Elsevier Editorial System(tm) for Tectonophysics
Manuscript Draft

Manuscript Number:

Title: Crustal structure and topography in the Iberian Chain

Article Type: SI:Iberia Geodynamics

Keywords: Moho depth, Bouguer anomaly, topography, Iberian Chain

Corresponding Author: Dr. Joan Guimerà,

Corresponding Author's Institution: Universitat de Barcelona

First Author: Joan Guimerà

Order of Authors: Joan Guimerà; Lluís Rivero; Ramon Salas; Albert Casas

Abstract: Using topographic and gravimetric data, several models of Moho depth are presented for the Iberian Chain (Airy Moho depth maps and a Moho depth map derived from the Bouguer anomaly map). These maps show a similar depths of the Moho. The maximum Moho depths obtained in the different maps range from 37 to 43 km.

***Cover Letter**

Dear Editors,

The paper entitled *Crustal structure and topography in the Iberian Chain*, authored by J. Guimerà, L. Rivero, R. Salas, A. Casas, is submitted for publication in the Special Issue *Iberian Geodynamics* of Tectonophysics.

Best regards,

Joan Guimerà

(Corresponding author).

Abstract

Using topographic and gravimetric data, several models of Moho depth are presented for the Iberian Chain (Airy Moho depth maps and a Moho depth map derived from the Bouguer anomaly map). These maps show a similar depths of the Moho. The maximum Moho depths obtained in the different maps range from 37 to 43 km.

Crustal structure and topography in the Iberian Chain

J. Guimerà[1], L. Rivero[2], R. Salas[2], A. Casas[2]

[1] Departament de Geodinàmica i Geofísica, Facultat de Geologia, Universitat de Barcelona, Martí i Franqués s.n. 08028 Barcelona, Spain (joan.guimera@ub.edu).

[2] Departament de Geoquímica, Petrologia i Prospecció Geològica, Facultat de Geologia, Universitat de Barcelona, Martí i Franqués s.n. 08028 Barcelona, Spain (lrivero@ub.edu, ramonsalas@ub.edu, albert.casas@ub.edu).

Abstract

Using topographic and gravimetric data, several models of Moho depth are presented for the Iberian Chain (Airy Moho depth maps and a Moho depth map derived from the Bouguer anomaly map). These maps show a similar depths of the Moho. The maximum Moho depths obtained in the different maps range from 37 to 43 km.

Key words: Moho depth, Bouguer anomaly, topography, Iberian Chain.

1. Introduction

The major features of the geology in the Iberian Peninsula, between the Pyrenees and the Betics, include areas developed as a result of the geological events produced during the Phanerozoic (Fig. 1).

The older areas are the remains of the Variscan Iberian Massif (VIM, SW region of the peninsula), strongly eroded during the latest Paleozoic. A generalized planation surface developed over it, which was covered by the Lower Triassic red beds (Buntsandstein facies). This planation surface is still preserved in wide areas of the VIM and, as a consequence, the major altitudes reach 600 m locally, while the mean altitudes range between 300 and 500 m. These mean altitudes and the ones below, have been obtained after a moving average grid (with a radius of 15 km) from the GTOPO30 DEM (Fig. 2). DEM data were converted over an equally spaced grid using a moving average with a 15 km radius search. This interpolation system confers a crustal significance to the data, and is very convenient for an isostatic study (Tsuboi, 1983). The crustal thickness below the VIM ranges between 30 and 35 km, as determined by deep seismic reflection profiles (Simancas et al., 2003).

Most of the interior of the Iberian Peninsula contains a geological structure and a topography that are the result of the Cenozoic contraction, which was a consequence of the Euroasiatic and African plates convergence: mountain ranges and Cenozoic foreland basins formed. The mountain ranges constitute the Iberian Chain, a double-vergent intraplate thrust-belt, with a NW-SE main trend, which resulted from the contractional inversion of the Iberian Mesozic basins –also involving the Variscan Basement–, and the Spanish Central System, a result of the contractional deformation of the VIM by means of NE-SW thick-skinned thrusts. The Iberian Chain and the Spanish Central System exceed 2000 m above sea-level locally, but their mean elevation ranges between 800 and 1500 m in the former and 800 to 1400 in the latter. The elevations in the Cenozoic sedimentary basins (Ebro, Duero, Tajo, etc.) range from 700 to 1000 m in the Duero Basin, 500 to 900 m in the Tajo basin, and 200 to 700 m in the Ebro basin. The only deep seismic reflection profile available (ECORS) in the northern Ebro Basin displays a crustal thickness of about 34 km (Muñoz, 1992).

In the eastern coastal areas of the Iberian Peninsula, the topography is strongly influenced by the late Oligocene-to-Present development of the Western Mediterranean. NE-SW extensional faults related to the crustal thinning between the Balearic Islands and the Iberian Peninsula are preserved on-shore of the peninsula, producing a descending topographic gradient from the elevated inner parts to the Mediterranean coast.

The Uppermost Cretaceous to Lowermost Cenozoic rocks are the youngest pre-contractional rocks preserved within the Iberian Chain. They are good markers of the overall structure of the chain and of the topography developed during the Cenozoic contraction. It should be taken into account that previously to the Cenozoic contraction, the uppermost Cretaceous rocks indicate a shift from marine environments to continental with sporadic marine intercalations (Gautier, 1980; Canérot et al., 1982). This indicates that these rocks were formed near the sea-level, which was at that time about 200m above the present one. These Upper Cretaceous rocks are preserved in wide parts of the Iberian Chain, even in many of the more elevated, exceeding locally 1800 m of altitude.

Gravity and seismic constrains about the crustal structure beneath the Iberian Chain can be obtained from the literature. A shallow Moho (32-34 km) have been proposed by Dèzes & Ziegler (2002), Gómez-Ortiz et al. (2005), de Vicente et al. (2007) and Díaz & Gallart (2009), while Vera et al. (2004) have proposed a Moho between 32 and 38 km. Deeper Moho (35-43 km) have been proposed by Salas & Casas (1993) and Rivero et al (2008).

