COMPARATIVE STUDY OF GRANITIC BODIES FROM SUBSURFACE GEOMETRY. CENTRAL IBERIAN ZONE, HESPERIAN MASSIF, SPAIN

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En un sector de la Zona Centro-Ibérica, del Macizo Hespérico (rama Sur), comprendido entre las provincias de Toledo y Córdoba, se ha realizado un estudio comparativo, sobre la geometría en profundidad de los distintos cuerpos graníticos que existen en esa región.

La localización y estudio en profundidad de estos cuerpos graníticos se ha realizado mediante estudios geofísicos, fundamentalmente gravimétricos. Las anomalías gravimétricas se han estudiado con el fin de poder establecer modelos de dos dimensiones (2 D) o de dos dimensiones y media (2 D ½).

Se ha observado una variación de la geometría en profundidad de los diferentes plutones estudiados, variación que está relacionada con el nivel de emplazamiento. Así, los plutones emplazados en niveles profundos tienen sus paredes divergentes hacia la superficie, mientras que los emplazados en niveles someros tienen sus paredes convergentes hacia la superficie.

Se han localizado también toda una serie de cuerpos graníticos no aflorantes, que forman una alineación de dirección Este-Oeste situada al Sur de Ciudad Real, y que son localizables solamente por métodos geofísicos.

El emplazamiento y la localización final de estos cuerpos graníticos, parece estar controlado por fallas en dirección y por las estructuras de superposición de plegamiento de las últimas fases de deformación hercínicas, estructuras que son las responsables de la dirección de alargamiento horizontal máximo que muestran estos afloramientos graníticos.

Palabras clave: Hercínico, Plutones graníticos, Geometría en profundidad, gravimetría.

In a sector of the Central Iberian Zone, between the Toledo and Córdoba provinces, a comparative study on the subsurface geometry of granitic bodies, pertaining to the Hercynian basament, has been carried out.

The localization and subsurface study of these granitic bodies has been made by geophisical methods, mainly gravimetric ones. The gravity anomalies have been analysed in order to fit them into bidimensional models (2 D and D ½).

A variation on the geometry of the different plutons has been observed. This geometrical variation is related to the emplacement level. Plutons emplaced in deep levels show a geometry with clearly divergent walls, and plutons emplaced in shallow levels show geometries with convergent walls.

Key words: Hercynian, granitic plutons, subsurface geometry, gravimetry.

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Until recently the study of outcropping granitic bodies was limited to the genesis of plutonic rocks, together with their chemical and mineralogical evolution.

In this paper we investigate granitic bodies from another point of view; we determinated the structure and subsurface geometry of those bodies and their possible relationship with the mayor tectonic structures. For those studies we used several geological and geophysical techniques.

We have investigated the region by gravimetric methods, with the aim to establish the continuity and shape of most of the outcropping granitic bodies and to locate and characterize other possibly hidden plutons. We will show in this paper the results obtained from the studies of the following areas (see Fig. 1):

- The oriental sector of Orgaz region.
- Madridejos region.
- The Valdepeñas Fontanosas region.

This paper describes the subsurface geometry of granitic bodies pertaining to the hercynian basament. The study has been made by geophysical methods (mainly gravimetric ones).

Interpretation of the geometries have been based on the relative emplacement level and the associated hercinic deformation structures.

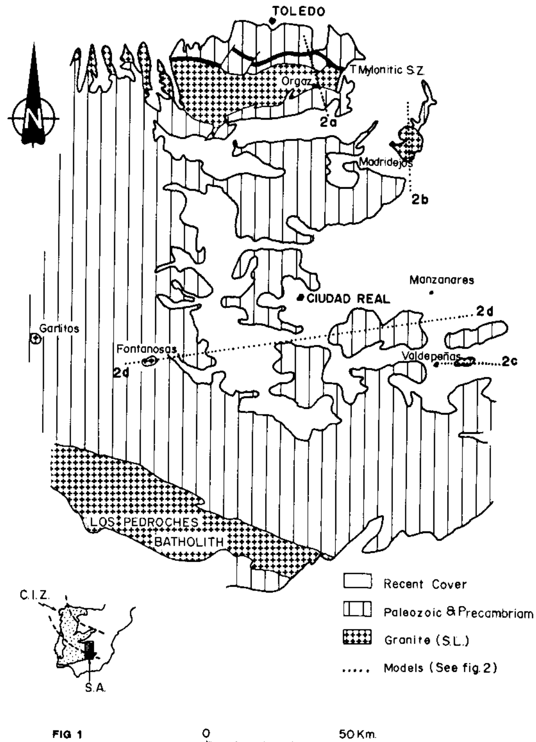

Fig. 1.—Geological map. 2a, 2b, 2c, 2d, gravimetric profile situation. C.I.Z., Central Iberian Zone. T.M.S.Z., Toledo mylonitic shear zone.

