Article

THE FARALLON BASIN BASEMENT STRUCTURE, SOUTH CALIFORNIA GULF BY INTERPRETATION OF POTENTIAL AND SEISMIC DATA

MSC, Lieutenant Marco BARTENS (Peru)
Directorate of Hydrography and Navigation of Peru

Abstract

The Gulf of California is an active continental rift with an oblique and dextral opening displacement and is one of the few examples of an initiating continental rift where processes can be studied along a complete rift. Establishing the boundary between continental and oceanic basement holds the key to fully understanding the tectonic mechanisms acting on this initial rifting stage. Unfortunately, this is also a challenging task due to the presence of a newly formed oceanic crust. The aim of this work is to identify, delineate and estimate the thickness of the oceanic and continental crusts in the Farallon Basin. For this purpose, high-resolution 2D multichannel seismic reflection data from the Ulloa's 2006 expedition along with gravity anomaly data from the global marine gravity database, obtained by repositioned radar altimetry from Geosat and ERS-1 satellites, was used. To assist with the interpretation, two-dimensional gravity modeling was carried out along each seismic profile, followed by 3D inversion of potential field data from the Farallon Basin area as constrained by the interpreted seismic profiles.

The interpreted depths from the gravity models indicate that a thin oceanic crust exists at the center of the basin, with minimum thicknesses of 2.5 km in the abandoned south axis and 3 km in the dorsal axis. The continental crust gradually thickens towards the continent.

Keywords: seismic reflection, gravity anomaly, Farallon Basin, Gulf of California.

Résumé

Le golfe de Californie est un rift continental actif avec un déplacement d'ouverture oblique et dextre, et constitue l'un des quelques exemples de rif continental naissant permettant d'étudier les processus le long d'un rift complet. L'établissement de la limite entre le socle continental et le socle océanique est la clé pour comprendre au mieux les mécanismes de la tectonique qui interviennent lors de cette phase initiale de formation du rift. Malheureusement, cette tâche constitue également un défi en raison de la présence d'une croûte océanique nouvellement formée. Ces travaux ont pour objectif d'identifier, de délimiter et d'estimer l'épaisseur des croûtes océanique et continentale dans le bassin de Farallon. A cette fin, des données de réflexion sismique multicanaux 2D à haute résolution de l'expédition Ulloa de 2006 ont été utilisées en même temps que des données d'anomalies gravimétriques de la base de données gravimétriques marines mondiales issue de l'altimétrie radar repositionnée des satellites Geosat et ERS-1. Pour aider à l'interprétation, une modélisation bidimensionnelle du champ de pesanteur a été effectuée le long de chaque profil sismique, suivie d'une inversion tridimensionnelle des données de potentiel de la zone du bassin de Farallon, contrainte par les profils sismiques interprétés.

Les profondeurs interprétées déduites des modèles du champ de pesanteur indiquent l'existence d'une fine croûte océanique au centre du bassin, avec des épaisseurs minimum de 2,5 km dans l 'ancien axe sud et de 3 km dans l'axe dorsal. La croûte continentale s'épaissit progressivement vers le continent.

Mots clés : sismique réflexion, anomalie gravimétrique, bassin de Farallon, golfe de Californie.

Article

Resumen

El Golfo de California es una falla continental activa con un desplazamiento de abertura oblicua y dextral y es uno de los pocos ejemplos de falla continental incipiente en el que pueden estudiarse los procesos a lo largo de toda la falla . El establecimiento del límite entre la base continental y la oceánica es la clave para una comprensión total de los mecanismos tectónicos que actúan en esta etapa del *rifting* (apertura) inicial. Lamentablemente, esta también es una tarea compleja debido a la presencia de una corteza oceánica recién formada. El objetivo de este trabajo es identificar, delimitar y estimar el espesor de las cortezas oceánicas y continentales de la Cuenca Farallón. A este efecto, se han utilizado los datos de reflexión sísmica multicanal 2D de alta resolución, de la expedición de Ulloa del 2006, junto con los datos de anomalías gravimétricas procedentes de la base global de datos de gravimétricos marinos, obtenidos mediante altimetría por radar reposicionado desde los satélites Geosat y ERS-1. Para ayudar en la interpretación, se llevó a cabo una modelización bidimensional de la gravedad a lo largo de cada perfil sísmico, seguida de una inversión 3D de los datos de campo potenciales procedentes del área de la Cuenca Farallón según las restricciones de los perfiles sísmicos interpretados.

