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A New Exploration Play in the southwestern Region of the Golfo San Jorge Basin

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Abstract

The Golfo San Jorge basin, located in the central Patagonia, is the oldest producing basin of Argentina. It is an intracratonic extensionla basin, where the first economic discovery took place in 1907.

In the sothwestern sector, the Cerro Piedra – Cerro Guadal Norte area has a surface of 1835 sq Km, and only one field in production, the Cerro piedra field that has a daily production of 330 cubic meters of oil and 44500 cubic meters of gas from 40 wells. The reservoir unit is the bajo Barreal formation, that belongs to the Chubut Group (K) and is part of the best known play of the basin. Though 2D seismic analysis and the use of special techniques, an AVO study was made that showed an interesting response in the P normal wave incidence and the fluid factor.

This way it was possible to discriminate the top and base of an important gas bearing zone in the seismic, with a good correlation in the field with the well logs .From this a new Play is recognized, the Patagonia Formation of Tertiary Age. It consist of sandstone deposit, oroginated in a marine environment, up to 35 m thick, that by wells, with a production of 165000 m3/day.

This discovery is a new case in the basin and makes up an interesting exploration play in this part of the basin.

Introduction

The structure of the Cerro Piedra field began to be investigated in the 1974 after drilling the first exploratory well, YPF.SC.CP.x-1 (Cerro Piedra). This well penetrated 3011 m (bellow ground level) and reached the Pozo D-129 Formation. However, it was cased only to the top of the Castillo Formation with the basal and middle sections of the Bajo Barreal Formation being assessed through perforations. In the latter Formation, some layers showed steady water flow rates whereas non-entrance of fluids was found to be the case with others. This could be due to formation damage during both drilling and cementing stages.

From 1983 to 1985, a new exploration campaign was conduced in the west where 4 exploratory wells were drilled. Of these, 3 proved to be liquid and gaseous hydrocarbon discovery wells from reservoirs located in the middle to upper section of the Bajo Barreal Formation and yielded low flow rates.

Due to the low productivity from these wells and on account of the distance to the nearest oil pipeline, exploitation, development and resumption of exploration activities were postponed until as late as 1992. That year, a new seismic recording program was conducted and intervention of the Cerro Piedra x-4 well was proposed. After reassessing this well through swabbing and TST testing, one of the layers producing oil at a low flow rate was stimulated by hydraulic fracturing, which resulted in a significant productivity increase. This encouraged the drilling of new exploration wells, such as the Cerro Piedra x-7, which involved several oil and gas-bearing layers. The former were brought on production and yielded good production rates with economically significant cumulative production. Thus, an important development activity was initiated in the area which currently has some 51 exploration , outpost, and development wells. Nearly all of the involve 4 to 6 primary recovery layers as a result of the high reservoir energy wich is largely due to the presence of dissolved and/or associated gas. The field shows a high GOR . Occurrence of gas-bearing layers with flow rates ranging from 60,000 to 100,000 m3/d is significant. These layers, which would provide a considerable economic resource, are yet unexploited.

It should be noted that the field is currently provided with both oil and gas pipelines, gas batteries and compressors, which promotes field development and exploration.

Stratigraphy

The basament of the area involves a set of different units for the different basin positions. In some relative highs, it consists of Upper Paleozoic metamorphites, dark gray carbonaceous shales and gray sandstone of Carboniferous-Permian age or predominantly epiclastic marine sedimentites and also limestones and tuffs of Lower Jurasic age (Lias). Subaerial,

shelf, lacustrine and proximal deposit with coarse fan deltas, occur in the depocenters developed from the Bajocian-Bathonian onwards. Their composition is predominantly volcanic to the North and West or pyroclastic to the South and East. This section, called Sedimentary Volcanic Complex (SVC), shows different lithologic characteristics depending on its position within these depocenters.

Overlying are the deposits informally known as Neocomian. These deposits clearly onlap the older ones have been historically divided into two secuences which are partially equated to the Aguada Bandera and Cerro Guadal Formations or their equivalents. They represent the record of a mature half-graben phase where the predominantly shaly Aguada Bandera sequence constituted the fill at a starved basin stage, whereas the predominantly sandy Cerro Guadal sequence corresponds to a maximum flooding event with marine influence from the Pacific and integrated dranaige.

