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Lithosphere Thickness, Heat Flow and Moho Depth in The South of Portugal

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Abstract. In the last years, several models have been presented trying to obtain lithosphere and Moho thickness in the Iberian Peninsula, using data related to geoid elevation and topography, gravity, seismicity and thermal analysis. The results obtained show a decrease in the thickness of the crust and the lithosphere in the SW part of the Iberian Peninsula. Density anomalies in the crust are also referred. Data obtained in the region was collected and deviations from average values used were detected. In this work, models were made taking into account the specific characteristics of the region. Heat flow, thermal conductivity, heat production, topography, gravity, seismic and geological data available for the region, were used to adjust the model. The results show that this region is different from other parts of the Iberian Peninsula and a special attention must be given to it. This work shows the importance of trying to know and understand the thermal structure of the region.

1. Introduction

The models made for the Iberian Peninsula, based on surface elevation data, geoid anomalies, gravity and thermal structure, considering isostasy in the region, clearly indicate an anomaly in the thickness of the lithosphere in the SW of the Peninsula. The models presented to explain this anomaly consider an elevation of 400 m in the region, average thickness of the crust of around 30 km and heat flow values lower than those measured in the region. The present study relates to the South Portuguese Zone (SPZ) where Dundar et al [1] present crust thickness values between 28 and 31 km. The same work shows V_p/V_S values for the region. A high value (1.80) was obtained in the SE part of the region, where the crustal thickness is 28 km. The altitude of the region is not homogeneous, with no values that reach the 400 m used in previous works. Temperature gradients and thermal conductivity values obtained in the region are relatively high, and the measured values of heat flow are relatively elevated. This work presents the results obtained with models for two of the four regions presented by Duque [2].

2. Fundamentals

A three-layer model composed of crust, lithospheric mantle and asthenosphere is considered. The elevation in the region is positive and the effect of the ocean water is not considered. The assumption of isostasy can be used to develop relations between elevation and density of the lithosphere and the asthenosphere.

Using the work presented by [3], it is possible to say that the elevation of the surface above sea level (E) is related with the thickness of the lithosphere (L) by:

$$E = \frac{\rho_a - \rho_L}{\rho_a} L - L_0 \quad (1)$$

where ρ_a is the density of the asthenosphere, ρ_L is the density of the lithosphere and L_0 is the depth of the free asthenospheric level (without any lithospheric load $-L_0$ = 2320 m). Equation (2) is obtained considering two layers (crust and lithospheric mantle) with constant density, and applying isostasy.

$$(E + Z_c)\,\rho_c + (Z_L - Z_c)\,\rho_m = (E + Z_L)\,\rho_L \quad (2)$$

Equation (3) is obtained combining equations (1) and (2).

$$(\rho_m - \rho_c)\,Z_c = \rho_a L_0 + E\,\rho_c + Z_L\,(\rho_m - \rho_a) \quad (3)$$

The geoid anomaly is proportional to the dipole moment of the anomalous mass distribution, and

$$N = -\frac{2\pi G}{g} \int_{LC} Z\,\nabla\rho(Z)\,dZ \;+\; N_0 \quad (4)$$

where G is the universal gravity constant, g is the Earth's surface gravitational acceleration and N_0, the integration constant, is used to adjust the zero level of the geoid anomalies. Equation (5) is obtained solving the integral of (4).

$$N = -\frac{\pi G}{g}\left[(Z_c^2 - E^2)\rho_c + (Z_L^2 - Z_c^2)\rho_m + (Z_{max}^2 - Z_L^2)\rho_a\right] + N_0 \quad (5)$$

It is assuming that the lithospheric mantle density, ρ_m, decreases linearly with temperature, and the relation (6) is used.

$$\rho_m(Z) = \rho_a\,(1 + \alpha\,[\,T_a - T_m(Z)]) \quad (6)$$

α is the linear coefficient of thermal expansion, T_a is the temperature at the LAB (lithosphere-asthenosphere boundary) and $T_m(Z)$ is the temperature at the depth Z in the lithosphere.