Las profundidades interpretadas de los modelos de gravedad indican que existe una delgada corteza oceánica en el centro de la cuenca, con espesores mínimos de 2,5 km en el eje Sur abandonado y de 3 km en el eje dorsal. La corteza continental se espesa gradualmente en dirección al continente.

Palabras clave: reflexión sísmica, anomalía gravimétrica , Cuenca Farallón, Golfo de California.

1. Objective

The aim of this study was to identify, delimit and estimate the thickness of the oceanic and continental crusts in the Farallon Basin in order to understand the geological processes that occur during the continental lithosphere's rupture and the deformation of passive margins. In order to achieve this objective, the following specific goals were defined:

- Process, interpret and identify high resolution 2D multichannel seismic reflection data from the seismic profiles;
- Create gravimetric models from the main measurements interpreted in the seismic profiles;
- Estimate the depth of the Basement supported by gravimetric data;
- Estimate the thickness of the crust in the area.

2. Seismic reflexion method

A marine linear array (***Figure 1***) was used for data acquisition. For this purpose, a 150 cubic inch (0.245m^3) per shot airgun was used as the energy source (see **Table 1**).

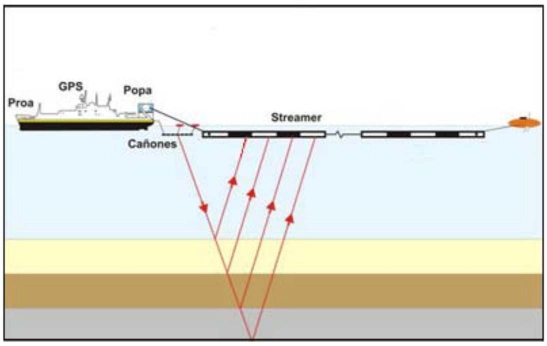

Figure 1. *Linear array*

Table 1. Seismic data acquisition parameters

Parameters	Values
Energy source	Air gun
Length of run	600 m
Distance between source	37.5 m
Distance between receivers	12.5 m
Field filter	Not applicable
Number of channels	48
Recording time	4000-6000 ms
Sampling interval	1 ms

3. Seismic Data Processing

Data from four seismic lines from the Ulloa-6 campaign (**Table 2** and ***Figure 2***) were processed using the ProMAX software of the Landmark software platform. The processing sequence shown in ***Figure 3*** used a typical reflexion seismic processing sequence described by Yilmaz (1987) and Sheriff and Geldart (1995).

Table 2. Seismic lines processed

Line	Length (km)	Number of shots
14-3	112	2927
18	71	1791
23	58	1423
24c	81	2062

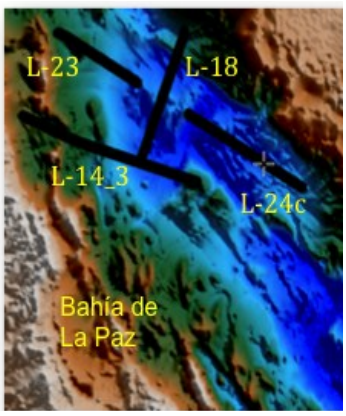

Figure 2. *Seismic line location*

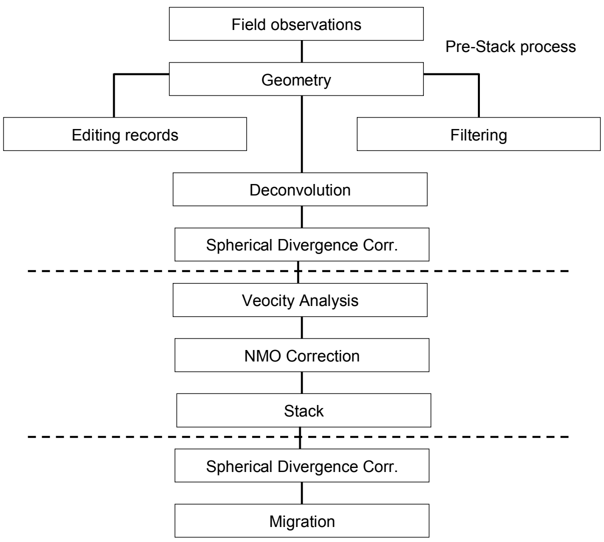

Figure 3. *Typical seismic processing sequence*

Once the seismic process sequence was finished the interpretation of the seismic line was performed (***Figure 4***).

