity inversion for shallow layers. Therefore, new approaches such as tomographic static are used. This method is able to create a near surface velocity model that allows to detect those velocities inversions (Roizman, 2002).

Golfo San Jorge Basin

This basin, located in the central patagonean area, is an extensional basin developed on top of a palezoic continental crust. From Late Jurassic to Early Cretaceous, the extension linked to the Gondwana break-up generated many isolated small half graben basins, with a NW-SE structural trend. Later, a new extensional-transtensional stress field gave rise a WNW-ESE trending, and reduced extensional deformation continued until the Oligocene. The basin is essentially asymmetric: in the eastern part the dominant extensional faults are on the northen section with the southern section being less faulted, flexural type margin. On the other hand, the western part is assymetric but major faults are on the southern flank while the northen flank is a flexural margin. The central portion of the basin is dominated by NW and NNW trending extensional faults that were reactivated by compression in Tertiary times (Figari et al., 1999). The more important productive reservoirs were deposited at the sag stage of the basin and there are associated to lacustrine and fluvial deposits. Such reservoirs are heterogeneous and laterally discontinuous lenticular sand bodies (Egusquiza, 2000).

We chose an example that involves those multilayer reservoirs with lenses of sand between 2-15 m (Egusquiza, 2000). Therefore, mapping such features becomes a challenge, considering we are below seismic resolution and most probably any information will be hidden under tunning effects. In the attempt of getting stratigraphic information from the seismic data correlated to well information, conventional attributes were compute. RMS amplitude and Instantaneous Frequency failed to give any relationship with well data. Searching for a way around so as to get information about these sand bodies lead to compute the correlation trace to trace and after that delta amplitude between successive correlations were computed. The former attribute shows interesting features but does not show any correlation with the net thickness data from well, while the latter gave a high correlation coefficient. Once a relation was found, geo-statistics method (krigging) was used to obtain the regional map of sand thickness

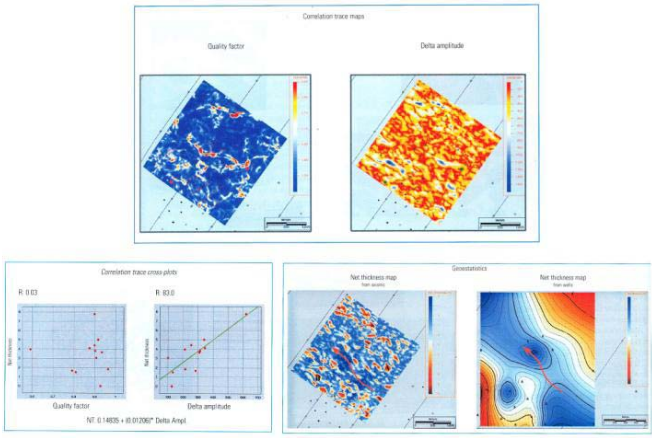

Figure 6: Top right map of quality factor. Top left: map of delta amplitude. Bottom: left, correlation between attributes and net thickness. Bottom right: geostatistical sand thickness map (left) and sand thickness map from well data (right). (Adapted from Egusquiza, 2000)

Techniques like spectral decomposition might be another interesting tool for this kind of reservoir. Also neural networks approach to obtain petrophysical information is a possible method given the quantity of wells in those fields.

Austral Basin

This basin is located in the southern extreme of South America. It covers a vast part of the province of Santa Cruz, the Magellan's Strait, the Chilean province with same name, Tierra del Fuego and an extended surface on the Argentinean Continental Platform. From the tectonic point of view it is next to southwest boundary of the South American Plate, between Deseado massif, the arc of Rio Chico-Dungenes that separates it from the Malvinas basin and the Austral Patagonian Andes. The evolution of this basin is related to three main stages. The first one related to an extensional period linked to Gondwana´s fragmentation, the initial opening of the South Atlantic Ocean and a retro arc basin or Marginal basin during Triassic-Middle to Upper Jurassic (*rift stage*). The second period is related with a "post-rift" stage and thermical subsidence developed during Upper Jurassic-Lower Cretacic. The Third one is linked to the development of a foreland basin during Upper Cretaceous and Tertiary. From the stratigraphic point of view, it can be recognized a set of cycles of sedimentation. The first one involves the filling of the half-grabens with lacustrine deposits and the development of thick sequences of acid volcaniclastic. From that moment the infill of the basin is basically pelitic. At coastal zones there are clastic facies marine-marginal with estuarine and fluvial deposits, as trangressive records. Regressive sequences developed unconformities locally and regionally with progradations fluvial-deltaic to aluvional fans in areas close to the Cordillera (Peroni et al, 2002).

