A 3D Gravimetric model of Las Salinas basin, San Juan, Argentina

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Abstract

From a gravimetric study done in the Las Salinas basin, situated in the province of San Juan, Argentina, the geometry of the geologic structures that form this sedimentary trough could be determined. The average depth to the basement was found to be about 5 km, and it increases to the north of the basin. The depth values were obtained by applying spectral analysis and Euler deconvolution to the Bouguer anomaly chart.

The alineations of the Euler solutions resulted highly consistent with the seismic interpretations and thereby permitted to confirm the existence of a wrench fault system mainly oriented north-south, which flank the sedimentary trough and cuts it off in the middle part.

This information, plus densities obtained from logs of two hydrocarbon exploration wells drilled in the basin, permitted the elaboration of a gravity inversion model with variable density, which justifies the Bouguer residual anomaly.

The results show that the basin extends over about 5750 km^2. The sedimentary depths, reaches 5 km, is 1.5 km larger than those obtained with seismic. This leads to the assumption that our results show the depth of the crystalline basement, whereas the seismic ones indicate a shallower presence of a technical basement.

Introduction

Las Salinas basin is situated in the Northwestern part of the province of San Luis, and extends in neighbouring areas of the provinces of San Juan and La Rioja. It lies between the Valle Fértil and Los Llanos ranges, which respectively limit the basin to the west and to the east, whereas to the south it is limited by a basement high, the San Pedro dorsal (Figure 1).

The main structural pattern of this basin is made up by a series of asymmetric anticlines, which trend to the NNW, with a steep western flank, and which are related to east dipping reverse faults. The tectonics is thick skinned tipe produced by inversion of a former extensional tectonics

(Schmidt et al., 1995; Gardini et al., 1999, 2002). The reverse faulting, which extends deep in the subsurface, has uplifted and exposed Mesozozoic and Tertiary rocks in the surface Criado Roque et al., 1981).

Seismic studies carried our by the ex state company YPF and other petroleum companies in the zone show that these faulted anticlinal structures gave origin to no less than four blocks separated by longitudinal faults. These blocks affect the sedimentary cover, which, near the northern end of the basin, surpasses 3500 meters in thickness. The region shows a compressional shortening which affected the sedimentary cover (Criado Roque et al., 1981; Gardini et al., 2002).

Another structural element to be into account is the San Pedro dorsal, which separates the southern end of this basin from the Beazley basin. This dorsal is a basement sill tectonically active at least since Cretaceous and it have controlled the sedimentation of the adjacent basins. It trends ENE-WSW is formed by two small blocks limited by two faults: The General Roca fault and a smaller parallel fault in the east (Criado Roque et al., 1981).

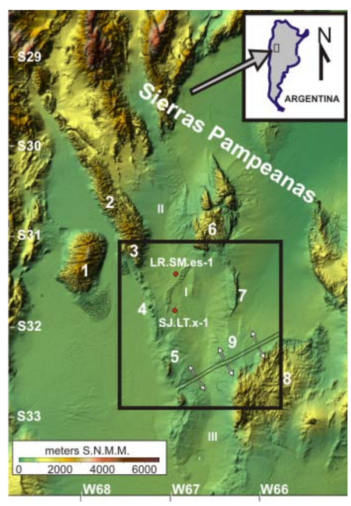

Figure 1. Geographic situation and digital elevation model (DEM) in which have been referred the main structures and the hydrocarbon exploration wells drilled in the area. I – Las Salinas basin; II- Marayes basin; III- Beazley basin. Rectangle; Studied area. Small circles; Wells. Mountain ranges;1. Pie de Palo; 2. Valle Fértil; 3.De La Huerta; 4. Guayaguás-Catantal; De las Quijadas; 6.Chepes; 7. Ulapes 8. San Luis. Regional structure; 9. San Pedro Dorsal.

Previous geophysic research

- In the studied region a 2D reflection seismic survey was carried out.

- Two hydrocarbon exploration wells were drilled in the area. One was situated near the locality of Mascasín (LRSM. Es-1) and the other at the locality of Las Toscas (SJLT. X-1). Table 1 is a summary of the information given by both wells: geologic formations, lithologies, depths and average densities.