Most exploration wells drilled in the area penetrated the entire stratigraphic column for the Chubut cycle recognized there. Overlying the Neocomian deposits are the depositional sequences belonging to the Pozo D-129 / Matasiete Formation, which consist mainly of claystones, silstones, sandstones, and oolitic limestones. It should be noted that the low source rock quality of the shales belonging to the former formation is due to the marginal deposit condition, which is confirmed by the occurrence of the Matasiete Formation facies recognized in this part of the Basin. Contributed hydrocarbons would be generated from organogenic shales (source rock) of Neocomian age.

The Castillo Formation deposits which are mostly composed of tuffs, sandy tuffs, tuffaceous sandstones, tuffites, claystones, and siltstones also involving tuffaceous components are separated by an unconformity. They gradually pass into the Bajo Barreal Formation, whose basal section consist of tuffs and tuffaceous sandstones, and whose middle and upper sections involve intercalated sandstones, claystones and silstones with pyroclastics almost disappearing. Sandy layers in this formation are the main oil and gas reservoirs and exhibit very good petrophysical characteristics.

Uncorformably overlying the earlier formation are the Tertiary Rio Chico, Patagonia, and Santa Cruz Formations which represent completely different environmental conditions and consist as a whole of claystones, siltstones, and sandstones of both marine and continental origin.

Structure

The structural framework of the area is characterized by two superimposed tectonic styles. The first and older one is represented by normal faults which affect the economic basement and give rise to westward-verging asymmetric half-grabens initially and predominantly filled by Neocomian sediments of marine and continental origin. Filling was completed with continental Chubutiano deposits.

The second tectonic style was the result of a compressional tectonics which began during the middle Tertiary and is still effective providing preexisting structures with an anticlinal configuration due to tectonic inversion which mainly affects the Chubut and Tertiary cover rock.

Petroleum system

From the spatial and evolutionary independence of the source rock intervals of the Neocomian and Chubut cycles, as well as from the predominant occurrence of sandy bodies of the bajo Barreal Formation as practically the only reservoirs of economic importance for the entire basin, two main petroleum systems can be defined after Magoon and Down (1994): D-129 - Bajo Barreal (!) and Aguada Bandera – Bajo Barreal(!). The geographical area occupied by the main petroleum systems is shown in Fig 2: I) central- eastern area with oils generated from D-129; II) western area with oils from Aguada Bandera; III)an area incluiding mixtures of oils from both intervals (Figari et al, 1999).

The cerro piedra field would correspond to the second petroleum system with hydrocarbon accumulations detected in the Tertiary belonging to a subsystem thereof. Following is a summary of the main elements of the system:

The source rock

A geochemical and stratigraphic outline of the Neocomian column on the Western Flank (Fig 3) shows that the lacustrine shales of the Aguada Bandera Formation have the richest organic content (sometimes higher than 2 % TOC) with Rock-Eval pyrolysis S2 peaks of 10 mg HC/gram of rock and hydrogen indices (HI) of 400mg HC /gram TOC (Laffitte, 1994). In this part of the basin, the shales associated with the Cerro Guadal Formation and those assigned to the Sedimentary Volcanic Complex are of a significantly poorer organic content and/or quality. In the same column, below a thick pyroclastic interval, a shaly section displays similar geochemical characteristics suggesting the occurrence of an additional petroleum system, which is only speculative for the time being.

The Aguada bandera Formation contains a predominantly amorphous, type (I) / II kerogen which is associated with abundant Celyphus rallus algal remains (distal lacustrine setting, water stratigraphic column). The Cerro Guadal Formation, on the other hand , contains mostly type III kerogen due to the significant terrestrial organic contribution resulting from the progradational nature of this unit. Isochron/isopach maps of the Aguada Bandera Formation show major depocenters where thick black shale columns (increased hydrocarbon-proneness) were deposited during the starved basin stage. Along the edges and intermediate highs, age-equivalent sections are arranged in condensed proximal facies with low to zero oil generation potential.