The depth temperature distribution is obtained by solving the steady-state heat conduction equation,

$$\frac{d}{dZ}\left[K(T)\frac{dT}{dZ}\right] + A = 0 \quad (7)$$

where Z is the depth, T is temperature, K(T) is thermal conductivity and A is the volumetric heat production. The boundary conditions used are $T(Z=0) = T_0$ and $K(T)\,[dT/dZ] = q_0$, where T_0 is the temperature at the surface (Z=0) and q_0 is the heat flow density measured at the surface.

3. Data used

Heat flow data values were obtained in the region since 1982. In this work it is used data published by Fernández et al [4] and Correia et al [5]. Figure 1 shows the crustal thickness distribution presented by Dundar et al [1] and 5 different regions characterized by different heat flow, thermal conductivity and crustal depth values presented by Duque [2]. Models were made for region 1 and region 3. Fernandez et al [6] characterized the southwestern Variscan Crust of the Iberian Peninsula as composed of three layers: an upper crust with variable thickness (the value used is 6 km), a middle crust with a thickness of 18 km and a lower crust whose thickness is obtained from the thickness of the crust obtained with seismic data (4 km in region 1 and 7 km in region 3). The minimum thickness of the crust, obtained with seismic data in Region 1 is 28 km and the heat flow values measured are between 72 and 103 mW m^{-2}.