		Well Las Toscas		Well Sal.de Mascasín	
Formation	Lithology	Density	Depth	Density	Depth
Quaternary	Alluvium	2,03	-93,75	No data	-100,6
Middle and Upper Miocene	Brown and red shales with light brown to red siltstones	2,18	-975	No data	-1487,5
Middle Miocene (San Roque Formation)	Sandstones red to brown	2,32	-1635	2,33	-2304,8
Upper Cretaceous (Lagarcito Formation)	Sandstones red, fine to medium.	2,29	1795	2,46	-2498,1
Cretaceous Gigante Group	Shales and sandstones.	2,48	-2050	2,41	-2927,5
Triassic Marayes Group	Sandstones , grey to red	2,42	-2485	2,48	-3308,5
Carbonif. Malanzán Formation	Sandstones grey to dark grey, lithic and arkosic	2,63	-2690	2,6	-3494
Basement	Grey to green schists.	No data	No data	No data	No data

Table 1: Depths are given in meters and densities in g/cm^3. In column 2, the lithologies mentioned are the predominant ones.

Method

150 new measurements of gravimetric and topographic data were added to the database of the Instituto Geofísico Sismológico Volponi – Universidad Nacional de San Juan and of Instituto de Física Rosario – Universidad Nacional de Rosario. With all this information was possible to cover entirely the Las Salinas basin and neighbouring areas. All the gravity data are referred to the International Gravity Standardization Network 1971.

The geographic processing of the measured points was obtained by means of a Trimble 4400 GPS Geodetic equipment, working in differential mode with a GPS base situated at a distance no longer than 50 km.

With the mentioned observed gravity measurements, the topographic elevation and the geographic positioning, was calculated the Bouguer anomaly according to the standards established by Hinze et al. (2005) and considering a normal gradient of 0.3086 mGal/m and the density of 2.67 g/cm^3 for the flat slab correction. The anomaly values were corrected for topographic effect as far as a 167 km distance.

As the objective of the present work is centered in the first kilometers of the upper crust, it is necessary to separate the gravimetric effects produced by deep geologic structures. For this purpose were applied gravimetric filtering techiques, such as the field ascending prolongation at different prolongation altitudes and pass band filters (Pacino and Introcaso, 1987). The authors think the chart resulting by prolonging the Bouguer anomaly at 30 km is the one that best separates the gravimetric effects. The Bouguer residual anomaly chart (Blakely, 1995) was obtained from the difference of the observed anomaly minus the prolonged anomaly. The result thereof is shown in Figure 2.

In this chart a small structural high is clearly observed which corresponds to the La Huerta range. This structure separates two depocenters, one situated in the north, which corresponds to the Mascasín basin, and the other, in the south, to the Las Salinas basin. Both centers are flanked to the west by the Valle Fértil, De La Huerta, Guayaguás and Catantal ranges, and to the east, by the Chepes and Ulapes ranges. In a first approach, according to the Bouguer residual anomaly (Figure 2) the Las Salinas basin would have an approximate length of 115 km and a width of 50 km, whilst its extension can be estimated in 5750 km^2.

Spectral analysis

The spectral method permits an estimation of depths of a source system from the identification of the wave numbers that make up the potential fields produced by this system (Spector and Grant, 1970; Bhattacharya and Leu, 1975, 1977; Urrutia Fucugauchi, 1999).

The depths of the roofs of these bodies are related to the slope of the logarithm of the power spectrum in function of the frequency. The depths represent statistical estimations of the interfaces which permit to evaluate an average structural model (Martínez and Introcaso, 1999; Introcaso, 1999).

With the purpose of evaluating the average depth of the sedimentary column from the crystalline basement top to the surface, were prepared 4 sections, one parallel and three transverse to the major axis of the basin (See their situation in Figure 2). The responses given in these sections are affected by the influence of the basement, the basin sedimentary fill and the structural highs at the east (Ulapes- Chepes range system) and the west (Valle Fértil - La Huerta- Guayaguás range system).