After the four seismic profiles were processed and interpreted, a Basement's type distribution map was generated using the seismic data collected in the area of study (***Figure 5***).

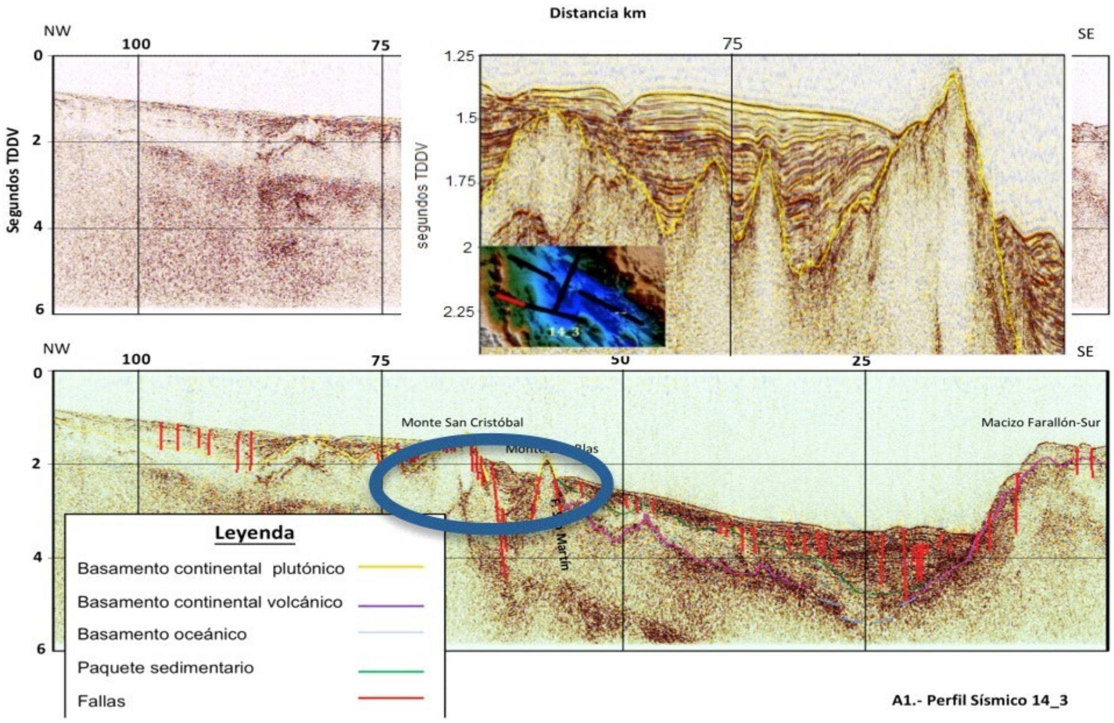

Figure 4. *Processed and interpreted seismic profile 14_3*

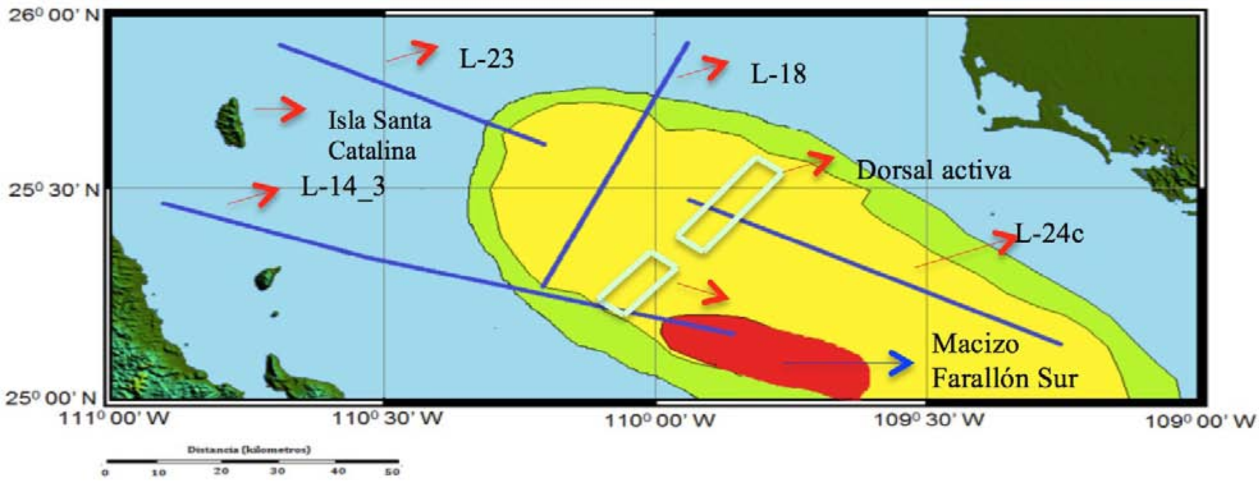

Figure 5. *Distribution of the different types of Basement interpreted over the area: Plutonic: (lightblue); Volcanic from Farallon-Sur Massif (red); newly created oceanic crust (yellow) and transition between crusts (green). Seismic profiles are in blue.*

4. Potential Field Methods (Gravimetric Method)

The gravimetric method of geophysical exploration is based on the measurement of small variations of the earth's gravitational field on its