Bouguer and aeromagnetic anomalies in the Iberian Chain (NE Spain); a qualitative interpretation

Anomalías de Bouguer y aeromagnéticas de la Cordillera Ibérica (NE España); una interpretación cualitativa

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ABSTRACT

This work shows the Bouguer and aeromagnetic anomaly maps of the Iberian Chain (NE Spain) and surroundings in relation to its main geological and structural units. In general, both gravity and aeromagnetic anomalies are aligned following the same trends in both maps highlighting the major role played by the structural configuration of the Iberian Chain on their origin. In detail most anomalies do not coincide, pointing to different potential field sources to account for them. Further studies would be needed to decipher the origin of most magnetic anomalies observed in the Iberian Chain.

Key-words: *Gravity anomalies, Bouguer anomalies, magnetic anomalies, Iberian Chain.*

RESUMEN

Este trabajo muestra los mapas de anomalías de Bouguer y aeromagnéticas de la Cordillera Ibérica (NE España) y zonas limítrofes y su relación con sus principales unidades geológicas y estructurales. A grandes rasgos, ambos tipos de anomalías se alinean siguiendo las mismas directrices lo que sugiere el importante papel jugado por la configuración estructural de la Cordillera Ibérica en su origen. En detalle, muchas anomalías gravimétricas y magnéticas no coinciden, señalando su distinto origen. Más estudios serían necesarios para descifrar el origen de la mayoría de las anomalías magnéticas observadas en la Cadena Ibérica.

Palabras clave: *Anomalías gravimétricas, anomalías de Bouguer, anomalías magnéticas, Cadena Ibérica.*

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Introduction

Gravity and magnetic methods show numerous and successful applications in Earth Science due to their relative low acquisition cost, wide availability and well-established processing and interpretation techniques (e.g. Blakely, 1995).

Bouguer anomaly maps represent a very useful tool to complement our knowledge of the subsurface architecture of different terrains (e.g. Casas *et al*., 1997). They illustrate lateral variations in density, where positive values are often related to denser rocks and/or basement highs and negative values to sedimentary basins or areas where the basement or Moho is deeper. Magnetic anomaly maps, on the other hand, show contrasts between geological bodies with different magnetic properties (magnetic susceptibility and remanence) and have often been used on the exploration of mineral resources and definition of structural lineaments (e.g. Reeves, 2005).

Several works have dealt with the application of different geophysical studies to unravel the crustal structure and thickness of the Iberian Chain (e.g. Gómez-Ortiz *et al*., 2011; Seillé *et al*., 2015). The aim of this work is to show a qualitative interpretation of the Bouguer and aeromagnetic anomalies of the Iberian Chain in relation to its main geological and structural units.

Geological setting

The Iberian Chain represents an intraplate Alpine mountain range developed mainly from late Eocene to early Miocene times (Fig. 1). Its origin is related to the convergence between Europe and Africa in a generalized N-S compressional setting influenced by inherited Variscan and/or Mesozoic major faults (e.g. Guimerà and Álvaro, 1990). Since the Late Miocene, the Valencia Trough rifting has caused an extensional tectonic period responsible for the formation of normal faults and Neogene-Quaternary grabens in the Central-Eastern Iberian Chain (e.g. Simón, 1982).

The Iberian Chain is surrounded by the Cenozoic foreland Duero, Ebro and Madrid-Tajo basins, the Neogene Valencia Trough and the Central System, Catalan Coastal Ranges and Betic Cordillera (Fig. 1). It can be divided into the following structural units (Fig. 2A,B) (e.g. Guimerà, 2004): the Demanda Massif, the Cameros and Maestrazgo Mesozoic basins, the Cenozoic Almazán, Loranca and Calatayud basins, the Aragonese and Castilian Branches, the Linking Zone and the Altomira Range.

Methods

The Bouguer gravity data were obtained from the compilation done by Ayala *et al*. (2016) using the geodetic reference system GRS80 and a reference density of 2670 kg/m^3. Information about the data processing and gridding of the Bouguer anomaly can be found in Ayala *et al*. (2016).

The magnetic data derives from the compilation done by the Instituto Geográfico Nacional (IGN, Spain) integrating several aeromagnetic surveys in 1986 and 1987 (see IGN, 2004 for more information). Aeromagnetic data were gridded using the exponential kriging method with an anisotropy ratio of 1, a search ellipse with R1:3.5E+005, R2:673000, and an angle of 0º, and a cell size of 2.5x2.5km. Subsequently, the grid was reprojected from geodetic datum to the ETRS89 UTM Zone 30N coordinate system and cropped to the study area. The aeromagnetic anomaly map showed in Fig. 2 corresponds to the reduction to the pole applied to the total magnetic intensity map at 3000 m high and using the date 1987/01/30.