The reservoirs

The most important basin reservoir in terms of distribution, thickness, and production belong to the Bajo Barreal Formation. This unit, wich is more than 2000 m thick in the Chubut depocenter and thinner than 400 m on the edges, was deposited during a sag phase.

Other reservoirs are available in the Cerro Guadal Formation and in the coarse proximal facies of D-129. Here, investigation density is really low and drilling focused mainly on the basin edges. An idealized schematics of Neocomian half-grabens is shown in Fig 4.

Special emphasis should be placed on the reservoirs attributed to the Tertiary which are little know for the time being and are just under study. Tertiary deposits generally consist of the Salamanca, Río Chico, Sarmiento, Patagonia, and Santa Cruz formations and their lateral equivalents(legarreta et al, 1990). During their deposition, occurrence of extensional episodes coupled with eustatic changes led to an Atlantic-verging transgression and regression history. According to some author (Nocioni, 1993), the first incursion from the Atlantic coincides with an increase in the subsidence rate of the basin with the pre-Salamanca effusive phase (Ferrello, 1969) being the cord of such event (Chellotti, 1996). Rio Chico Formation of continental origin laterally interfingers with this unit (Legarreta and Uliana, 1994). Prior to and during the deposition of the tuffs and tuffites of the Sarmiento Formation, four base level falls resulted in an equal number of hiatuses (Legarretta and Uliana, 1994). Ingression of the Patagonian, which partially interfingers with the Sarmiento Formation, is conditioned by a new extensional pulse . Coinciding with this pulse, post-Eocene and pre-Patagonian effusive volcanism appears as a good record (Chellotti, 1996). New highstand sea level events lead to marine incursion of the Superpatagonian which extends diachronically westward. Fluvial and eolian deposits of the Santa Cruz Formation laterally interfinger with, and prograde onto, the superpatagonian beyond the available accommodation space, which show the beginning of the Cordilleran massif uplift (Legarretta,, et al., 1990).

To date, in Cerro Piedra area, Tertiary sections (Figs 5 and 6) have been attributed as follows:

a) A basal variegated sandstones complex which unconformably overlies the Bajo Barreal, to the Río Chico and equivalent formations.

b) A middle section where thick shallowing upward conglomeratic sand bodies separated by a significant shaly neck occur, to the Patagonia Formation (sensu lato).

c) Coarse clastic layers, to the Santa Cruz Formation.

This is a preliminary nomenclature which can be totally modified on the bases of detail stratigraphy.

Seal

Within the Bajo Barreal and its equivalent formations, the characteristic of the most effective seals vary significantly depending on where they are located. For example, in the central-western part, the tuffaceous claystones of the middle section of the Bajo Barreal Formation (thicker than 150 m) provide the primary seal with no major hydrocarbon accumulations occurring above them. In the folden belt, such seal is absent because it has been partially or totally eroded and depends to a certain extent on minor seals or on tar sands themselves. To the west, the unconformity at base of the Tertiary gradually eliminates the upper section of Bajo Barreal as a result of erosion concurrently with a decrease in its capacity as a seal. In particular, for the base of the Patagonian, the main seal present is attributed to the thick middle shaly section (flood).

The overburden

This is deemed to include the entire stratigraphic column succeeding the Aguada Bandera Formation and Pozo D-129 Formation for each of the respective petroleum system. However, in the eastern part where the D-129 thickness is of a thousand meter-scale, the additional overloading effects from the upper layers of this unit on the basal sections was crucial. This turns modeling difficult because, within the D-129 Formation itself, the time range involved is considerably wide when considering timing of generation and expulsion at unit ends. Therefore, it is advisable to differentiete them.

Migration pathways

Vertical migration through the WNW-ESE oriented extensional system, which developed from the Lower Cretaceous to the Oligocene and controls hydrocarbon occurrence along both basin flanks and even within the folded belt, has proved the best migration route basinwide . This resulted in a high degree of compartmentalization where each suck block behaves as an independent unit as regards filling and preservation . Within this framework, there are several examples where recurrent fault movement has caused periodic filling of vertically-stacked reservoir which in turn resulted in occurrence of both biodegraded heavy oils from an early filling and degradation process and light and mixture oils from late migration and biodegradation pulses across the same structure (Villar, et al., 1996).

