GEOTHERMAL POTENTIAL OF MADRID BASIN FROM INTEGRATED GEOPHYSICAL AND WELL DATA ANALYSIS (CENTRAL SPAIN)

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Summary

New energy demand linked to world population growth and awareness about climate change have brought out the need to develop new forms of energy guided by the urgency of an ecological transition. In this context geothermal resources have the potential of contributing significantly to sustainable use in many parts of the world. In Spain, during the 80´s, oil and gas explorations carried out in the Madrid Basin confirmed the existence of two geothermal reservoirs.
Here we present diverse geological features of the basin essential in geothermal exploration. We use airborne radiogenic and magnetic data to characterize the basement. Detailed ground concentration estimates of the heat producing elements are used to calculate the heat production and heat flow in the near surface. The distribution pattern of both parameters is heterogeneous with two main areas separated by southward prolongation of the Berzosa Fault. The eastern sector is characterized by both low heat production and heat flow rates while the western area is distinguished by high values as a response of the exposed granites. In addition, we build one 3D geological model and one 3D isothermal model with Leapfrog Geothermal from seismic, well data and mapping information.

Geothermal potential of Madrid Basin from integrated geophysical and well data analysis (central Spain)

Introduction

New energy demand linked to world population growth and awareness about climate change have brought out the need to develop new forms of energy guided by the urgency of an ecological transition. Within this context, geothermal resources have the potential of contributing significantly to a sustainable use energy generation in many parts of the world (Axelsson et al., 2005).

Spain has a good number of promising geothermal areas located in different regions of the country. The potential of the Madrid Basin (Figure 1) was proved during the oil and gas explorations campaigns between 1960 and 1980. In this context, in the 80's it was decided to drill three different wells: Tres Cantos, San Sebastián de los Reyes and GeoMadrid-1. All these investigations led to the conclusion that in this basin exist two sedimentary units with geothermal potential: The Cretaceous unit and the syntectonic unit T2 (Oligocene-Miocene).

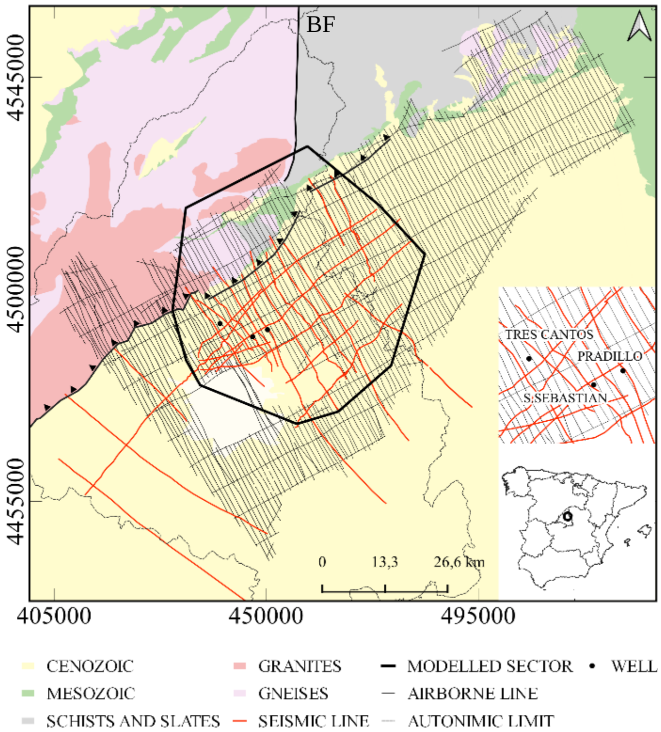

Figure 1: Location of study area and simplified geological map. Location of the airborne survey data, seismic lines, and wells. BF Berzosa Fault.

Geological Setting

The study area is part of the Madrid Basin located in the Spanish Central System (SCS), which in this area comprises two main basement domains separated by the Berzosa Fault (Fig. 1). To the West, the SCS batholith and high-grade metamorphic rocks are exposed, while to the east outcrop low grade metamorphic rocks. This basement uplift is a thick-skinned double-vergence (pop-up) intraplate range built as a result of a polyphase evolution (De Vicente and Muñoz Martín., 2013 and references therein).

The Madrid Basin is constrained to the north by the southern border thrust of the SCS which uplifted the basement up to 5000 meters. It shows a continuous sedimentary record from the Late Cretaceous to the upper Miocene with few short-term hiatuses. Next to the northern margin of this basin the thickness of sediments reaches 3500 m (De Vicente and Muñoz Martín., 2013). This basin was filled and deformed during the Cenozoic in relation to folding of the Iberian lithosphere.