Interpretation

The comparison between the Bouguer and aeromagnetic anomalies in the Iberian Chain is not straightforward highlighting different potential field sources to account for the different anomalies. There are, however, several anomalies that roughly coincide in both maps; NW-SE gravity and magnetic anomalies located in the Ebro basin and Aragonese Branch of the Iberian Chain, N-S anomalies coinciding with the Loranca basin and Altomira Ranges, the easternmost part of the Madrid basin and those of the Demanda Massif (Fig. 2).

Bouguer anomaly map

The Iberian Chain coincides with a large negative Bouguer anomaly with values between -130 and 0 mGal and a wavelength of 500 km, consistent with the presence of a thickened crust beneath the mountain range. Shorter wavelength (c. 4-6 km) anomalies can be also differentiated showing different relative gravity maxima and minima. The Bouguer anomaly only shows positive values close to the Mediterranean coastline and in the offshore area (gravity anomaly "B" in Fig. 2C). This relative gravity high corresponds to the Valencia Trough and it is related to a thinned crust (e.g. Roca and Guimerà, 1992; Ayala *et al*., 2003). The Ebro foreland basin is characterized by a relative gravity high (gravity anomaly "A" in Fig. 2C) with an elongated shape following a NW-SE trend that opens towards the Mediterranean coastline. The rest of foreland basins margins adjacent to the Iberian Chain show a different behaviour. In the Duero foreland basin, a NE to SW trending gravity low (gravity anomaly "I" in Fig. 2C) appears parallel to the gravity minimum located in the Madrid foreland basin (gravity anomaly "G" in Fig. 2C) and to the main structures of the Central System (e.g. De Vicente *et al*., 2007). Gravity anomaly "I" has been interpreted to be related to basement-involved thrusts (De Vicente *et al*., 2022). Closer to the Iberian Chain, the gravity anomaly "H" (Fig. 2C) oriented N-S and located in the Madrid foreland basin has been interpreted linked to a Cenozoic sedimentary depocenter active during the Oligocene and a lower density basement (De Vicente and Muñoz-Martín, 2013).

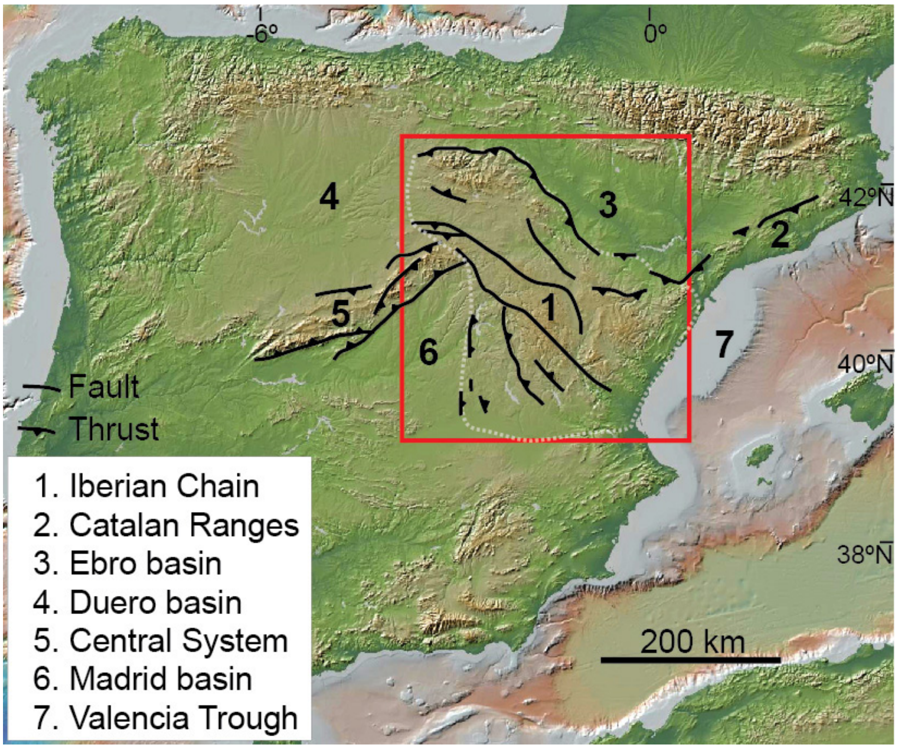

Fig. 1.- Location of the Iberian Chain and adjacent structural units (from GeoMapApp; http://www.geomapapp.org). In grey dotted line, location of the Iberian Chain.