Regarding the fracture system which is nearly parallel to the meridian direction, the compressional tectonic inversion pulse is considered to have caused mainly exhumation of most of the D-129 Formation taking it out of the generation window, destruction of accumulations occurring in the inversion area, remigration along new structures , development of reverse faults as seals and only occasionally - development of new migration path-ways. This seems to be the case with the Cerro Piedra structure where the antithetic release fault relative to the major reverse fault may have provided the main migration route. Probable combination with lateral migration should also be considered on account of the extent and permeability of these Tertiary units which could render them effective carrier rocks.

The traps

This is a typical case of structural entrapment across the apex of a tectonic a tectonic inversion anticline resulting from Tertiary fault propagation (reactivation of the active edges of the older rifting phase). These structures, the axes of which are nearly parallel to the meridian direction , are fragmented and compartmentalized by transverse faults. Some of them show clear lateral offsets. The Sierra Silva Anticline located

between Muster and Colhue Huapi lakes is an excellent example at surface.

New Play

The middle to upper section of the Bajo Barreal Formation (Upper Cretaceous) is the best known play to date. The Neocomian play is considered to be similar to those described across the Basin edges (Figari et al, 1996). Only the Tertiary Play should therefore be described.

The Tertiary play was first noted as a seismic amplitude anomaly within the Patagonia Formation (sensu lato). This anomaly would be related to a considerably thick sand deposit of marine origin which, according to logs, would carry gas. From this evidence , and AVO study was performed which showed an interesting response in normal P wave incidence and fluid factor. Thus, we could diferentiate the top and base of the gas carrier area (derived from seismic) and good correlation was found to exist across the field (Pianelli, 1999).

The layer where liquid hydrocarbon shows occur at the Río Chico basal section provides an additional basis. This was tested in an exploration well across the Campo Zabala area. Despite testing formation water, it is an unprecedented case for the Western Flank of the San Jorge Basin.

Background data on gas in the Patagonian

Avo analysis across the Cerro Piedra Field (Pianelli et al): a report showing that certain AVO attributes actually discriminate the top and base of gas carrier zones was published in 1999.

Gas thickness maps: were prepared on the basis of data derived from electric wel log analysis and porosity data and a gas thickness map for the Cerro Piedra area was subsequently constructed (Fig 7)

Gas assessment of the Cerro Piedra 41 well: the gas interval was tested and yielded the follows results :

a) -flows gas on a 50 mm choke. DP: 25 Kg /cm2
b) -flows gas on a 25 mm choke. DP: 21 Kg /cm2
c) -flows gas on a 18 mm choke. DP: 26 Kg /cm2
d) -flows gas on a 11 mm choke. DP: 30 Kg /cm2
e) -Static pressure measured throughout 30 min 24 kg/cm2

Based on the test, it was decided to measure the gas flow rate. This rate, 165,000 m3/day on average after 24 hs, showed reservoir capabillity.

Other methodologies

In the Cerro Piedra area, from a set of 2D lines and using a grid of an approximate 2.5 Km line spacing, seismic amplitude anomalies were identified. These anomalies are associated with thick sandy bodies of the Patagonia Formation (Tc) which are up to 35 m thick. Therefore, the top and base can be mapped because seismic data resolution for that time is 12 m..

The linkage between amplitude anomalies and gas reservoirs has been addressed in the section on background data. This anomally involves a phase change (reverse polarity) caused by the occurrence of gas in the reservoir (Fig 8). The seismic event tied to the anomaly top is consistent with structure and seismic event tied with the base is flat, which would indicate the fluid contact. Following anomaly identification, manual mapping on seismic lines was done in order to determinate areal shape and distribution and anomalus zone was found to coincide with both the structural high and the gas thickness mapping (Fig 9).