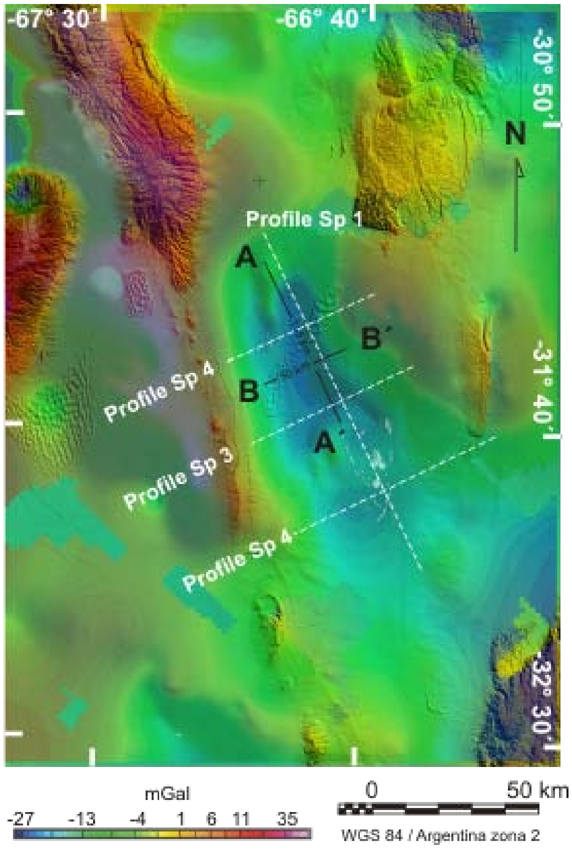

Figure 2. The superimposed residual Bouguer anomaly with the digital elevation model. The colour scale is given in mGal. The full line indicates the basin boundaries, and the dash line the power spectrum profiles.

It is convenient to remark that the structural highs, either exposed or in the subsurface, contaminate the input signal, if what has to be evaluated is the depth of the basement – sediment interphase.

In Figure 3 are shown the power spectra corresponding to the four sections, in which are plotted the adjustment straight line and the depth obtained measured in km. The results obtained for the sediment – basement interphase in the sections are: Sp1 = 5.3 km; Sp2 =5.49 km; Sp3 = 5.18 km; Sp4 = 4.08 km.

On the basis of these results we can infer that the structures deepen towards north. This is consistent with the Bouguer residual anomaly map, where is observed a negative increase in the anomaly values, which is associated to an increase of the sedimentary column thickness to the northeast. This occurs also in the wells: the information supplied by them (Figure 1) indicate that the base of the Paleozoic deposits is deeper in the Salinas de Mascasín well than in the Las Toscas one (See Table 1).

The discrepancies in depth values between the data extracted from the well files and those obtained by the spectral analysis technique are because by the seismic survey the basement was placed at the bottom of the Carboniferous deposits, while by the spectral method the basement is placed at the contrast surface between the average density of the sedimentary cover and the 2.28 g/cm^3 estimated for what we assume for crystalline basement

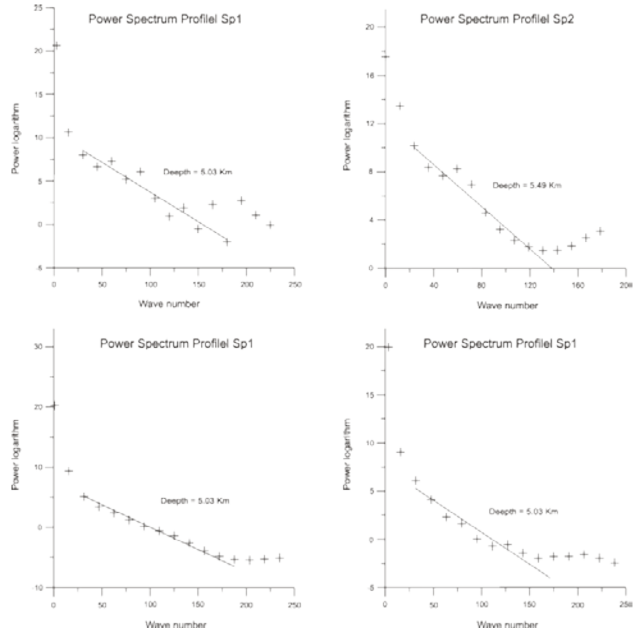

Figure 3. Power spectra corresponding to the four sections shown in Figure 2. Are shown in this figure: the corresponding spectrum, the adjustment straight line and the depth to the basement top.

Euler deconvolution

The Euler deconvolution technique is a method frequently used for estimating the localization and depth of zones with density contrasts in the analysis of gravity or magnetic fields. This method was introduced by Thompson (1982) for 2D profiles and later by Reid et al. (1990) for grilled data. The Euler deconvolution is used as an aid for the interpretation of potential field data.

According to Barbosa et al (1999) and Silva et al (2001), the main reason for its success is because it requires only a small previous knowledge of the geometry of the geologic sources, and, most important, that it does not require information of the physic characteristics of the sources. For instance, the magnetization vector for the magnetic sources and the density distribution for the gravity sources.

The Euler deconvolution is based on the application of the Euler homogeinity equation to a data mobile window for a fixed parameter called structural index. For each position of the mobile window an overdimensioned lineal system of equations is resolved and the position and depth to the sources is thus obtained.

This tecnique was applied to the Bouguer anomaly with the purpose of obtaining preliminary estimations of the sources that cause the generation of the observed field. Only two parameters can be modified in this process. One is the structural index, which is related to the geometry of the generating force and is represented by a number which varies from 0.5 to 2 (Roy et al., 2000). The other is the window width.