Fig. 1.- Localización de la Cordillera Ibérica y unidades estructurales adyacentes (GeoMapApp; http://www.geomapapp.org). En línea gris discontinua, localización de la Cordillera Ibérica.

The northern margin of the Almazán basin with more than 4000 m of Cenozoic deposits (Rey-Moral *et al*., 2000) and the southeastern sector of the Cameros basin correlate with gravity anomaly "E", whereas the southern part of the Almazán basin and northwestern part of the Castilian Branch and the northwestern sector of the Cameros and northern Aragonese Branch match with two relative gravity highs oriented NW-SE (gravity anomalies "L" and "C", respectively) (Fig. 2). The Demanda Massif corresponds to a relative gravity high (gravity anomaly "D") following the E-W rounded shape of the Paleozoic outcrops.

The central part of the Castilian Branch relates to an important gravity low (gravity anomaly "J"), which does not define a significative trend. Towards the North, the NW-SE-oriented gravity low "M" coincides with the Cenozoic Montalbán basin in the southeastern part of the Aragonese Branch and gravity low "F", also oriented NW-SE, coincides with the Neogene Calatayud basin. Anomaly "K" defines a gravity low oriented NNW-SSE and coincides with the southwestern end of the Castilian Branch and Loranca basin.

Aeromagnetic anomaly map

The aeromagnetic anomaly map shows a very variable distribution of positive and negative magnetic anomalies of different shapes and wavelengths between c. 7 and 100 km (Fig. 2E). The reduced to pole magnetic intensity values range between -62 and 85 nT while most values vary between -0.4 and 27 nT. The preferred orientation of most magnetic anomalies is NW-SE and N-S in the northeastern-easternmost and southwestern sectors of the Iberian Chain, respectively.

An array of magnetic anomalies arranged in a NW-SE trend (magnetic anomalies "e") is located inside the Ebro basin (Fig. 2E). The Demanda Massif coincides with a magnetic high oriented in an