GEOLOGICAL SETTING

The South branch of the Centro-Iberian Zone (Zonal division of Julivert *et al.* 1972) pertains to an area of the Spanish Hercynian Belt with a low density of outcropping granitic bodies as compared to the surrounding areas to the north (North branch of the Centro-Iberian Zone (Division of Julivert *et al.* 1972)) and south (Ossa Morena Zone (Julivert *et al.* 1972)), or even to the west (Caceres region) (Castro, 1986).

The south branch of the Central Iberian Zone, according to the zonal division of Julivert *et al.* (1972), is a wide, NW-SE oriented region, more than 200 Km in length. The rocks of this region are Precambriam and Palaeozoic metasediments (quartzites, metapelitic rocks, metagreywackes, orthogneisses, ...) deformed and metamorphosed (epizonal domains) during the Hercynian orogeny, and some granitoid plutons.

Between the Orgaz pluton and the Los Pedroches batholith, both located at the boundaries of the studied area (Fig. 1), regional geologic mapping shows only a few stocks of granitic rocks, as those of Garlitos, Fontanosas, Valdepeñas and Manzanares (Fig. 1).

Such granitic bodies can be considered compositionally as calcoalcaline granites (granodiorites and monzogranites), with variable participation of the intruded materials, alumino-silicates are also frequent (Ugidos and Bea, 1976). They belong to the late and post-kynematic Hercynian plutonic series grouped by Capdevila *et al.* (1973), Corretge *et al.* (1977) under the name of «mixed group».

The Fontanosas pluton, was the first radiometrically dated in this section of the chain, giving an age of 302 ± 10 Ma. (Leutwein *et al.* 1970).

According to Aparicio *et al.* (1977), the granitic rocks of southwest Centro-Iberian Zone, are post metamorphic plutons, generally epizonal, para or discordant with the wall-rock structures, forming late or post-kynematic batholiths and stocks.

GRAVIMETRIC METHODOLOGY

For the gravimetric study, we have subdivided the gravimetric grid into four sector. In two of the sectors, Orgaz and Valdepeñas, the observation points have been distributed along longitudinal bands, cutting transversally the preferred orientation of the body. The third sector has a wide distribution and is located between Fontanosas and Valdepeñas. Here the objective was to locate possible hidden bodies which continue the Valdepeñas Montanchez alignments, to the east. The fourth sector forms a radial pattern around the Madridejos pluton.

In Orgaz (Santa-Teresa *et al.* 1983) the grid had 254 reading points covering an area of 1,500 Km^2 (75 × 200 Km) with a density of one station each 2.5 Km. Valdepeñas (Bergamín and De Vicente, 1985) had 44 observation points in a 32 Km^2 sector (16 × 2 Km), with one station each 0.85 Km. The density increases here because this is a reduced zone. The third sector (Bergamín, 1986) had 1,075 observation points covering 8,000 Km^2 (100 × 80 Km) with one station each 2.7 Km. In Madridejos (Bergamín y González Casado 1987), we made 95 readings within a radius of 13 Km around Madridejos.

Forty four conveniently located observation points of the I.G.N. *(«Instituto Geográfico Nacional de España»)* grid were used as a basis. The estimated positional error of each reading is lower than ± 3 m.

The topographic correction was made using a 1:50,000 cartography, till the «K» Hammer zone. The estimated error for this correction is in the order of the 0.2 or 0.3 G.U. (Gravimetric Units) as the topography is practically flat. The observations were made with a Worden Prospector gravimeter (0.1 G.U.) and the readings have been corrected for the instrumental drift, daily variation, free air, and Bouguer. The average density for this last correction is 2.67 Mg/m^3. The square average error for 70 repeated stations is 2.7 G.U.

The theoretical anomaly calculations, generated by the bidimensional (2 D and 2 D ½) theoretical models and their comparison with the observed Bouguer anomalies, were made with the Talwo 580 program (Carbo unpublished), which basically uses the calculation method developed by Talwani *et al.* (1959). The theoretical anomaly calculation, generated by the bidimensional model (2 D ½) and its comparison, were made also with a program, based in Cady's (1980) method.

Densities

Densities have been obtained from a systematic sampling of the most representative geological formations. The granitic bodies give variable densities ranging from 2.67 Mg/m^3 in Orgaz and Madridejos to 2.7 Mg/m^3 in Fontanosas and Valdepeñas. In the Ordovician materials the different density of each sector was estimated as a function of the quartzite (average density 2.67 Mg/m^3) and shale (density 2.83 Mg/m^3) content. As a whole, we estimated as characteristic values 2.7 Mg/m^3 for the Lower Ordovician and 2.82 for the Middle-Upper Ordovician. For the Cambrian and Precambrian materials the average calculated densities are 2.75 Mg/m^3 and 2.81 Mg/m^3, for Orgaz, and Fontanosas-Valdepeñas region respectively (see Bergamín, 1986 and Santa-Teresa 1982).