The window size has to be adapted to the size of the structure to be observed, if reasonably good results are expected to be obtained. In ideal conditions, this means that, for a given window width, only one type of anomaly should be detected and, therefore, produce adequate results (localization and depth).

For the particular case of the Las Salinas basin , the best results that represent the geometry and depth of its geologic structure are given by a 0.7 structural index and a window width of 10 km on a 1 x 1 km grill, considering a 10 % error. The smaller the window the better the shallow inhomogeneities will be emphasized, which generally have short wavelengths. In such conditions the resolution efficiecy diminishes for the deeper and/or with long wavelength structures. Figure 4 shows the results of the application of the standard Euler method with the already specified parameters. The solutions shown are restricted to the studied zone.

Most solutions obtained are between 4 and 8 km depth (represented in red, yellow and green). A smaller group of solutions is sketched, which are originated from depths shallower than 4 km (light blue). Still lesser solutions are observed, represented in blue, that reach 11 km in depth. This is due to the window width used, which favours the identification of structures with wavelengths below 10 km.

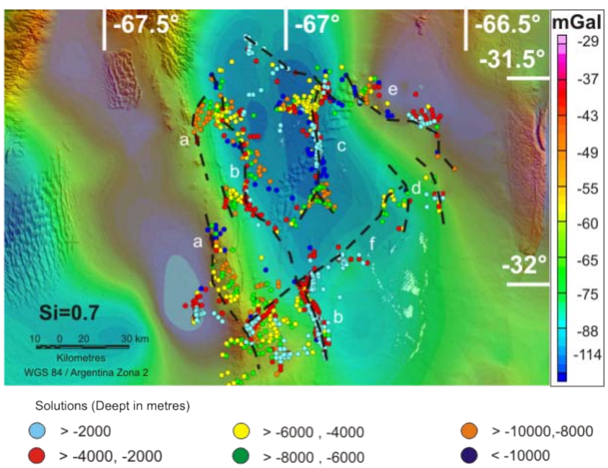

Figure 4. Euler deconvolution solutions for a 0.7 structural index, plotted on the Bouguer residual anomaly and the digital elevation model. The colour scale for the Bouguer residual anomaly is the same as in Figure 2. The lineaments interpreted by this technique are indicated with a dash black line and identified with a white letter.

In Figure 4 are represented six lineaments, or possible faults, interpreted by alineation of Euler deconvolution solutions. Because exists a notable coincidence between the faults interpreted from seismic and the alineations interpreted from Euler deconvolution, both have been identified with the same nomenclature for their better vinculation.

In the north – south trending faults, especially those identified as a, b, and c, a migration of the solutions is observed towards the east in the depth. This could be related to a tendency of the fault system to become horizontal as the depth increases.

The lineament identified with c (Figure 4) divides the basin in two parts and is the one that shows the least dispersion of the solutions.

The faults identified as c and d are related to the orogenic front of the Chepes and Ulapes ranges, whereas the lineament f marks the southern closure of the basin.

Gravimetric inversion model

In the gravimetric inversion model, the procedure proposed by Graterol and Gubert (1998) was followed for the observation of the gravimetric effect of the topography, by prolonging the residual anomalies to a height above the maximum topographic altitude corresponding to the work area. In the present case, they were prolonged to 2200 meters above sea level.

The gravimetric inversion model used is based on the Parker algorithm (1972). The densities and depths of the sediments filling the basin were obtained from the logs of wells SJ.LT-x-1 and LR.SM-es-1 (Table 1). In this way, sediment densities from 2.0 to 2.62 g/cm^3 were considered down to 3500 meters depth, and for the upper crust the considered density was 2.75 g/cm^3.

In Figure 5 are shown the results of the inversion model, in which were plotted the basement depth contours. The outcrops were incorporated to the model in full lines, whereas the dash lines represent the interpretation of the fault system that defines the basin geometry. This interpretation is based on seismic information and Euler deconvolution.

