Geothermal Heat Flow by Conduction in Mainland Portugal

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Abstract

Heat flow density measurements in Portugal were made in boreholes used for mining prospecting. Heat flow density values in the sedimentary basins of the western and southern margins of the country were obtained using data from oil or gas prospecting works. Due to the scarcity of data in the central and northern regions of the country, numerical models based on some characteristics of the region were used to obtain more heat flow values. The total of heat flow values used in this work is 69, with 17 values obtained using numerical models, 36 obtained in boreholes and 16 obtained from oil/gas prospecting wells data. The analysis and location of these data allows to define different regions in the territory and characterize them using average values of heat flow density, temperature gradient and thermal conductivity. Statistical values with all the data in the territory are also presented.

Keywords: geothermal heat flow, thermal gradient, thermal conductivity, mainland Portugal

Introduction

The data used in this work were obtained in mainland Portugal located in the Western part of the Iberian Peninsula between latitude values of 37.3797 N and 41.6417 N and longitude values of 6.6061 W and 9.4008 W. Offshore sedimentary basins may be found in the Western and Southern margins of the country.

In the Central and Northern parts of the territory it is possible to find hot water springs related with deep faults traversing the region. The main type of rocks in the region are granites surrounded by schist. The massifs of Bragança and Morais located in the northeast part of the country and formed by basic rocks give rise to regional anomalies. In the Southern part of the territory subjected to metamorphic processes in the past, denser rocks with very low porosity values can be found.

Heat flow density data were obtained in the territory since 1982 and results have been published [1][2][3][4]. Due to scarcity of data in some regions it was very difficult to build maps, define regions with identical properties and obtain statistical values that can characterize them. More heat flow values were obtained in recent years [5][6] [7] using numerical models based in some characteristics of the region obtained from seismological data [8], heat production by radioactivity [9] [10], fault location and tectonics of the region. The method assumes that the heat flow value at the surface is the result of adding to the heat flowing from the deeper zones and arriving at the base of the crust as heat flowing from the mantle , Q_m, the heat flow generated by crustal heat sources, Q_c. The heat flow values were obtained considering heat flowing by conduction. Regions with springs or water movement in the subsurface were not considered in this work.

Heat flow data location is shown in Figure 1. Different colours are associated to the origin of the data. The map still shows some "spaces" without data, but it is possible with the existing data to identify different regions in the territory and to present statistical data characterizing them. This is the main target of this work.

The analysis of the heat flow density data made previously to this work shows that the heat flow from deeper depths has similar values throughout the territory. Different values of heat flow density measured/obtained at the surface are related to heat sources distribution in the crust and different thickness of formation layers with the sources. Heat from exothermic chemical reactions was added to the heat generated in the radioactive decay of Uranium Thorium and Potassium elements in some regions [11].

Heat Flow Density Data in Mainland Portugal

Heat flow density measurements in mainland Portugal were done in boreholes drilled for mining prospecting. Temperature values were measured directly in the borehole and thermal conductivity values were obtained in laboratory using core samples from the boreholes with temperature measurements. Data from oil and gas wells located in the sedimentary basins of the western and southern borders of the territory were also used to obtain heat flow density values in these regions. The location of data can be seen in Figure 1 with borehole location in black and wells location in sedimentary basins in brown. Due to the lack of data in the northern and central part of the territory, numerical models were made [5][6][7] to obtain more heat flow values in these regions.

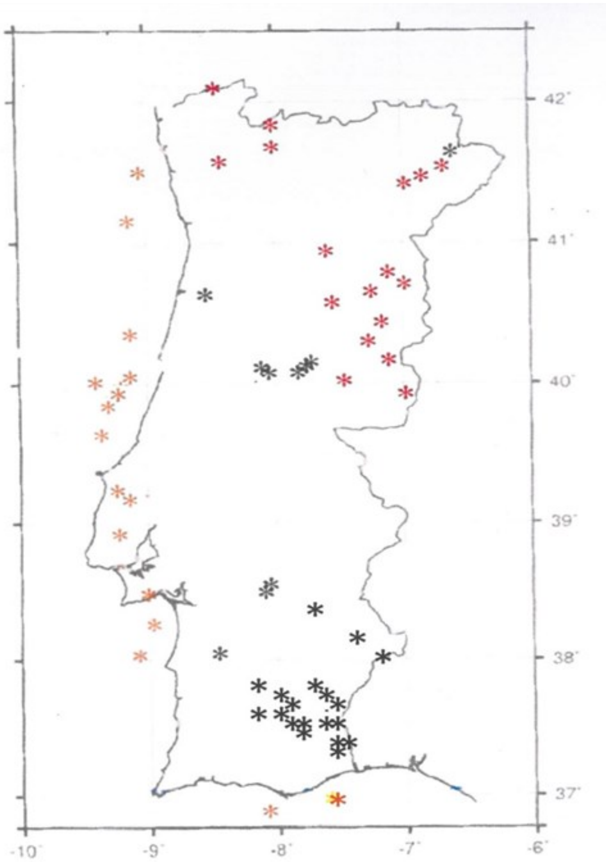

Fig. 1. Location of points with heat flow density values. Measurements were done in boreholes (dark), oil/gas wells (brown) and using numerical models (red).