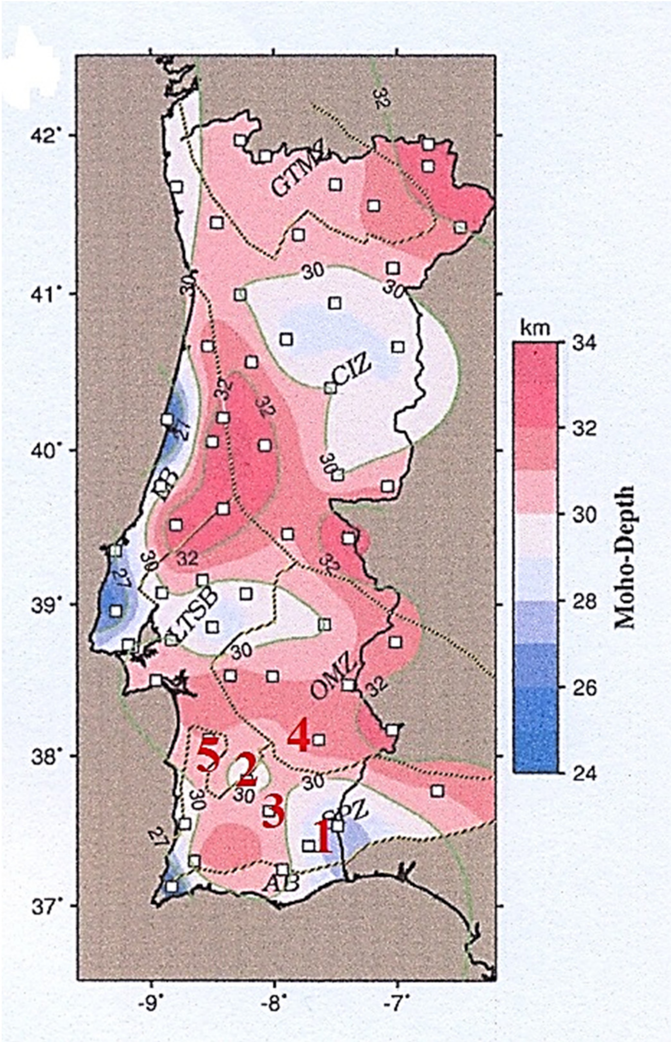

Figure 1. Moho depths and heat flow regions selected

For the model, a heat flow value of 75 mW m^{-2} is used. In the upper 2 km of the crust, the thermal conductivity value used is 3.4 W K^{-1} m^{-1}. For the upper and middle crust, the value of 2.5 W K^{-1} m^{-1} is used, and for the lower crust it is used the value of 2.1 W K^{-1} m^{-1}. For the thermal conductivity of the mantle, it is assumed a variation with temperature. A radiative and a conductive contribution is considered. In Region 3, the data show a crustal thickness of 31 km and heat flow values between 70 and 139 mW m^{-2}. A heat flow value of 100 mW m^{-2} is used in the model. The upper thermal conductivity value used for the crust in this region is 3.7 W K^{-1} m^{-1}. It is difficult to obtain heat production values in the region especially in Region 3 (Iberian Pyrite Belt) because it is necessary to consider the heat production by radioactive elements and also the heat generated in exothermic reactions occurring with water and pyrite. A heat production of 5.0 μWm^{-3} is considered for the region with ore deposits, and values of 2 μWm^{-3} for the upper and middle crust and 0.1 μWm^{-3} for the lower crust. No heat production is considered for the mantle. The surface elevation used is 100 m in Region 1 and 230 m in Region 3. For the density of the crust, are used the values presented by Fernandez et al [6]: density values from 2740 to 2800 kg m^{-3} for the upper crust, values of 2800 kg m^{-3} for the middle crust and 2950 kg m^{-3} for the lower crust. For the density of the mantle, values calculated by equation (6) using T values obtained in the model, are used. The value of N_0 was obtained considering a reference column with a lithospheric depth of 129 km and a crustal depth of 28 km. The compensation level (Z_{max}) is 300 km, the crustal density is 2780 kg m^{-3}, lithospheric mantle density 3245 kg m^{-3} and the density of the asthenosphere 3200 kg m^{-3}.

4. Results

The results obtained leading to the geoid anomaly values (see Table 1) are near the values found in Corchete et al [7].

Table 1. Results obtained in this work

	E [m]	Heat flow [mW m^{-2}]	Z_c [m]	Z_L [m]	P_c [kg m^{-3}]	N [m]
Region 1	100	75	27386	94900	2820	7.4
Region 3	230	100	30934	96000	2863	9.0

Looking at the crustal thickness values, it is possible to see results slightly below the values obtained with seismic data. The N value found in region 3 is slightly higher than the values presented with global models. Density values obtained for the crust are more elevated than those presented by Fernandez et al [6] but hey can be explained by the existence of pyrite deposits in the region. The heat production values used in the model predict a heat flow from the mantle (q_m) of 26.6 mW m^{-2} in Region 1 and 33.3 mW m^{-2} in Region 3.

5. Conclusions

The geoid anomaly values found are close to the values obtained in models of geoid anomalies for the region. Density values for the crust, in region 3, are higher than those used by other authors. Heat flow and thermal data are very important to obtain the density of the mantle and to predict the thermal conductivity values in deep regions. More work needs to be done in the other regions shown in Figure 1, to obtain more information related to the thermal state of the region and properties lithosphere in the SW of the Iberian Peninsula.

References

[1] Dundar S, Dias NA,Silveira G, Kind R,Vinnik L, Matias L, Bianchi M. Estimation of crustal Bulk properties beneath Mainland Portugal from P-wave teleseismic reveiver functions. *Pure Appl Geophys* 2016;DOI 10.1007/s00024-016-1257-4.
[2] Duque MR. Thermal models, lithosphere thickness and heat flow in South Portugal. Some comments about the subject. Communication presented in EGU2016, Vienna , Austria.
[3] Lachenbruch AH, Morgan P. Continental extension, magmatism and elevation, formal relations and rules of thumb. *Tectonophysics* 1990; 174: 39-62.
[4] Fernandez M, Marzán I, Correia A, Ramalho E. Heat flow, heat production, and lithospheric thermal regime in the Iberian Peninsula. *Tectonophysics* 1998; 291: 29-53.
[5] Correia A, Ramalho E. Update heat flow density map of Portugal. *Proceedings of the World Geothermal Congress* 2010.
[6] Fernandez M, Marzán I, Torne M. Lithospheric transition from the Variscan Iberian Massif to the Jurassic oceanic crust of Central Atlantic. *Tectonophysics* 2004; 386:97-115.
[7] Corchete V , Chourak M, Khattach D. The high-resolution gravimetric geoid of Iberia:IGG2005. *Geophys J Int* 2005; 162: 676-684.