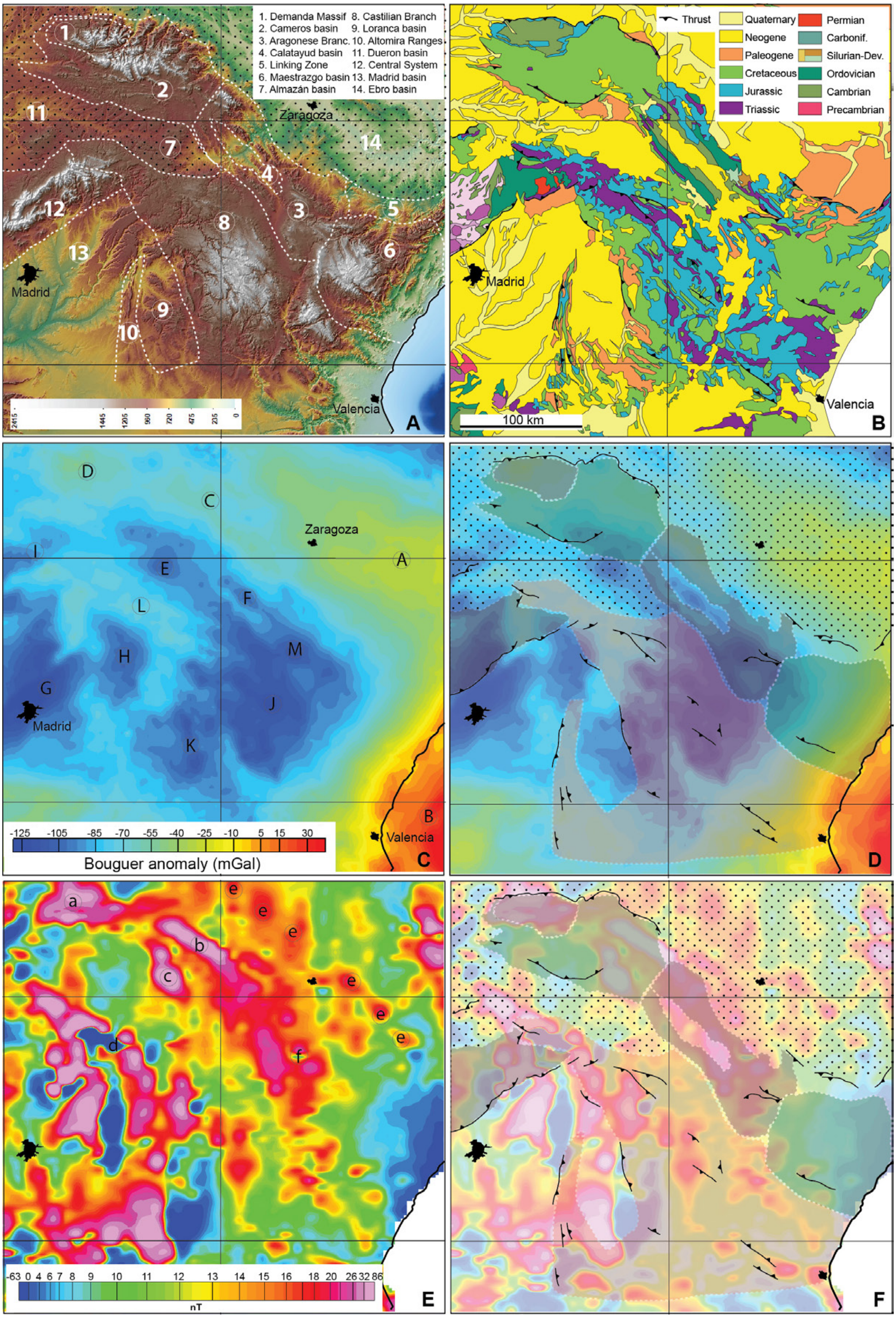

Fig. 2.- A) Relief map of the study area showing its main geological units. B) Geological map of the Iberian Chain and surroundings. C, D) Bouguer anomaly map of the study area and Bouguer anomaly map superposed with the main geological units shown in Fig. 2A. Contour interval is 5 mGal. E, F) Aeromagnetic anomaly map (reduction to the pole) of the study area and aeromagnetic anomaly map superposed with the main geological units shown in Fig. 2A. Contour interval is 0.1 nT. See color figure in the web.

Fig. 2.- A) Mapa del relive de la zona de estudio mostrando las principales unidades geológicas. B) Mapa geológico de la Cordillera Ibérica y zonas limítrofes. C, D) Mapa de anomalías de Bouguer de la zona de estudio y éste con las principales unidades geológicas de la Fig. 2A superpuestas. Intervalo de contorno de 5 mGal. E, F) Mapa de anomalías aeromagnéticas (reducción al polo) de la zona de estudio y éste con las principales unidades geológicas de la Fig. 2A superpuestas. Intervalos de contorno de 0.1 nT. Ver figura en color en la web.

E-W direction, parallel to its outcrops of Paleozoic rocks (magnetic anomaly "a", in Figure 2E). The northeastern sector of the Cameros basin is characterized by a noteworthy WNW-ESE elongated anomaly (magnetic anomaly "b") that has been interpreted as linked to subsurface volcanic rocks related to the Triassic rifting (Del Río *et al*., 2013). The magnetic anomaly c located to the South could have the same origin. It is also notable the presence of an array of N-S magnetic anomalies coinciding with the Altomira Ranges and Locanca basin (Fig. 2E).

Two magnetic lows (magnetic anomalies "d" and "f") have been previously studied. They correspond to the Atienza and Loscos magnetic anomalies, located over Permian igneous rocks (see Calvín *et al*., 2014). Most magnetic anomalies of the Iberian Chain and surroundings do not coincide with outcrops of igneous rocks at surface. In order to interpret their origin further studies would be needed.

Conclusions

The Bouguer and aeromagnetic anomaly maps of the Iberian Chain show that the main alignments of both gravity and magnetic anomalies coincide highlighting the major role played by its structural configuration.

In general, the study of Bouguer gravity anomalies of the Iberian Chain have deserved much attention compared with magnetic anomalies which would need further studies to better interpret and decipher their origin.

Authors' contribution

Soto, R.; Paper Structure, editing, figures, research/analysis, coordination, supervision.

Gamisel, A.; Methodology, data acquisition, figures, manuscript review, research/analysis.

Ayala, C.; Methodology, figures, manuscript review, research/analysis.

Martín-León, J.; Methodology, figures.

Mochales, T.; Methodology, manuscript review.

Rey-Moral, C.; Methodology, manuscript review.

Rubio, F.; Methodology, manuscript review.

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