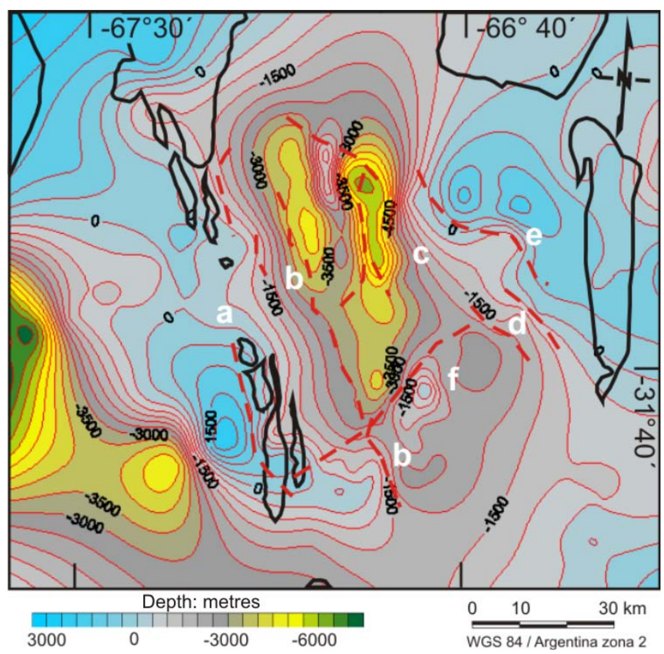

Figure 5. Gravimetric inversion model of the Las Salinas basin. The main outcropping geologic structures are plotted in full lines. Dash lines represent the faults interpreted by seismic and Euler deconvolution.

Results

The results here obtained show that the Las Salinas basin is 50 km wide and 115 km long. The basin has a quasi elliptical shape, and it is flanked by high angle reverse faults which are detected to depths reaching 11 km. The fault identified as "c" divides the basin in two at its central part.
This fault is a high angle, nearly vertical fracture. According to the seismic interpretation, the basin would be made up by an anticlinal asymmetric.

The southern boundary of the basin coincides with a SW – NE trending fault. The fault lineament can be linked to the one observed by Giménez et al. (2008).To the south thereof the stresses are attenuated, as it is the case of the difference in size of the Ulapes range respect to Chepes one, and to the west, the virtual absence of outcrops between the De La Huerta and the Guayaguás-Catantal ranges.

If we compare the gravimetric inversion model with the data given by the spectral method, we can see that the depth values are coherent in both and differ in less than 0.2 %. Both methods indicate that the basin has a similar maximum depth: 5500 m for the inversion model and 5490 m for the Sp2 section of the spectral analysis. Both methods indicate an increase in the basement depth towards the north.

The Euler deconvolution method indicates that the solutions begin near the surface, but that most solutions are deeper than 4 km, and extend down to 11 km beneath the surface.

The seismic model is shown in an isopach map of the sedimentary fill down to the Cretaceous top, and shows a maximum depth to the basement of 4 km, whilst the maximum depth to the Carboniferous top reached by the seismic holes is 3500 meters. It is evident that exists a 1500 m depth increase respect the the values given by seismic. We ascribe this difference to the desnsity contrast between sediments and crystalline basement, which at 3500 depth is still 0.12 g/cm^3, and then clearly justifies this observed difference.

The Euler deconvolution solutions identify the structures that make up the basin edges, and are consistent with the interpretation of the gravimetric inversion model. Nevertheless, there exists a discrepancy in the northern closure of the basin, probably originated by a weak gradient not able to generate Euler deconvolution solutions in this sector.

Conclusions

A gravimetric study was carried out in the Las Salinas basin, aimed at knowing its geometry and geologic structure. This basin is situated around the triple junction of the provinces of San Juan, La Rioja and San Luis, covering an extension of 5750 km2. For this purpose, by means of power spectra in four sections, was evaluated that the average depth to the crystalline basement is 5 km, and that increases from south to north. This deepening is consistent with the results obtained in the two deep wells drilled in the basin: Salinas de Mascasín in the north and Las Toscas in the South.

From the Euler deconvolution were obtained solutions for a 0.7 structural index. The interpretation of the solutions given by this technique show consistency with the seismic interpretations, and permitted to identify six lineaments that directly affect the basin geometry.

The lineament at the western basin edge is associated with the Desaguadero-Valle Fértil fault system, and the one at the east, with the Chepes-Ulapes orogenic front. The lineament at the south is a mega alineation trending SW-NE, and the one at the north is weakly defined because of lack of gravimetric gradient.

The depths obtained by this technique indicate a great concentration of solutions between depths from 4 to 11 km, related to faulting in the crystalline basement.

A gravimetric inversion model was prepared, with variable density for the sedimentary fill, and which justifies the Bouguer residual anomaly. The results given by this model indicate that the sedimentary trough would reach a depth of 5 km, which coincides with those obtained with other potential method techniques. There exists a 1.5 km discrepancy respect to the seismic interpretations, due to the difference existing between the technical basement and the crystalline basement identified by gravimetry.

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