STUDY ABOUT THE RELATIONSHIP AMONG CRUSTAL THICKNESS, HEAT FLOW AND GRAVIMETRIC TIDE IN THE ISLAND OF LANZAROTE

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Data from heat flow and gramivetric tides are at our disposal in the island of Lanzarote (Canary Islands); its formation is known and, in addition to it, a model of its crust which provides us with its thicknes is at our disposal.

When studying the relationship among these parameters, a disagreement with the results obtained from previous studies is observed; those studies show a clear relationship between positive anomalies in the cosine component of the M_2 and O_1 waves of the gravimetric tide harmonic development and high values of heat flow; while the heat flow values determined in the island are abnormally high, the cosine components of the residues for these waves, determined by observation, have no abnormal values, and in the case of M_2 wave, a negative value.

On the other hand, the measured heat flow values are as expected, once the island crust thickness and its recent volcanic activity have been seen.

CORTICAL STRUCTURE OF THE ISLAND OF LANZAROTE

Several experiences have been carried out, both seismic and gravimetric ones, destined to the study of the cortical structure of the island of Lanzarote, combining on occasions both techniques for the interpretation.

The interpretation of latter experiences (Banda et al. 1981) has resulted in a tipically oceanic crustal model for the island, placing its thickness between 11 and 12 km.; this value agrees with the results obtained from gravimetric data observed in 1988 which give a similar estimation for the depth of the crust-mantle discontinuity (Vieira et al., 1991(a)).

HEAT FLOW OBSERVATIONS

In 1977, the geothermal drilling Lanzarote-1 was carried out (Sánchez Guzmán et al., 1986); it went 2598 meters deep into the island crust. This drilling was carried out between Montaña Rajada and Tremesana obtaining a geothermal gradient value of Γ = 0.05

K/m. If we consider the area thermal conductivity as the average for the basalt (λ = 2.17 W/m K) we would obtain a heat flow value of

$$q = \Gamma\lambda = 109 \text{ mW/m}^2.$$

this heat flow value is the only reliable one available for the whole island.

In the superficial thermal anomalies of Timanfaya's National Park, located in the area where the last eruptions have taken place, in the years 1730-36 and 1824, heat flow values are very difficult to evaluate as the superficial thermal gradient is not a linear one, with some very high temperature values rising to temperatures of 610°C at 13 meter deep in the so called *Islote de Hilario*. The model for a convective thermal anomaly (Díez et al., 1987) in its application to Lanzarote (Araña et al., 1984) indicates to us that a heat flow of

$$q = 130 \text{ W/m}^2$$

is needed to justify the existence of such high temperatures in the surface. A recent convective experiment (Díez et al., 1990, 1991) over the *Horno del Restaurante* in the *Islote de Hilario* seems to experimentally confirm this surface heat flow value in thermal anomalies.

HEAT FLOW/CRUSTAL THICKNESS RELATIONSHIP

Crustal thickness should be directly related to heat flow (Čermák et al., 1982) through the contribution of the latter radiactive elements; nervertheless, there are areas where a clear inverse relationship between thickness and heat flow can be observed.

Kutas (1982) associates to young structures (geosynclinal ones from the Cenozoic, areas of the Neocene-Quaternary and areas of tectonic-volcanic activity) the highest flow values; he observes average values (60-76 mW/m^2) related to structures originated in the middle and last Paleozoic and at the beginnings of the Mesozoic; and the lowest values (30-50 mW/m^2) in older and more estable cortical structures. Comparing the values of crustal thickness and heat flow he concludes that there is not an only correlation between these parameters; finding only in structures of the same type and age an inverse relation between them.

It can be said (Kutas, 1982) that the general pattern of the heat flow distribution is disturbed by the tectonic-magmatic activity which originates an increase in the heat flow values.

GRAVIMETRIC TIDE/HEAT FLOW RELATIONSHIP

According to Yanshin et al. (1986) the anomalies distribution in M_2 wave is related to the movilities of the asthenosphere and/or lithosphere. Positive anomalies normally appear with a shallow and hot asthenosphere, while the negative anomalies usually appear near stable structures over a relatively cold and deep asthenosphere. They find that positive anomalies just come together with basaltic volcanism, either young or contemporaneous, which is connected with tectonic tensions and takes root in the asthenosphere.

Melchior et al. (1991) carried out a correlation analysis with heat flow values for 159 stations of gravimetric tide. For the M2 wave they obtained a correlation coefficient k = 0.76 and a variation of 0.10 μgal for a 10 mW m^{-2} variation of heat flow; and for the O_1 wave a correlation coefficient K = 0.71 and a variation of 0.12 μgal for a difference of 10 mW m^{-2} in heat flow.