As one of the problems to face in this basin there are velocities anomalies caused by the already mentioned progradations. Therefore it might be required the definition of a more accurate velocity model for the subsurface. In this sense, reflection tomography is one of the methods used at the interpretation step for depth conversion. Being this method able to model those velocities anomalies (Martinez et al, 1999).

From an interpretation point of view, an interesting example we found is the analysis of seismic facies based on neural networks method. In the field Barda Las Vegas (Silva Telles et al., 2002), two wells were drilled, one productive and the other "dry", both were proposed based only on 2D seismic information. After that, a 3D seismic acquisition opened the opportunity to perform a more detailed study. The goal was to define the boundaries of the stratigraphic trap for the reservoir of interest. A classification of families of seismic facies allowed to identify areas of possible productive areas and the proposal of a new well, which turn out to tested an oil/gas contact. This new well was later on included in the study of seismic facies to improve the analysis. Therefore, as a result it was possible to classify areas of seismic facies related to oil, gas and water or non-reservoir (figures 7-8).

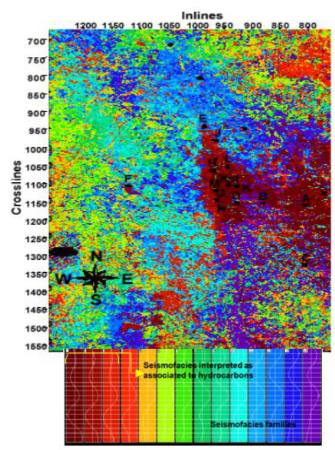

Figure 7: Clasiffication map, colors indicates families of seismic facies.(adapted from Silva Telles et al., 2002)

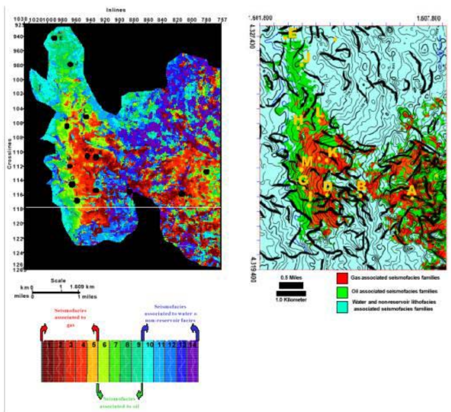

Figure 8: Right:Clasiffication map with the families of seismic facies. Left: estructural map (overlay colors indicates seimic facies) (adapted from Silva Telles et al., 2002)

Another interesting example in this Basin relates to an hybrid seismic inversion perfomed in Maria ines Oeste Field. In this field bright spots were traditionally used as hydrocarbon indicators for the sandstones reservoirs. However, this approach not always result in commercial locations. In order to isolate bright spots associated to hydrocarbon accumulations it was used a combination of hybrid seismic inversion, prestack seismic analysis and geologic modeling. Such inversion was perfomed in three steps. First, Prestack full waveform inversion was run at selected locations from the entire cube, providing detailed P-wave , S-wave velocities and density for those locations. Based on this data, P and S- wave impedance are computed. Secondly, Avo analysis is done on the entire prestack seismic cube using standard two-term intercept-gradient approach leading to AVO intercept (1) and the AVO gradient (2) for the entire data set. Using a background Vp/Vs, traces 1 and 2 are combined in order to get the pseudo-S reflectivity. Finally in the third step an inversion of the AVO intercept traces is performed using the low-frequency P-wave impedance trend obtained from the prestack waveform inversion (first step). Analogous analisys is done for for pseudo-Swave traces. As a result of this last step it was obtained P and S wave impedance for the whole sesimic cube. These data was combined into a new attribute, the Poisson´s ratio which is believed to be powerful in discriminating between differents lithologies and different types of fluids in reservoirs.