Data and Methods

Magnetic and radiogenic data

An airborne magnetic and radiogenic survey acquired by Haunting in 1980 at a constant clearance high of 120 meters, covering a total of 6350 line-km was provided by Instituto Geológico y Minero de España (IGME). For an adequate study of the magnetic data, the reduction to the pole (RTP) was performed based on a magnetic inclination of -5.6° W and a field inclination of 56.13° N (Fig. 2).

Radiogenic data was selected when valid measurement in all three heat-producing elements (HPE), Uranium (U), Thorium (Th) and Potassium (K) where available. For the estimation of heat production and heat flow (Fig. 3a) the equations of Rybach, (1976), Sandiford & McLaren, (2002), Turcotte & Schubert, (2014) were used (Table 1).

Seismic data

23 multichannel reflection seismic sections acquired during the 1980s (Querol, et al, 1989) were interpreted and depth converted using a 3D velocity model. Finally, a 3D geological model was developed using Leapfrog Geothermal software including seismic data, wells data and geological maps. The model includes the geometry of the top of the basement, the Cretaceous top, and three Cenozoic tectono-sedimentary units: pre-tectonic (T1), syn-tectonic (T2) and post-tectonic (T3).

Well data

The temperature data was obtained from three exploration wells drilled during the 80´s (Pradillo-1, Tres Cantos and San Sebastián) with a high-resolution temperature tool (HRT) in thermal equilibrium unaffected from drilling perturbations. Previous works showed normal gradients in all three wells (ADARO., 1981, 1982, 1984). Using the temperature data from wells, and constraining the data with the geological 3D model, an isothermal model was calculated for this basin sector to evaluate the geothermal potential.

Results

Magnetic data

On the RTP magnetic anomaly map (Figure 2 top) it is possible to differentiate three main areas according to their magnetic response. The magnetic fabric extends from the outcropping basement to the Cenozoic sedimentary cover, allowing to infer the characteristics of the basement below the sedimentary cover. The western area is characterized by low anomalies except for a small number of low amplitude circular anomalies related with shallow magnetic sources in the sedimentary record. The central sector is defined by broad north-south magnetic anomalies as a response of the direction of the main metamorphic folds in this area. The eastern sector is depicted by low magnetic anomalies.

The Southern border fault of the SCS is defined as a low magnetic zone associated with the alteration and circulation of fluids. Recent magneto-telluric studies carried out westwards from the study area show that the SCS´s south border fault coincides with a conducting band dipping to the N that affects the entire upper crust (Pous, et al., 2012).

Radiogenic data

The radiometric survey is mainly focused on the Madrid Basin and some parts of the basement. Thus, the basement is radiometrically characterized in correspondence with three lithological domains: granites, high- and low-grade metamorphic rocks (Table 1).

Rock type	**U (ppm)**		**Th (ppm)**		**K (%)**		**HP (μWm^{-3})**		**q_0 (mWm^{-2})**	
	Mean	1σ	Mean	1σ	Mean	1σ	Mean	1σ	Mean	1σ
Granites	2.49	0.89	0.90	0.21	16.69	2.14	2.49	0.35	77.81	4.96
Gneises	2.33	1.26	0.79	0.31	12.69	5.15	1.86	0.78	68.99	10.94
Schists and slates	1.54	0.58	0.74	0.28	8.35	3.44	1.24	0.46	60.36	6.42
Total	2.19	1.07	0.80	0.31	11.62	4.79	1.72	0.65	67.09	9.12

Table 1: Comparison of average K, Th, U, Hp and q_0 estimates derived from airborne.dataset.

Estimations made for heat production overlap the values observed in granites globally (1-3 μWm−3) (Artemieva et al., 2017) and the estimated mean of 2.49 μWm−3 also matches the global average of 2.5 μWm−3 calculated for this type of rocks (Rybach, 1976; Haenel et al., 1988). The heat production obtain for metamorphic rocks suits the range calculated in Fernández et al. (1998). Total surface heat flow results obtained here are quite similar to the average heat flow of Fernández et al. (1998) calculated with well data in this area.

The heat production (Figure 2 middle) and heat flow distribution map are used to define and highlight regions of high geothermal potential. The distribution shows two main areas separated by the southward prolongation of the Berzosa Fault. The eastern sector is characterized by both low heat production and heat flow rates while the western area is distinguished by high values as a response of the exposed granites. Mean values of heat production and heat flow are expected to be higher as airborne measurements have less resolution than field data.

Basin structure from Seismic data

The interpretation of the different horizons in the seismic sections and the geological mapping has allowed us to reconstruct the geometry of the stratigraphic units in 3D (Figure 2 bottom), and to quantify the geothermal potential of the reservoirs. The geometry of the top basement and top Cretaceous is quite similar. Both describe a deepening towards the northwest with a marked depocenter in the north-central zone. On the top of Unit T1, the same configuration is sensed, although the existence of a depressed northwest-southeast direction band begins to be guessed, a fact that is contrasted in the top of Unit T2.