Robinson (1991), in a similar study with data from 10 stations located in the eastern area of north America, obtains for the M2 wave a relation with the heat flow of 0.043 μgal/mW m^{-2}, with a 0.79 correlation coefficient. The typical deviation of points in the linear regression is of 0.2 μgal. In this study harmonics O_1, K_1 and S_2 reveal similar tendencies, but the low values obtained for the correlation coefficients, lower than 0.06, confer very little signification to those tendencies. According to Robinson (1991) it would be necessary to increase the accuracy to determine the residues corresponding to these waves to be able to use them in this type of study.

Contrary to the results presented in the above paragraphs, Rydelek et al. (1991) do not find significant correlations between the gravimetric tide residues and the terrestrian heat flow, due to important error sources such as instrumental calibrations and the corrections of oceanic loading used, which can produce higher residues than the effects imputed to the correlation with the heat flow found in other works.

On the other hand, the effects predicted by the theory (Rydelek et al., 1991) and produced by side heterogeneities of the upper crust with a similar magnitude and extension to the indicated by seismology would not affect the gravimetric tide to the level indicated by correlations.

GRAVIMETRIC TIDE'S OBSERVATIONS IN LANZAROTE

Since 1987, within the investigations carried out by the Instituto de Astronomía y Geodesia in Lanzarote, a gravity continous recording is being carried out in the Geodynamic Station of the *Cueva de los Verdes* (Vieira et al.,1991 (b); Vieira et al., 1991(c).

On Table 1 vectors **B**, **L** and **X** can be seen, close to the values of the X cosχ, X sinχ residues for the M_2 and O_1 waves corresponding to gravimetric observations carried out in the Station. To carry out this analysis the Venedikov method has been used (Ducarme, 1975) adopted as standard methodology by the International Center for Earth Tides. The gravimeter (LaCoste Romberg, n° 434, G model) used in this work has been standardized with the Brussel's fundamental base.

The values of the cosene components of the residues for the M_2 and O_1 waves are, in absolute value, fairly less than μgal, which together with the possible error in the oceanic effect calculation makes these residuals unsuitable to be considered anomalous ones. They are of the level of noise (Melchior et al., 1991).

M2	(B, β)	= (8.35, 160.9)
	(L, λ)	= (7.85, 165.3)
	(X, χ)	= (0.80, 111.9)
	$X \cos \chi$	= -0.30
	$X \operatorname{sen} \chi$	= 0.74
O1	(B, β)	= (0.75, -91.2)
	(L, λ)	= (0.58, -96.2)
	(X, χ)	= (0.18, -74.8)
	$X \cos \chi$	= 0.05
	$X \operatorname{sen} \chi$	= -0.17

Table 1. **B**, **L**, **X** vectors and cosine and sine components of the latter determined in the Station of *Cueva de los Verdes* (Lanzarote) for the M_2 and O_1 waves of gravimetric tide.

To calculate the oceanic effect for the M2 component the EIO program (Toro, 1989) has been used, this program allows the calcultation of such effect from any of the oceanic charts existing in our data base. In an optimal way EIO determines the total effect for a given constituent from the combination of two or more charts. In this case we have used the Schwidersky charts complemented by the domestic charts Iberia and Canarias.

CONCLUSIONS

We can calculate the $X \cos\chi$ values expected for the values of heat flow measured in Lanzarote following Melchior et al. (1991). We would obtain for the value of $q = 109$ mW/m^2:

$$M_2 \text{ wave}: \quad (X \cos \chi)_C = 0.520\ \mu\text{gal}$$

$$O_1 \text{ wave}: \quad (X \cos \chi)_C = 0.612\ \mu\text{gal}$$

If from these calculated values we deduct those observed, we will find desagreements near 1.5 µgal for the M2 wave and 1 µgal for the O1 wave. If we were to consider the most anomalous value of the heat flow the 130 W/m determined in the volcanic area of most recent activity, National Park of Timanfaya, the predicted values would be totally foolish, although we have to take into account that this anomaly is very well located.

Another desagreement found with the above results is the associated with the type of recent volcanism generated in the island, basaltic one, and to which, according to Yanshin et al. (1986) would correspond a positive anomaly in the M_2 wave residue, which does not happen, even producing a negative value.

The results obtained in the station *Cueva de los Verdes* in Lanzarote, in spite of the high quality of the series and to perfectly agree within the expected relationships among the thickness of the crust, its age and recent volcanic activity and the observed values of the heat flow; do not fit in with the models proposed in other works for the relationship between the residues of the M_2 and O_1 waves of gravimetric tide and the values of heat flow, agreeing better with the results offered by the work of Rydelek et al. (1991).

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