The aim of this paper is to discuss the crustal structure of the Iberian Chain and the surrounding Cenozoic basins after the present day topography and the Bouguer anomaly data analysis.

2. Results

2.1. Local Airy isostatic model

As stated previously, during the Cenozoic contraction, the Upper Cretaceous marine rocks (the last pre-contractional rocks) have been uplifted over 1500 m above the present sea level in several areas of the Iberian Chain, being these areas more than 40 km-wide, thus indicating a crustal significance for this topography. This and the previously described topography of the Iberian Chain need for a thickened crust below this region. A simple calculation assuming a local Airy isostatic model was performed comparing the proposed present VIM crustal thickness and mean elevation with the more elevated areas of the Iberian Chain (Fig. 3). Taking a crustal density of 2.7 g·cm^{-3}, a mantle density of 3.2 g·cm^{-3}, a mean topography of 400 m, and a crustal thickness ranging between 30 and 35 km for the VIM (Simancas et al, 2003), the 1500 m of maximum moving average elevation in the Iberian Chain implies a maximum crustal thickenning of about 7 km, resulting in a crust thickness ranging between 37 and 42 km. This simple calculation sets minimum and maximum values for the crustal thickness after the Alpine contraction, in an area not affected by the subsequent crustal thinning related to the opening of the Western Mediterranean during the Neogene.

2.2. Airy Moho depth map

To calculate the isostatic Airy root (Moho depth), the 15 km moving average DEM was used. After this grid, the Airy root was calculated using the formula (Simpson et al., 1983):

$$T_{(x)} = h_{(x)} \frac{\rho_t}{\Delta\rho} + T_c$$

where $T_{(x)}$ is the Airy root in km, $h_{(x)}$ is the topographic height in meters, ρ_t is the density of topography, $\Delta\rho$ is the density contrast between lower crust and mantle and T_c is the normal crustal thickness in km (crustal thickness at the coast).

Four maps were obtained by using a ρ_t = 2.65 g cm^{-3}, T_c of 27 and 30 km, and $\Delta\rho$ of 0.3 and 0.5 g cm^{-3}. These maps show a similar shape of the Moho variations but maximum Moho depths range from 37 to 43 km below the Iberian Chain (a 1.5 km of topographic elevation have to be added to obtain the maximum crustal thickness). Fig. 3 displays the obtained map using $\Delta\rho$ of 0.5

and T_c of 30 km. A thicker crust was obtained beneath the Iberian Chain and the Spanish Central System than in the surrounding Cenozoic basins. Three deeper areas can be distinguished: the Central Iberian Chain, reaching 36 and 37.5 km, and the Demanda Cameros and the Spanish Central System which reach 36 km. Adding the mean topographic elevation depicted in Fig 2, the maximum crustal thicknesses are about 37.5 to 39 km and about 37.5 km, respectively.

2.3. Bouguer anomaly map

A Bouguer Anomaly Map of the area studied was produced by the compilation of pre-existing data (Fig .4). All data were converted to International Gravity Standardization Net (IGSN 71). From the above compilation the most significant errors arise from elevation and topographic reductions, which yields a compounded error of not more than 5 mGal. Random data were converted over an equally spaced grid using a moving average with a 15 km radius search as was performed previously with de DEM data. Bouguer map was machine contoured within an interval of 10 mGal. The Bouguer anomalies depict a regional gravity low under the Iberian Range contrasting with the relative gravity high of the Ebro basin and the other surrounding Cenozoic basins.

The gravity map also shows a rising trend towards the shoreline which reaches its maximum around the coast. The Bouguer anomalies depict a regional gravity low under the Iberian Chain contrasting with the relative gravity high of the VIM. Bouguer gravity anomalies over the Iberian Chain are both large and negative (reaching -110 mGal), and therefore consistent with a thickened crust beneath the mountain range.

2.4. Moho depth map derived from the Bouguer anomaly map

The method of Wolard & Strange (1962) was used to perform this map. This empirical method uses the value of the Bouguer Anomaly (BA) to obtain the Moho depth:

Md = 40.5-(32.5*TANH((BA+75)/275))

were: Md = Moho depth (in km); TANH = Hyperbolic tangent; BA = Bouguer anomaly

This calculation is optimized for a density contrast between crust and mantle of approximately 0.6 g·cm^{-3}. The effect of major Cenozoic sedimentary basins (Tajo, Ebro and Duero) with low density sediments on the gravity anomalies (Fig. 5) was subtracted. This calculation was performed using a 3D algorithm based on prisms (Cordell 1973) taking an average basin density and increasing it in the depth, using the values obtained by Gómez et al. (2005, Fig. 4). Figure 6 shows the resulting Bouguer anomaly map. Applying the algorithm of Wollard & Strange (1962), a map of Moho depth was obtained (Fig. 7). In this map, values of the Moho up to 44 km were obtained, up to 6 km deeper than the previous local Airy isostatic model.

3. Discussion

Comparing the structural map (Fig. 1) with the mean topography (Fig. 2), a good match between them is evident: the elevated areas of the Iberian Chain and the Spanish Central System coincide with the areas of basement involved thrusts, displaying similar areal patterns and trends. The Airy Moho depth map (Fig. 3) displays the same relationship with structure, as it is directly derived from topography. Moho depth ranges from 37 to 43 km (are obtained using standard values of ρ_t = 2.65 g cm^{-3}, T_c of 27 and 30 km, and $\Delta\rho$ of 0.3 and 0.5 g cm^{-3}). Shallower Moho depth beneath the Iberian Chain (34 km maximum) have been proposed by Muñoz Martín et al. (2004) using T_c of 30 km, and $\Delta\rho$ of 0.83 g cm^{-3}. This large value of density contrast between the lower crust and the mantle, which is needed to compute a thinner crust, is too different from the mean global density contrast of 0.52 g cm^{-3} in continental lithosphere (Sjöberg & Bagherbandi, 2011). Hence, Moho depths from 37 to 43 km can be considered more consistent results.