In the map presented it is also possible to identify some regions without data but it is now possible to have an idea about the heat flow density distribution in the territory.

Average values of thermal gradient, thermal conductivity and heat flow density data are shown in Table 1. As expected, the lowest value of thermal conductivity was obtained in the sedimentary basins. The wells used are deep enough to see the effect of pressure increase in the decrease of porosity, increasing density and thermal conductivity values with depth. The high average thermal conductivity value obtained for drilled boreholes is due to the high thermal conductivity values obtained in the points of the Iberian Pyrite Belt located in the Southern part of the territory. For the Algarve Basin, located in the Southern border of the territory near the contact of the Eurasian and African Plates, the average values found for thermal gradient, thermal conductivity and heat flow values are 25.5 K/Km, 2.65 W/ (K m) and 68 mW/m^2 respectively. In this region there are only two heat flow values. For the onshore Lusitanian Basin located in the western part of the territory at latitude values close 39 N the average data are 30 K/Km, 2.8 W/(K m) and 82 mW/ m^2,respectively.

Tab. 1. Average values of thermal gradient, thermal conductivity and heat flow density data

Data origin	**Thermal gradient (K/km)**	**Thermal conductivity (W/ Km)**	**Heat flow density (mW/m^2)**
Drilled boreholes	23	3.4	77
Sedimentary basins	28	2.9	82
Numerical models	27	3.2	88
Measured data	24	3.3	79
All data	25	3.2	81

The dispersion of values is different in each region. Table 2 gives some information related with data used.

Tab. 2. Other data about the set of values used. N is the number of points with data.

Data origin	**N**	**Thermal gradient (Max – min values)**	**Thermal conductivity (Max –min values)**	**Heat flow density (Max- min values)**
Drilled boreholes	36	38 - 13	4.7 – 1.8	136 – 42
Sedimentary basins	16	36 - 21	3.6 – 2.5	106 – 63
Numerical models	17	31 - 24	3.7 – 2.4	99 – 62
Measured data	52	38 - 13	4.7 – 1.8	136 – 42
All data	69	38 - 13	4.7 – 1.8	136-42

The explanation of the values obtained and the construction of the numerical models required the value of heat originated in the crust and the heat coming from deeper areas. Maximum and minimum values of the heat flow measured at the surface (Q_o), heat flow originated in the crust (Q_c) and the quotient between the two values are presented in Table 3.

Tab. 3. Heat flow originated in the crust by radioactive sources. * means another source of heat added to radioactive sources.

Region	Q_o (mW/m^2) (Max – min values)	Q_c (mW/m^2) (Max – min values)	Q_c/Q_o (%) (Max – min values)
Northeastern	86 -62	51 -27	59 -44
Northwestern	97 -86	62 -51	64 -59
Central - Beiras	99 -81	64 -46	65 -57
Southern	100* -74	67* -40	67* -54

Values around 35 mW/m^2 were used for heat flow from deeper regions (Q_m) throughout the territory.

Using the data of Table 3 we can conclude that the heat sources located in the crust are responsible for 44 to 67 % of the heat flow obtained at the surface. This difference of 22% between the maximum and minimum values may be explained by two different phenomena. The highest values of heat flow measured in the Iberian Pyrite Belt, in the Southern part of the territory needs the addition of another source of heat to that generated by radioactive decay (the heat generated in chemical reactions of Pyrite and water [11]). In the Northeastern part of the country a region with low content of radioactive elements can be seen in Gamma-Ray Charts [12]. The low Q_c values were found in this region.

The territory is traversed by several faults. Some of them are inclined and deeper than the bottom depth of the holes studied. The measurements made in these regions may be affected by heat diffusion through the fault. This problem may be detected when several values of heat flow were obtained in close boreholes showing great dispersion of results.

Conclusion

The heat flow density values in mainland Portugal seem to be directly related with the heat sources content of the crust. The crust is heterogeneous in the region and there is great heterogeneity in gamma radiation charts. In some places non-radioactive heat sources must be added to radioactive heat sources in the region. The results clearly show the need to analyze the heat flow values taking into account the characteristics of the place where the measurement was done and the dispersion of data in the region. Heat flow values from deeper regions are the same in all the territory.

An average value of 81 mW/m^2 was obtained for the heat flow density in mainland Portugal. The highest heat flow values were obtained in the northern part of the territory and decrease to the south. Two exceptions should be mentioned. In the Northeast of the country there is a region with low values, associated with the massifs of Bragança and Morais. In the South of the country, high values are found in the Iberian Pyrite Belt

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