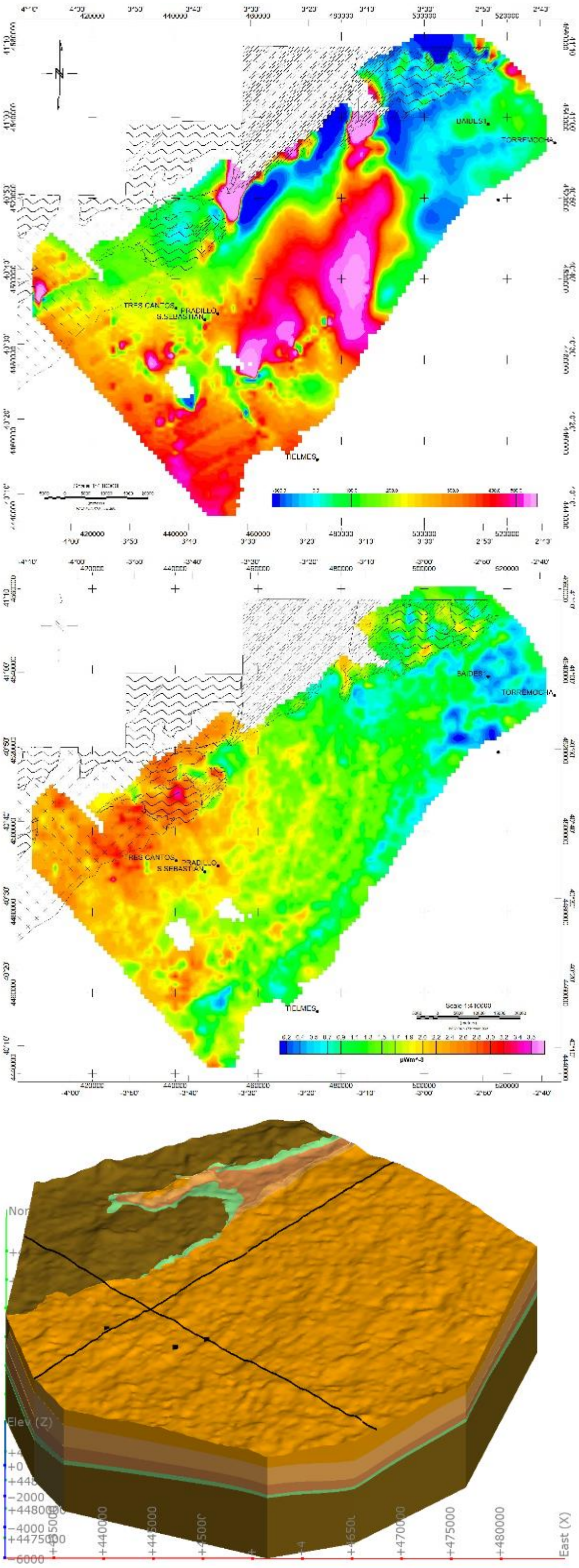

Figure 2: Top: Reduced to the pole magnetic anomaly map. Middle: Heat production map from airborne radiometric survey. Bottom: 3D geological model of the selected area.

Conclusions

This paper demonstrates that reprocessing different geophysical data previously studied could be an efficient option for preliminary exploration phases related to geothermal resources. The most important observations and their interpretation led to the following main conclusions:

Airborne gamma radiations measurements have yielded a considerable data set that has been useful for preliminary analysis of radioelement concentration and calculation of heat production and heat flow:

- In the eastern sector, for low-grade metamorphic rocks, an average heat production of 1.78 µWm^3 and a heat flow of 67.86 mWm^2 are estimated.
- To the west, the mean heat production for the granitic rocks in this part of the Central System, is estimated at 2.49 µWm^3 with a corresponding heat flow of 77.81 mWm^2.

Map distribution of both parameters, HP and q0 show a heterogeneous distribution pattern with two areas differentiated by southward prolongation of the Berzosa Fault. This way, it is possible to conclude that the western zone of the studied area, has bigger geothermal potential due to the higher heat production and heat flow of the lithologies that conform the basement.

The integration of mapping information, seismic and well data, radiogenic information, and temperature data, allow the construction of both geological and geothermal models that could be combined in order to map temperatures throughout the sedimentary units. The 3D geological model here presented has allowed us to understand the geometry of the basin, including the nature of the basin basement. This model provides a major advance on traditional 2D analysis and allows us to quantify the volume and temperatures of all the sedimentary units.

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