surface and their interpretation in relation to possible mass distribution in the subsurface (Nettleton, 1976). The gravimetric observations can be used to interpret changes or differences of mass below different regions of the earth (Lillie, 1999).

A first step is to isolate the gravity field fraction originated by these mass differences. This is the reason calculating the Free-Air gravimetric anomaly (***Figure 6 - left***). Second, in order to remove the gravimetric effect generated by the sea and the land in the area of study, the gravimetric anomaly of Bouguer was cal-culated (***Figure 6 - right)***.

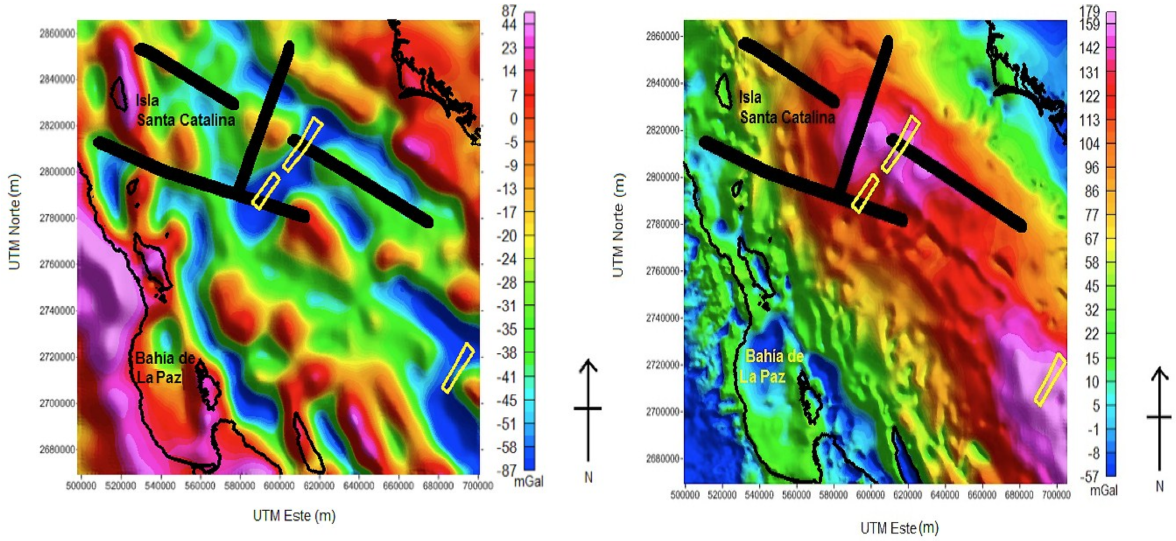

Figure 6. Free-Air Anomaly (mGal) map. (right) Total Bouguer Anomaly (mGal) map. Lines show the seismic profile locations.