Two seismically anomalous zone were identified, i.e. anomaly A (located to the North) has an areal extent of 400 Ha, whereas anomaly B (located to the South) covers an areas of 100 Ha. Finally, amplitude was extracted on top of the target sand using a 50 mseg window and from available data an amplitude map was prepared showing three anomalies: anomaly 1 which matches the reservoirs in the gas thickness map; anomaly 2 which is located in the southern part of the Field, and anomaly 3 which could not be correlated at all because no wells are available in that sector (Fig 10).

Conclusions

- The development of the Cerro Piedra Field is a demonstration of the remainging potential of the typical Bajo Barreal Play , in the western part of the Basin.
- The low deep well density in the area allows to speculate on the exploration potential of the clastic D-129 Formation and the Neocomian cycle.
- The test run on the Cerro Piedra 41 well showed and confirmed the occurrence of a major gas reservoir coinciding with the seismic anomaly.
- Hydrocarbon discovery in the Tertiary reservoirs attributed to the Patagonian in the Cerro Piedra area leads to the discovery of a new play for the San Jorge Basin.
- Anomaly mapping is a valuable but not conclusive tool for detecting gas reservoirs.
- 2D seismic is not the most suitable technique due to its low spatial resolution which makes it difficult to see the anomaly shape and distribution.
- The overall study of the Western Tertiary Paleogene Sequence will enable us to take further steps towards exploration of such sections.

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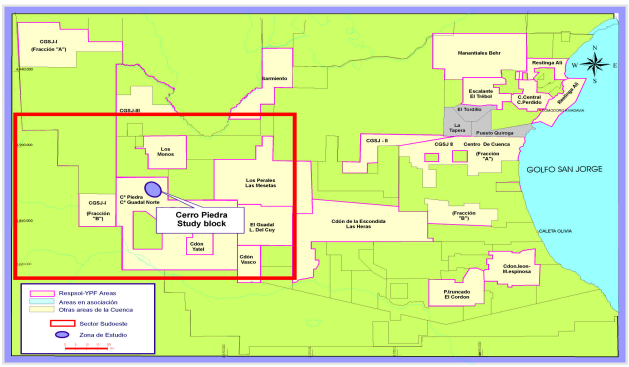

Fig. 1- San Jorge Basin location map.

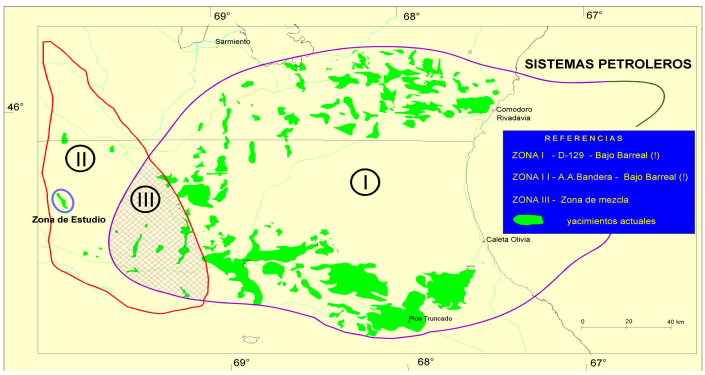

Fig. 2- Map showing geographical framework for petroleum systems in the San Jorge Basin.