The Moho depth map derived from the corrected Bouguer anomaly map (Fig. 7) depicts a more complex correspondence with the Cenozoic structure and the topography. In the Iberian Chain, a wide area containing a Moho depth below -42 km appear in its central elevated part, while below the similarly elevated part of the Demanda-Cameros area, Moho depth is shallower, about -40 to -41 km. The Spanish Central System, also displays a Moho bellow -42 km beneath its central part (Fig. 7), while its NE and SW parts do not reach this depth. This distribution contrasts with the general NE-SW topographic trend, with similar elevations along the whole unit. Thus, there are no a general correspondence between the elevated areas of the Demanda-Cameros area and the Spanish Central System, and the areas with a thicker crust: similarly elevated areas are underlied by quite different Moho depths. This may be the result of areal density variations that are not taken into account by the method, producing apparent Moho depth variations.

The crustal thickening deduced under the Iberian Chain should be generated coeval to the topographic uplift of the youngest pre-contractional rocks of the Iberian Chain (Uppermost Cretaceous to Lowermost Cenozoic), that is during the Cenozoic. Hence, the crustal thickening was generated during the Cenozoic contraction.

Comparing the results obtained by the three different methods used, we propose a maximum Moho depth ranging from 37 to 42 km for the central part of the Iberian Chain.

4. Conclusions

A good match was obtained comparing the geological structure with the mean topography: the elevated areas of the Iberian Chain and the Spanish Central System coincide with the areas of basement involved thrusts and display similar areal patterns and trends. The Airy Moho depth map, as derived from the topography, displays the same relationship with structure.

A more complex correspondence with the Cenozoic structure and the topography, and the Moho depth map derived from the corrected Bouguer anomaly map was obtained, with areas of similar elevations being underlied by quite different Moho depths. This may be the result of areal density variations that are not taken into account by the method, producing apparent Moho depth variations.

The results obtained by the three different methods used point to a maximum Moho depth ranging from 37 to 43 km for the central part of the Iberian Chain.

Acknowledgements

Funding for the research was provided by the I+D+I research project: CGL2008-04916, and by the Consolider-Ingenio 2010 programme, under CSD 2006-0004 “Topo-Iberia”.

References

Canérot, J., Cugny, P., Pardo, G., Salas, R., Villena, J.. 1982. Ibérica Central-Maestrazgo. In: El Cretácico en España. Universidad Complutense, Madrid, 273-344.

Cordell, L., 1973. Gravity analysis using an exponential density–depth function—San Jacinto Graben, California. Geophysics 38 (4), 684– 690.

De Vicente, G., Vegas, R., Muñoz-Martín, A., Silva, P.G., Andriessen, P., Cloetingh, S., González-Casado, J.M., Van Wees, J.D., Álvarez, J., Carbó, A., Olaiz, A., 2007a. Cenozoic thick-skinned and topography evolution of the Spanish Central System. Global and Planetary Change 58, 335–381.

Dézes, P., and Ziegler P. A., 2001. European map of the Mohorovičić discontinuity, paper presented at 2nd EUCOR-URGENT Workshop (Upper Rhine Graben Evolution and Neotectonics), Mt. St. Odile, France.

Díaz, J.and Gallart, J., 2009. Crustal structure beneath the Iberian Peninsula and surrounding waters: A new compilation of deep seismic sounding results. Physics of the Earth and Planetary Interiors 173, 181–190.

Gómez-Ortíz, D., Tejero, R., Babín-Vich, R., Rivas, A., 2005. Crustal density structure in the Spanish Central System derived from gravity data analysis (Central Spain). Tectonophysics 403 (1–4), 131–149.

Gautier, F. (1980): Mapa geológico de España 1:50 000. Núm 543 (Villarluengo), 2ª serie, 1ª ed. Memoria 45 p. IGME, Servicio de Publicaciones del Ministerio de Industria y Energía. Madrid.

Guimerà, J. and Álvaro, M. 1990. Structure et évolution de la compression alpine dans la Chaîne Ibérique et la Chaîne côtière catalane (Espagne). Bulletin de la Société Géologique de France 6 (2), 339–348.

Muñoz, J.A. (1992): Evolution of a continental collision belt: ECORS-Pyrenees crustal balanced cross-section. Thrust Tectonics, pp. 235-246.

Muñoz-Martín, A., Álvarez, J., Carbó, A., De Vicente, R., Cloethingh, S., 2004. La estructura de la corteza del Antepaís Ibérico. In: Vera, J.A. (Ed.), Geología de España. SGE IGME, Madrid, pp. 592–597.

Rivero, L., Guimerà, J., Salas, R. and Casas, A., 2008. Constraints on the Moho depth in the Iberian Chain. Geo-Temas 10, 673-675.

Salas, R., Casas, A., (1993): Mesozoic extensional tectonics, stratigraphy, and crustal evolution during the Alpine cycle of the eastern Iberian basin. Tectonophysics 228, 33-55.

Salas, R., Guimerà, J., Mas, R., Martín-Closas, C., Meléndez, A., Alonso, A., 2001. Evolution of the Mesozoic Central Iberian Rift System and its Cainozoic inversion (Iberian Chain). In: Ziegler, P.A., Cavazza, W., Robertson, A.H.F. & Crasquin-Soleau, S. (eds) Peri-Tethys Memoir 6: Peri-Tethyan Rift/Wrench Basins and Passive Margins. Mémoires du Muséum National de l'Histoire Naturelle 186, 145–185.