5. 2D Modelling

The Free-Air gravimetric data was used to generate subsurface models. To compile these models, the depths of the main interpreted reflectors of the seismic sections, the general characteristics inferred from the qualitative interpretation of the gravimetric anomalies' maps as well as the gravimetric data itself were used. A trial and error adjustment was used in the bi-dimensional case obtaining models of the four seismic profiles (Profile 18 is shown in ***Figure 7***).

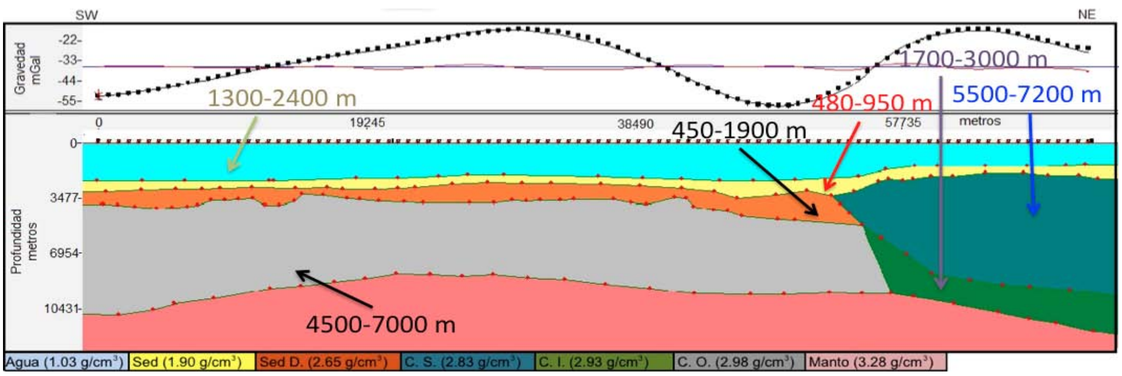

Figure 7. Bi-dimensional gravimetric model (Profile 18)

6. 3D Inversion

To perform the 3D gravimetric inversion of the data the GMLayers software (Gallardo et al., 2005), as amended in October 2010, was used. To guide the inversion process using the GMLayers software, it is necessary to set up a number of parameters grouped as:

- initial model;
- precision of the initial model and the geophysical data;
- acceptable smoothness level of each surface; and
- the feasibility limits of the thickness and depth of each layer of the model (as shown in ***Figure 8***).

The appropriate setting of theses parameters is key to obtaining an optimum model that not only justifies the data, but retains its geological meaning.

In ***Figure 8***, the s2 surface (black line) corresponds to the bathymetric relief which is always located above the s4 depth ranges. In this case, the upper surface is fixed at 0 km (sea level) and the effect of the sea level is suppressed, hence the minimum and maximum thickness of the overlying layer match the minimum and maximum depths in the area. In both cases it is possible to observe the seismic profile's restrictions given by depth.

After the program was run and the results checked, the anomaly obtained in the field was compared against the one calculated by the program. It was observed that their differences were minimal (***Figure 9***) which can be explained by the limitations of the seismic profiles.