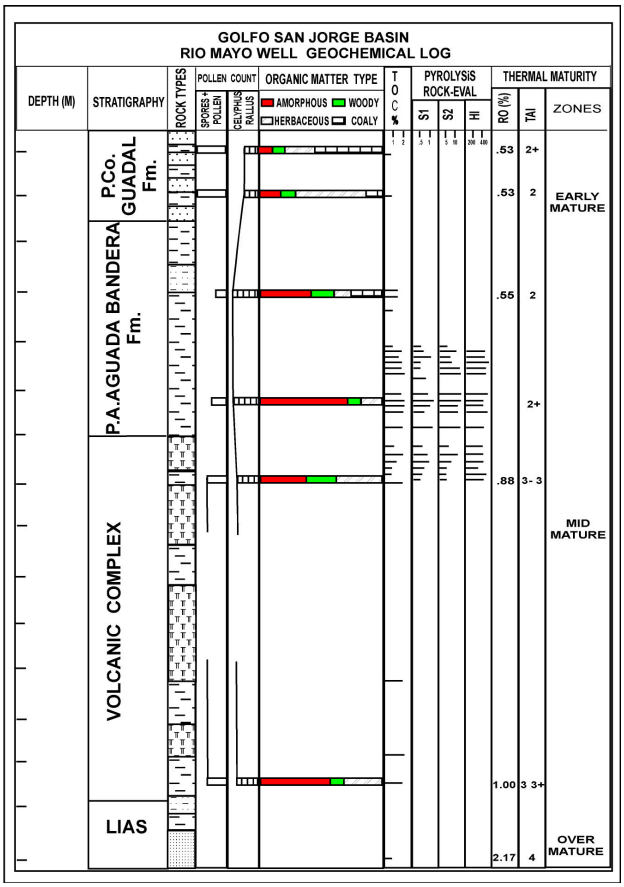

Fig. 3- Geochemical synthesis of Megasequences I and O in the Western sector.

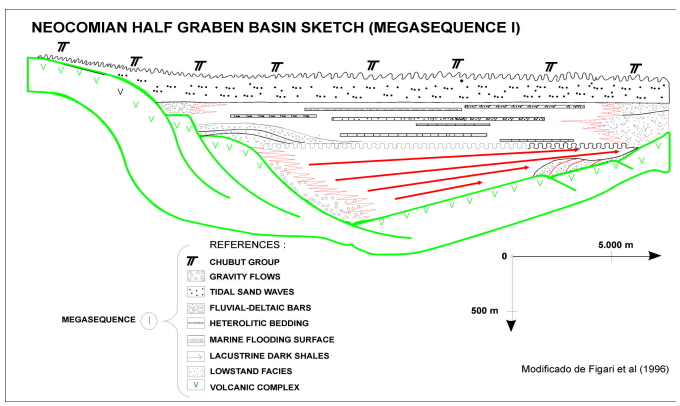

Fig. 4- Neocomian half-graben escheme showing rapid facies changes and the differences between active and passive margin.

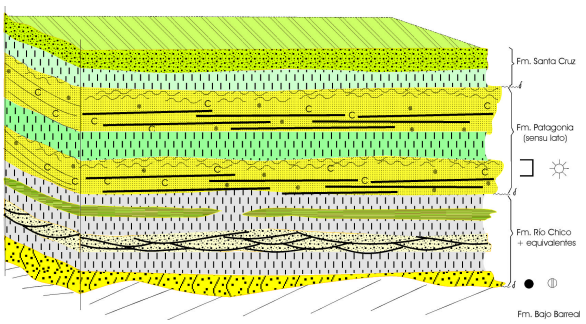

Fig. 5-Schematic block diagram. Tertiary (Paleogene) sequence in the Cerro Piedra zone.

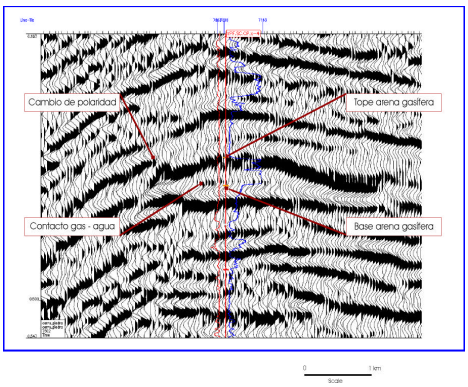

Fig. 8- Seismic amplitude anomaly.