Simancas, J.F., Carbonell, R., González Lodeiro, F., Pérez Estaún, A., Juhlin, C., Ayarza, P., Kashubin.P., Azor, A., Martínez Poyatos, D., Almodóvar, G.R., Pascual, E., Sáez, R. y Expósito, I., 2003. The Crustal Structure of the

Transpressional Variscan Orogen of SW Iberia: The IBERSEIS Deep Seismic Reflection Profile. Tectonics 22 (6), 1062.

Simpson, Robert W., Jachens, Robert C., and Blakely, Richard J., 1983. Airyroot: A Fortran Program for Calculating the Gravitational Attraction of an Airy Isostatic Root Out to 166.7 KM. U.S.G.S. Open-File Report 83-883, 66 p.

Sjöberg, L.E., Bagherbandi, M., 2011. A method of estimating the Moho density contrast with a tentative application by EGM08 and CRUST2.0, Acta Geophys 59 (3), 502-525.

Tsuboi, C., 1983. Gravity. George Allen & Unwin, London, 254 p.

Wollard, G.P. & Strange, W.E., 1962. Gravity anomalies and crust of the earth in the Pacific basin. In: The Crust of the Pacific Basin. Geophysical Monograph 6, p. 60-80. American Geophysical Union. Washington.

Figure Captions:

Fig. 1: Simplified geological map of the Iberian Chain and surrounding Tertiary basins. UTM coordinates (30T, ED50) are shown.

Fig. 2: Topographic map (in m) of the study area obtained from the GTOPO30 DEM, aplying a 15 km moving average search.

Fig 3: . Airy Moho depth map (in km) obtained from the topography depicted in Fig. 2, using $\Delta\rho$ of 0.5 and T_c of 30 km.

Fig 4: Bouguer anomaly map (in mGal) after applying a moving average interpolation of 15 km of radius search.

Fig 5: Map of the Bouguer anomaly effect (in mGal) caused by the Cenozoic sedimentary basins.

Fig 6: Bouguer anomaly map (in mGal) after substracting the effect of major Cenozoic sedimentary basins.

Fig 7: Moho depth map (in km) derived from the corrected Bouguer anomaly map of Fig. 6.

Figures

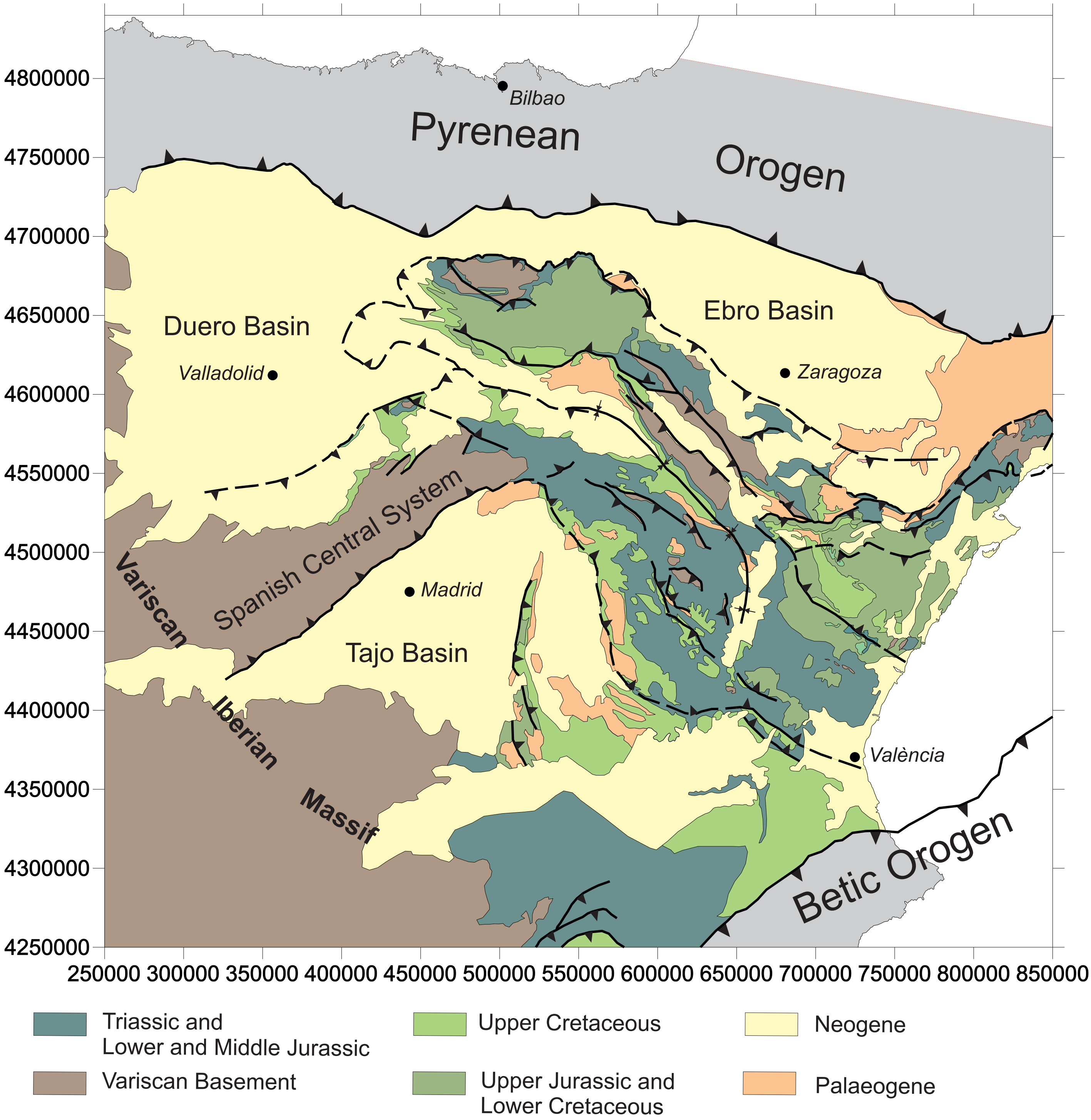
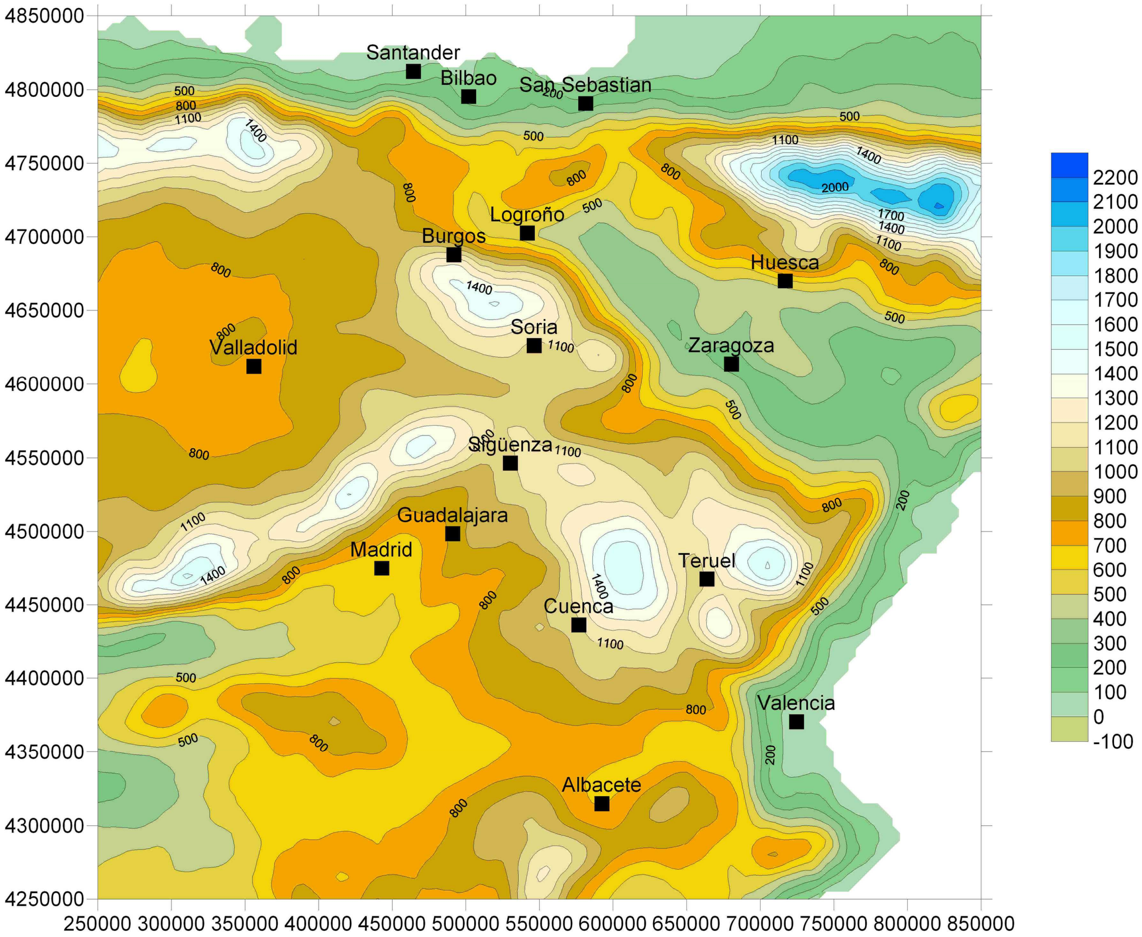