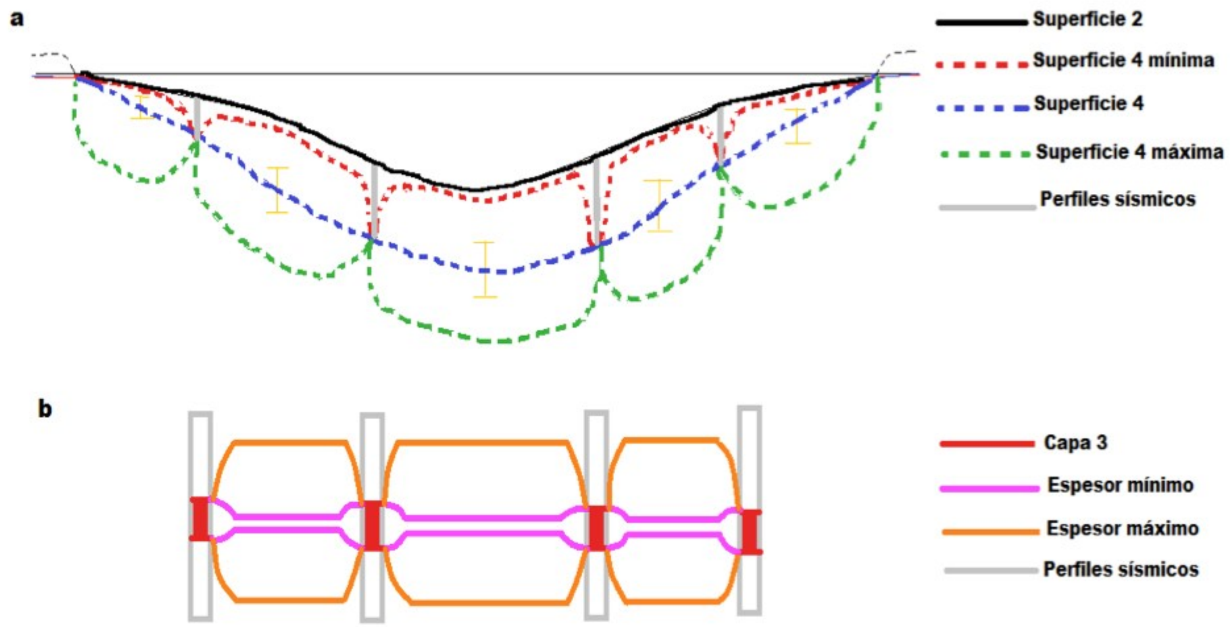

Figure 8. *Minimum and maximum depths imposed over surface 4 (top of the dense sediments).*

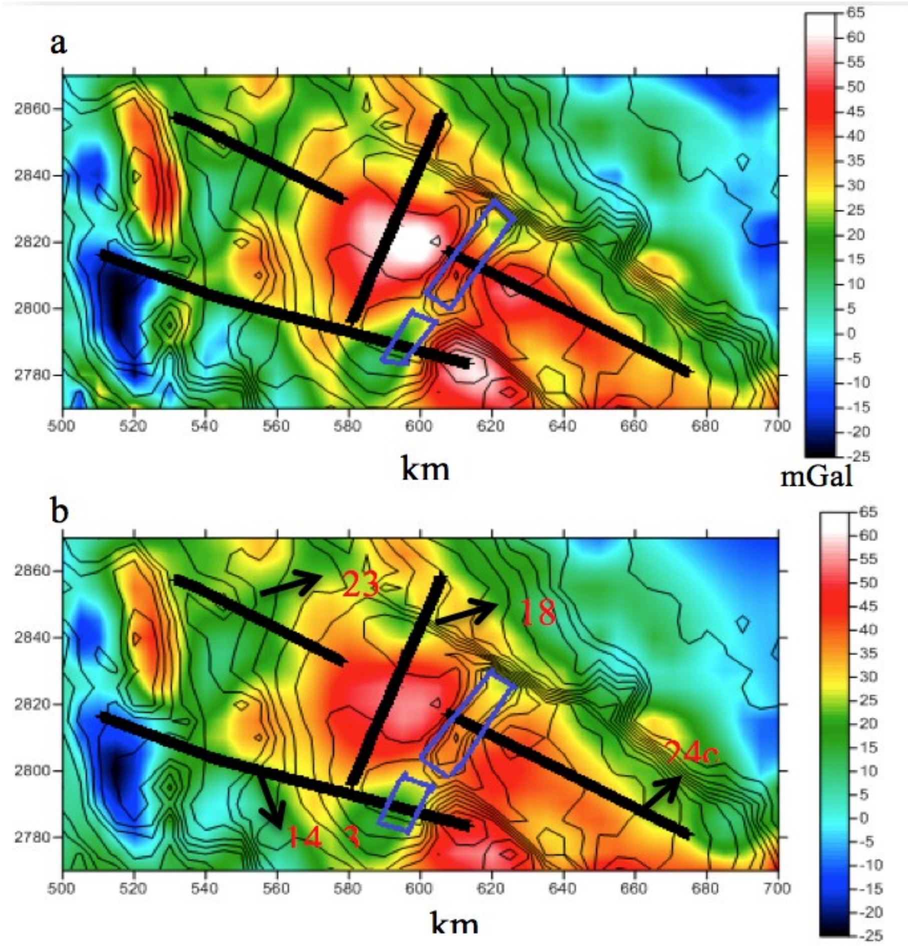

Figure 9. **(top)** *Observed gravimetric anomaly. (bottom) Gravimetric anomaly calculated using the optimum 3D model selected. Both figures show a vertical scale in mGals. The pink seismic profiles represent the continental crust and the blue ones the oceanic crust.*