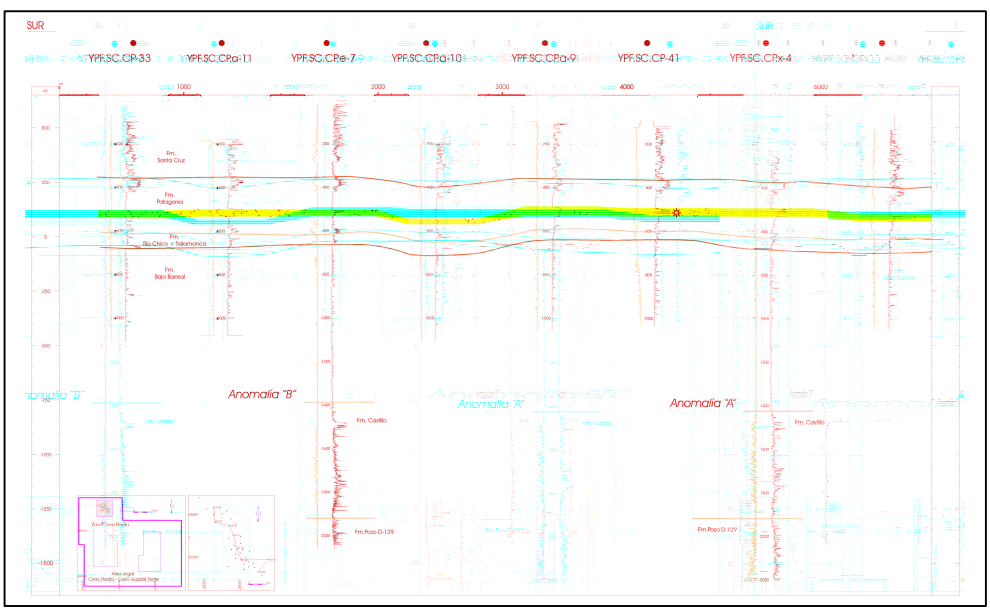

Fig. 6- South-north correlation chart. Cerro Piedra Zone.

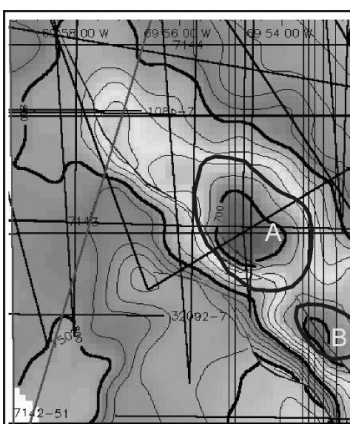

Fig. 9- Structure map draw on top of gas reservoir and seismic amplitude map.

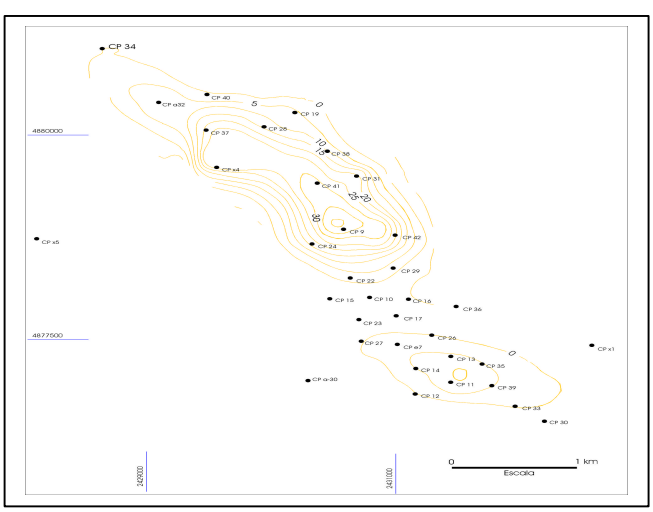

Fig. 7- Gas thickness map.

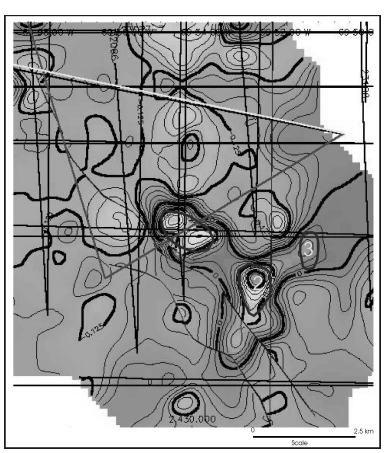

Fig. 10- Structure map draw on top of gas reservoir and seismic anomaly map.