Fig. 1



Santander
Bilbao
San Sebastian
Logroño
Burgos
Huesca
Soria
Zaragoza
Valladolid
Sigüenza
Guadalajara
Madrid
Teruel
Cuenca
Valencia
Albacete
4850000
4800000
4750000
4700000
4650000
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
250000 300000 350000 400000 450000 500000 550000 600000 650000 700000 750000 800000 850000
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
-100

Fig. 2

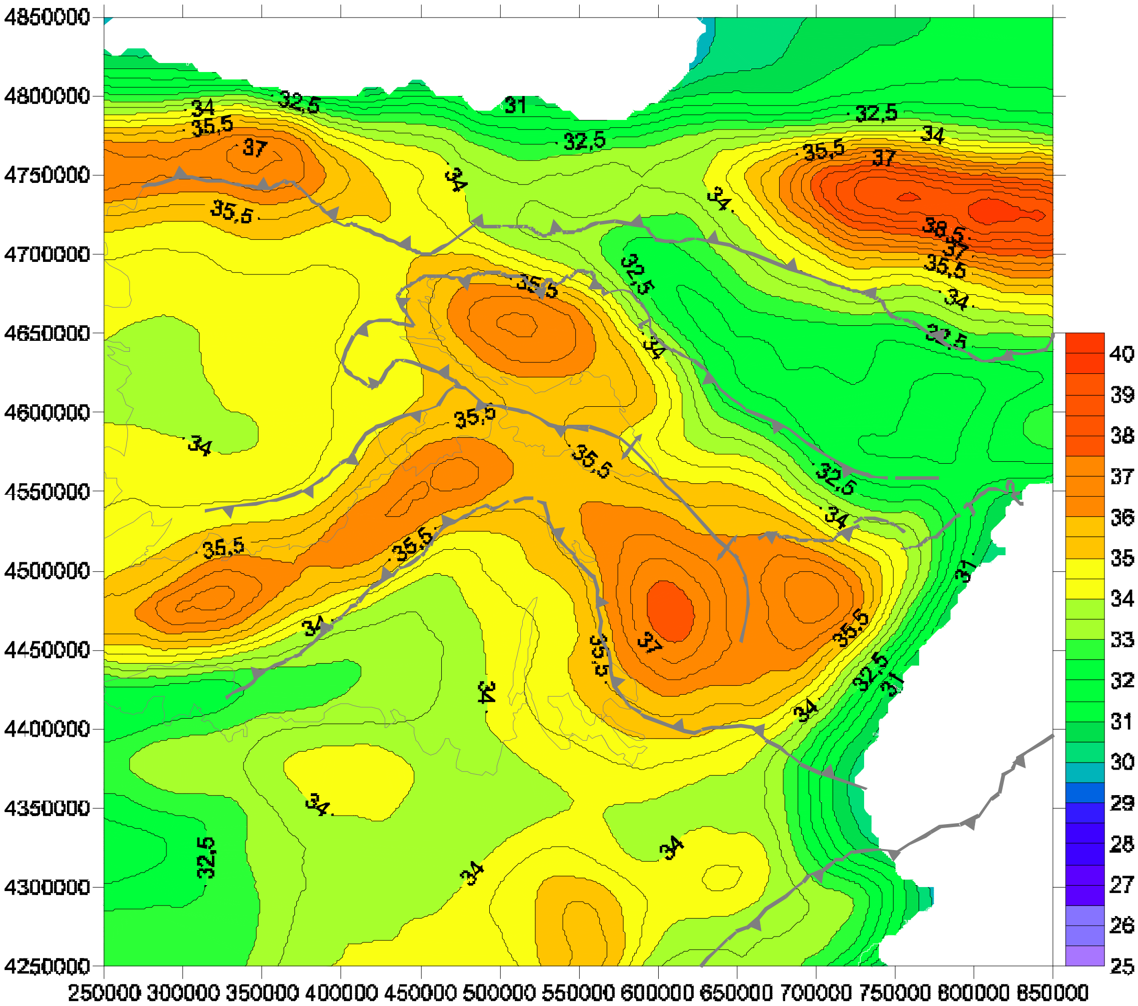
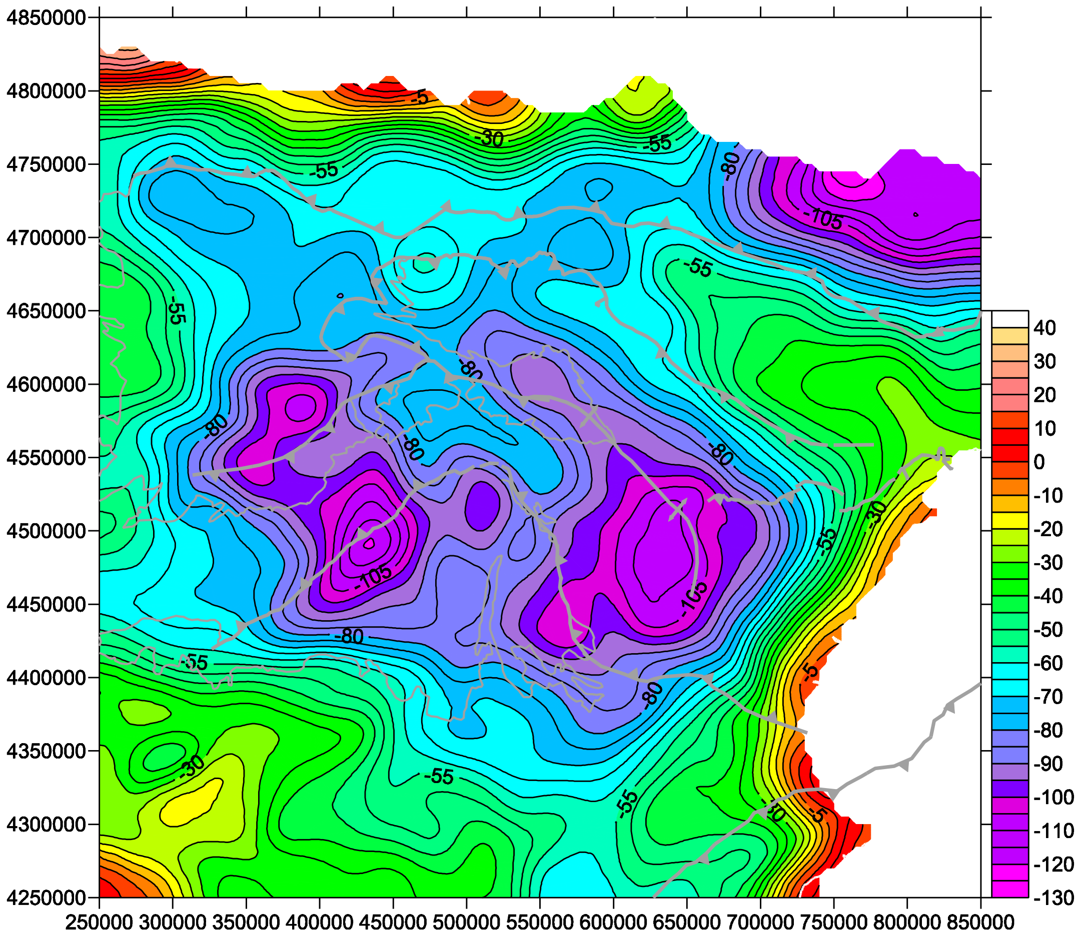

4850000
4800000
4750000
4700000
4650000
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
250000 300000 350000 400000 450000 500000 550000 600000 650000 700000 750000 800000 850000
40
39
38
37
36
35
34
33
32
31
30
29
28
27
26
25

Fig 3



4850000
4800000
4750000
4700000
4650000
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
250000 300000 350000 400000 450000 500000 550000 600000 650000 700000 750000 800000 850000
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130