7. Layer Structures

Figures 10 to ***13*** show the thickness of the various layer structures (km).

a. Sediments

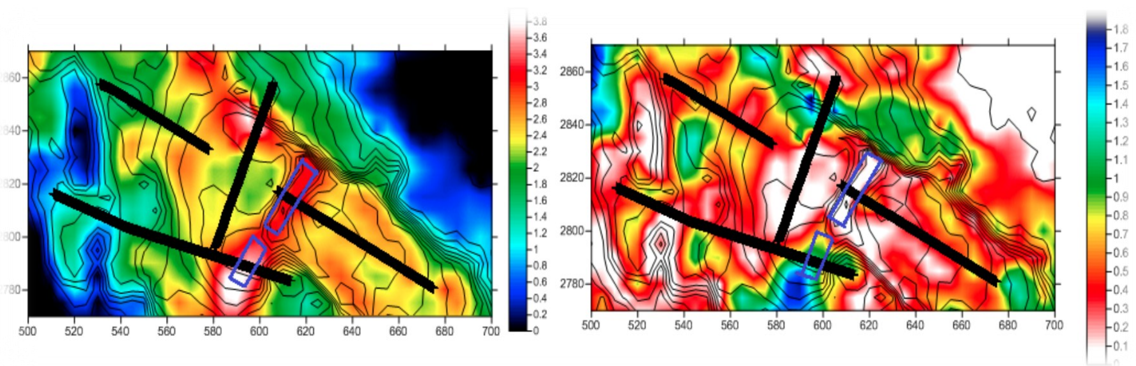

Figure 10. **(left)** *Depth of the surface which bounds the two proposed layers of sediments (km)* **(right)** *Thickness of the upper layer of sediments (km)*