As a result of these study it was found that while seismic amplitude from the stacked data was not able to distinguish between oil and gas content, a map of Poisson´s ratio showed differences between those cases (figure 9). On top of that, when comparing maps of Pseudo Poisson´s ratio from AVO analysis and Poisson´s ratio from hybrid inversion over an area with oil and gas discoveries, it was found that only the latter could distinguish between the two types of fluid reservoir (figure10) (Benabentos et al.,2002).

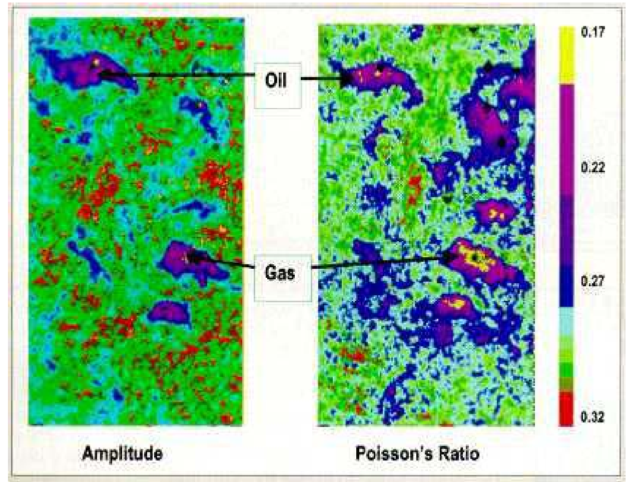

Figure 9: Right Amplitude map fro the stacked data, can not distinguish between oil and gas reservoir. Left: Poisson´s ratio from the hybrid inversion is able to give different answers for the different reservoirs (adapted from Benabentos et al,2002).

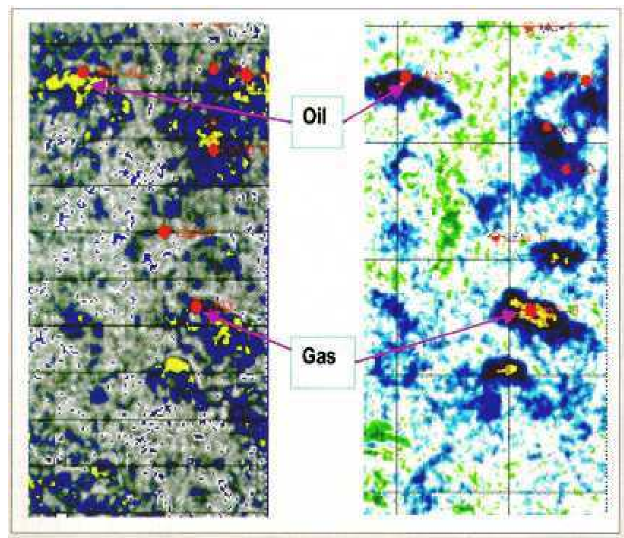

Figure 10: Right: Pseudo-Poisson´s ratio from AVO analysiscould not show a difference for gas and oil reservoirs. Left: Poisson ratio from hybrid inversion is able to separate cases of oil from cases of gas reservoir.

Conclusions

A brief summary of the most important Argentinean productive basin was presented. Some examples of the techniques used were shown. In this sense, we could observed that in terms of seismic attributes not only the traditional post-stack attributes are used but also combination of different ones in order to obtain more information of the explored field. Cases where amplitude related attributes fail to help in the understanding of the basin; techniques like inversion impedance, seismic facies classification and neural networks are a way out in those situations. On the other hand, as it is well known carefully treatment of the data before interpretation is a key point. We show cases where the processing step is critical to obtain a right image of the subsurface. Starting from the very basic processing step, such as static correction, might be critical in the presence of very heterogeneous shallow velocity, i.e. velocity variations associated to basalt flows. As well, defining the right velocity model in areas of complex structured data like the one found in the Northwest basin is a critical point. Pre-stack depth migration, where velocity models are detailed defined seems to be the best approach for those cases.

Finally we can conclude that nowadays there are many interesting tools that can be used alone or combined to explore the most an area. It is on the geophysicist mind to take properly advantage of them according to the characteristic of the basin under study.

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