Fig 4

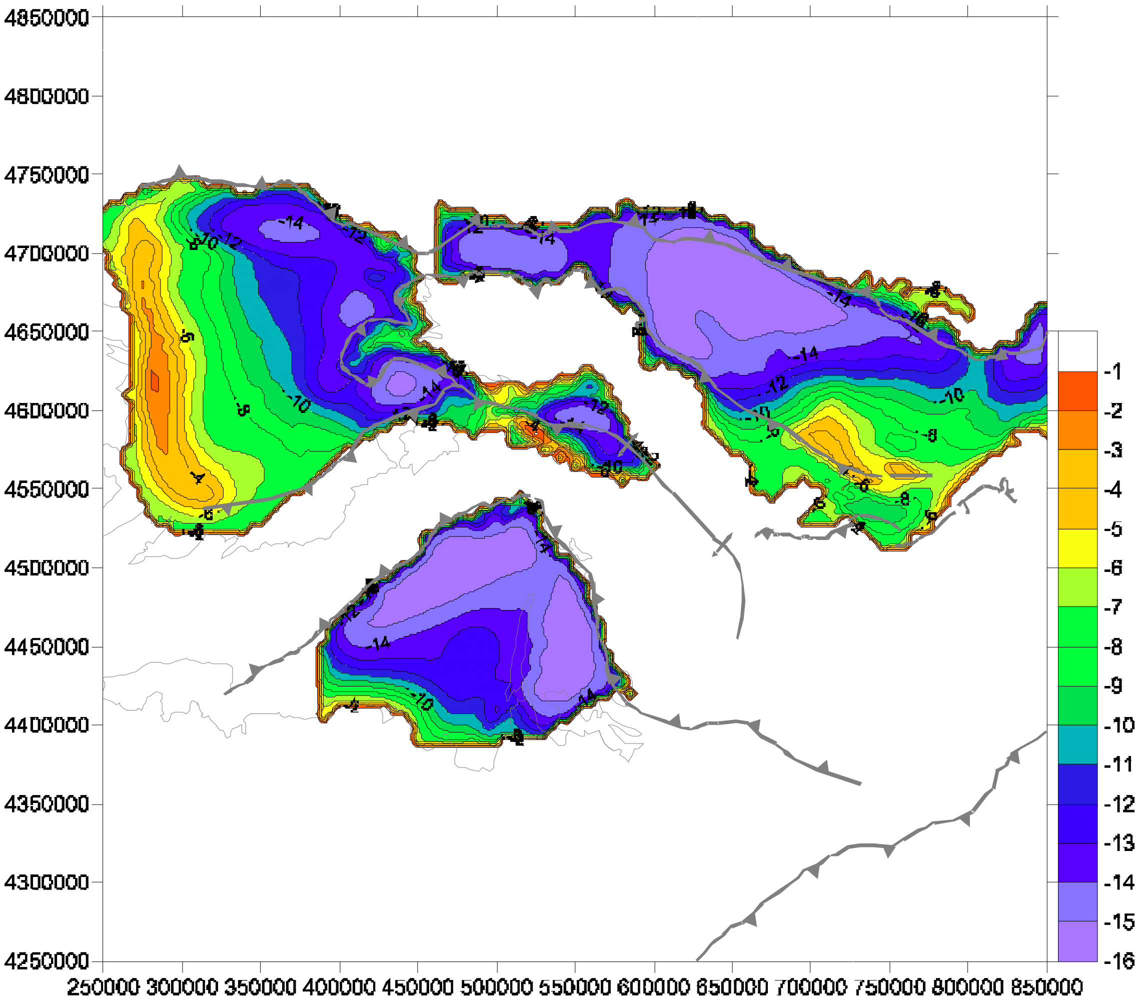
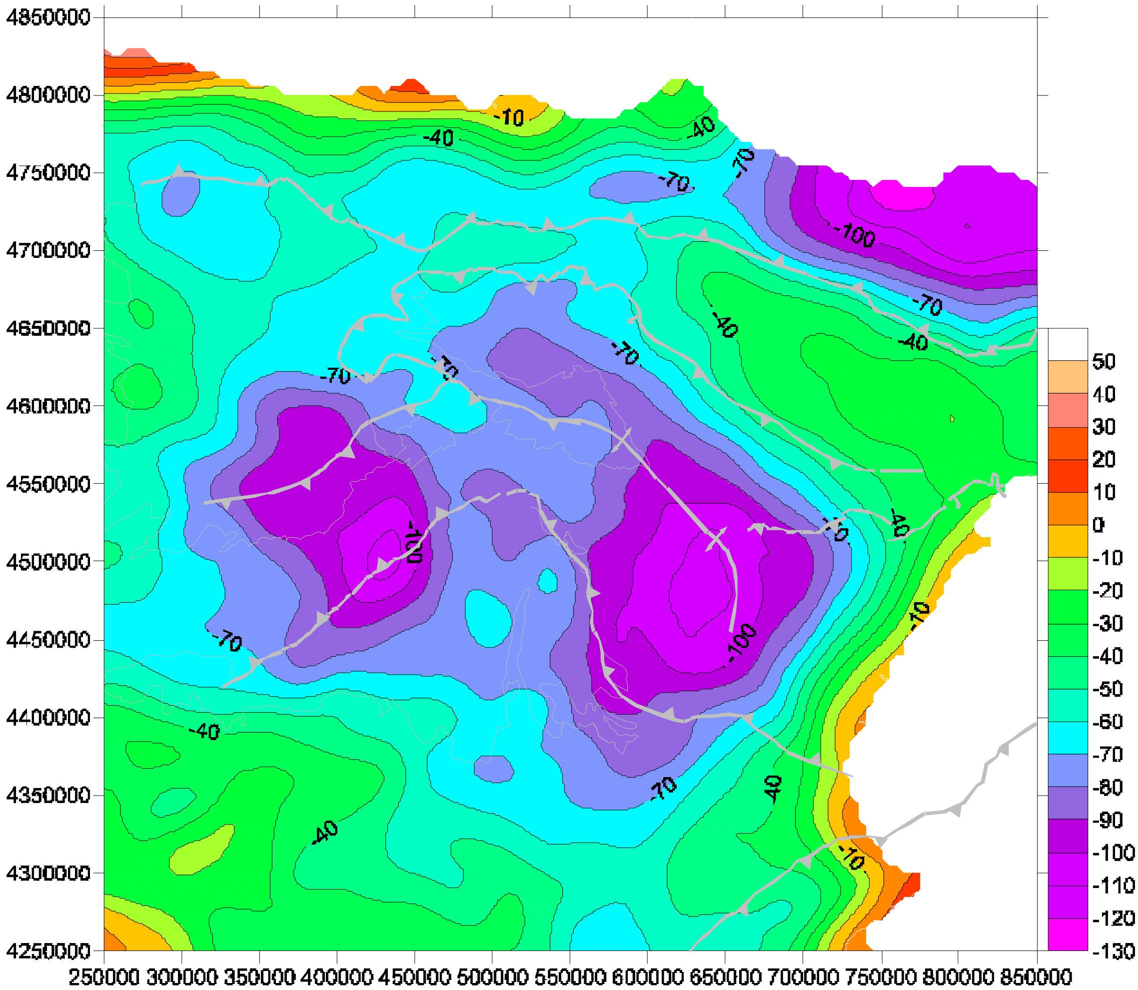
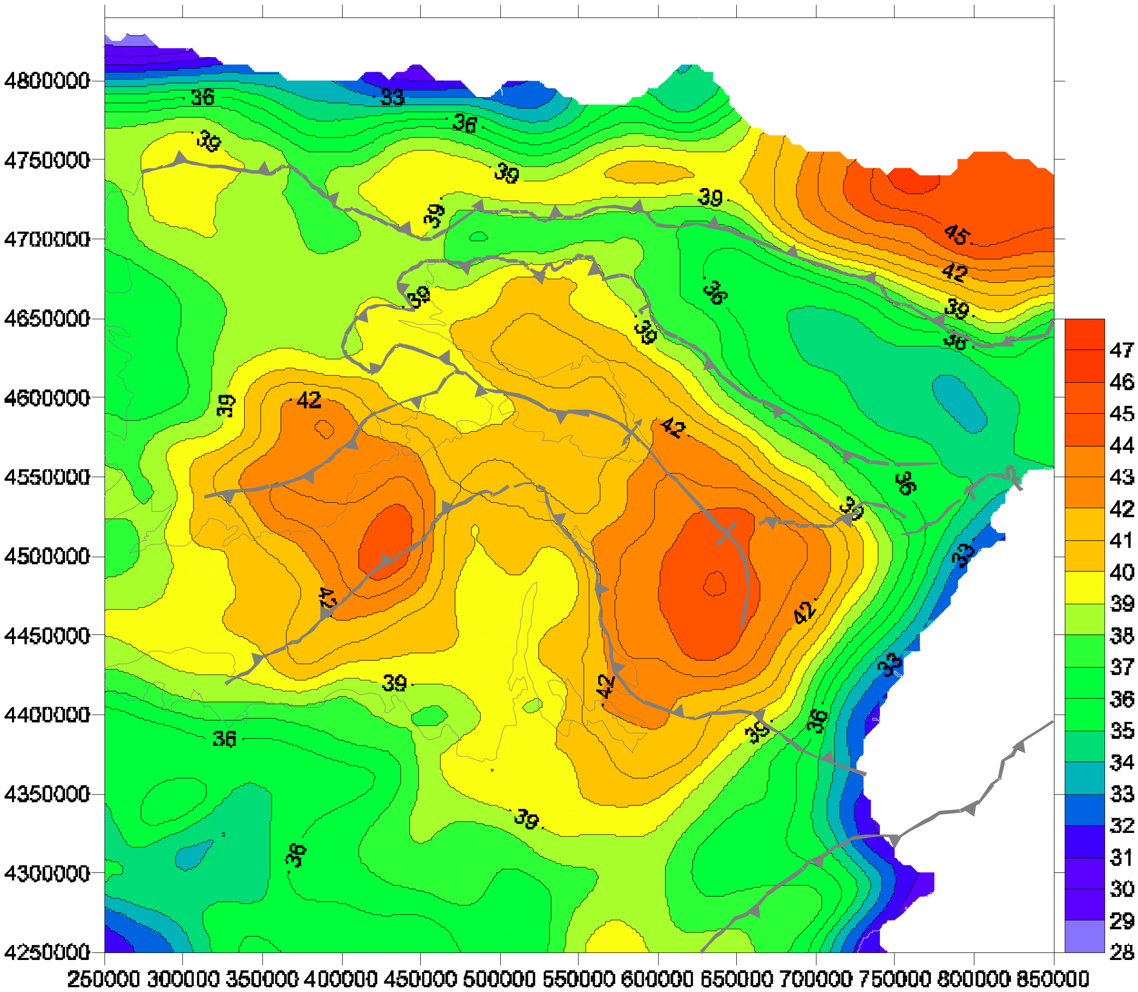

4850000
4800000
4750000
4700000
4650000
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
250000 300000 350000 400000 450000 500000 550000 600000 650000 700000 750000 800000 850000
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16

Fig 5



4850000
4800000
4750000
4700000
4650000
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
250000 300000 350000 400000 450000 500000 550000 600000 650000 700000 750000 800000 850000
-10
-40
-70
-100
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130

Fig 6



4800000
4750000
4700000
4650000
4600000
4550000
4500000
4450000
4400000
4350000
4300000
4250000
250000 300000 350000 400000 450000 500000 550000 600000 650000 700000 750000 800000 850000
36
33
36
39
39
39
39
45
42
39
36
39
36
39
39
42
42
36
39
33
42
42
39
42
33
36
39
36
39
36
47
46
45
44
43
42
41
40
39
38
37
36
35
34
33
32
31
30
29
28

Fig 7