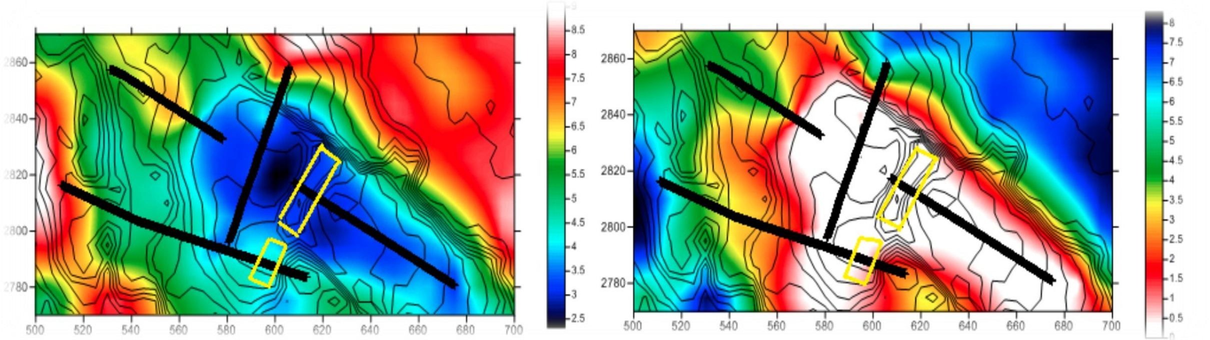

***Figure 11.* (left)** Depth to the top of the oceanic crust (km) (right) Thickness of the continental crust (km)

b. Continental crust

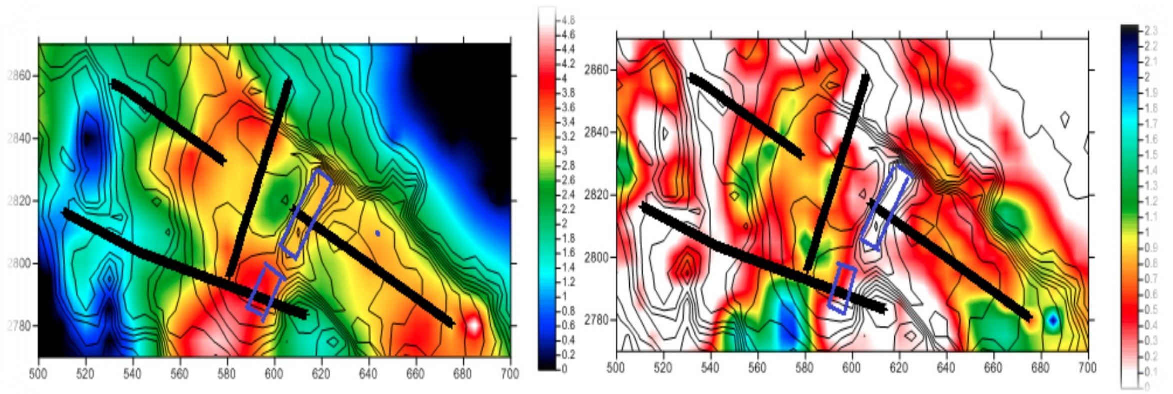

Figure 12*. (*left) *Basement's depth (top of the continental crust (km). (right) Thickness of the lower layer of the densest sediments (km)*

c. Oceanic crust

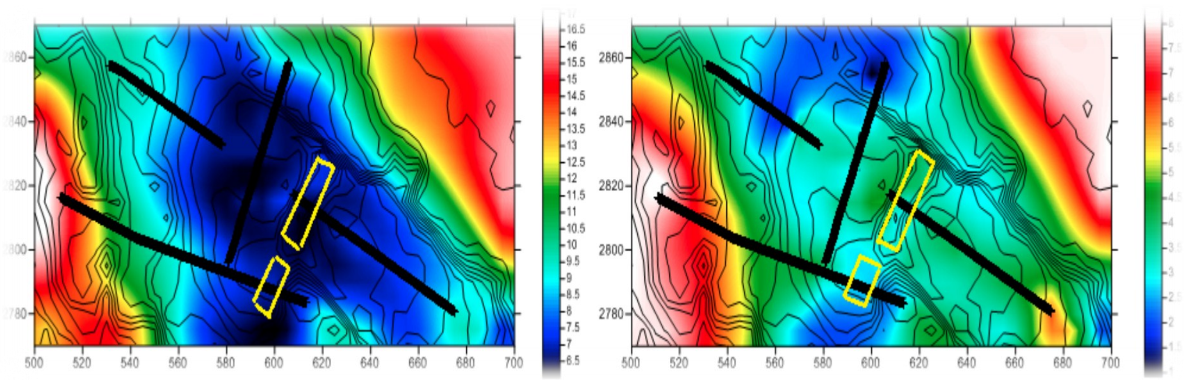

***Figure 13.* (left)** *Depth to the mantle (km). (right) Thickness of the oceanic crust (km)*

8. Conclusions

The integration of seismic data, potential fields and 3D gravimetric inversion identified the type and structure of the crust in the study area. The different thicknesses and distribution of each identified layer were compatible with the tectonic scenario as follows:

- In the uppermost part it was observed that the active axis of the Farallon Basin, at a depth of 3.2 km, does not present sediments; whereas, the abandoned axis, at a depth of 3.8 km, it is buried by a sedimentary package with a total thickness of 2.9 km.
- Evidence suggests that the sedimentary material which overlays the recently created oceanic crust is affected by magmatic intrusions. This was not detected in the sediments deposited on the continental crust.
- On the western zone, it was observed that a continental crust with a thickness of 15 to 17 kms thins towards the centre of the basin. At that point it is almost entirely replaced by a thin oceanic crust of recent creation which has a thickness of 2.7 to 6 km.
- Finally, the rise of the mantle layer in the rift areas is clearly observed, reaching 5.8 km on the active axis and 7.3 km on the abandoned axis. A deepening was observed towards the continental zone which corresponds to the margins of the Gulf of California.

9. References

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Biography

Lieutenant Marco Bartens graduated from the Naval School of Peru in 2006 and completed his IHO Category B certification in 2008 whilst working in the various divisions of the Hydrography Department. In 2011, he was promoted to Second Lieutenant and commenced his specialization studies at the *Cientific Investigation Center for Superior Studies of Ensenada* (CICESE), Mexico. He graduated in 2013 with a Master of Science, specialization in Applied Geophysics. In 2015, he was promoted to First Lieutenant and is now working as the Deputy Chief of the Oceanography Department of the Peruvian Directorate of Hydrography and Navigation.
mbartens@dhn.mil.pe

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