In the crystalline core outcropping to the north of Orgaz, we considered two big units as density functions: Metasediments, 2.83 Mg/m^3 and orthogneisses 2.67 Mg/m^3 (see Santa-Teresa *et al.* 1983).

RESULTS AND DISCUSSION

The Orgaz pluton (Santa-Teresa, 1982):

The Bouguer anomaly value over the granitic body is −110 G.U. (−11 mgal) with a length of 20 Km. These first data induce us to think that the pluton is not excessively deep. Bott and Smitshon (1967), Ager *et al.* (1972), Isaacson and Smithson (1976) showed granites with anomalies between −200 and −300 G.U. (−20 to −30 mgals) for depths between 10-20 Km, with wavelenghts similar to the ones considered here. On the other hand, the body is north-bounded by a non-plutonic con-

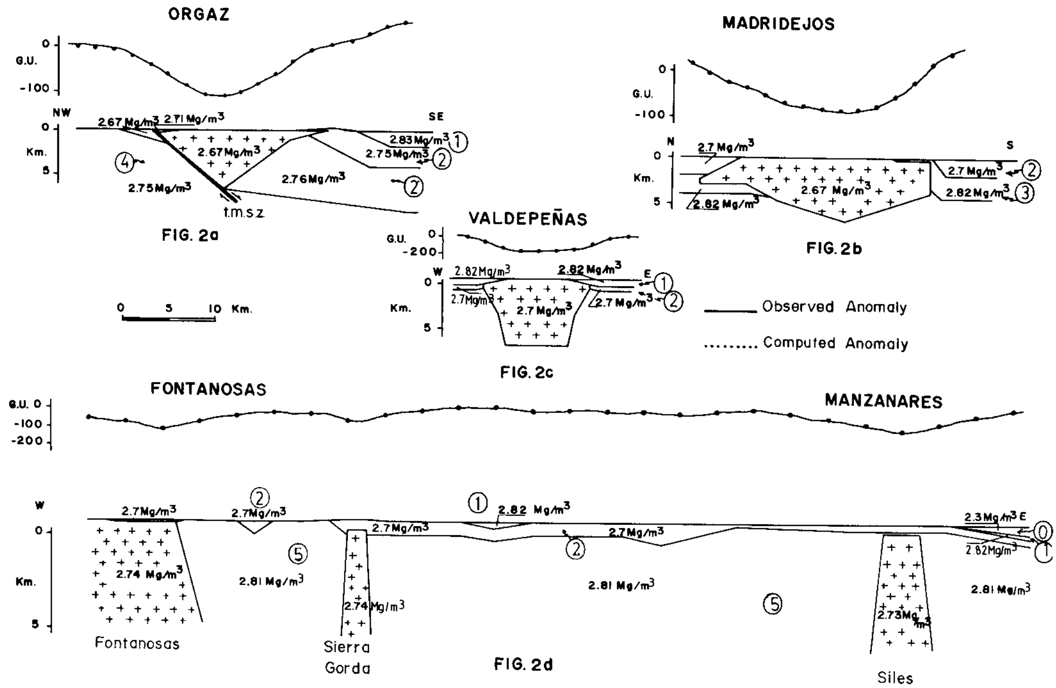

Fig. 2.—Calculated models from Fig. 1 profiles, 0—Recent cover, 1—Ordovician slates, 2—Ordovician quartzites, 2'—Ordovician quartzites and slates, 3—Cambrian limestones, 4—Orthogneisses, 5—Precambriam shales.

tact with the migmatitic massif due to a ductile shear zone (Toledo mylonitic shear zone (T.M.S.Z.)). The T.M.S.Z. is a tectonic structure developed after the emplacement of the granitoid (Aparicio, 1971). The change between the crystalline core materials to the north and the Palaeozoic to the south must be explained similary (Fig. 2a). With these facts we can develope three basic types of geometrical bodies in depth:

I) Convergent contacts in depth.
II) Divergent contacts in depth.
III) Models with implicit stoping processes.

It seems clear from the observation of the anomaly shape, that the models to be considered are of type I (Fig. 2a). We obtain a model that gives an anomaly that correlates perfectly with the observed one. The geological interpretations of the model can be summarized as follows:

– The Orgaz pluton shows an inverted triangular shape reaching 6.6 Km in depth.
– It is an allochthonous body, actually unrooted and cutting discordantly the core materials of the Sonseca-Orgaz anticline.
– The crystalline basament (crystalline core) changes its position, outcropping to the north, and deepening till about 9 Km under the Yebenes syncline.
– The Palaeozoic materials of the monadocks are confirmed as «roof-pendants» floating on the granite.

The Madridejos pluton (Bergamín and González Casado, 1987):

Is similar to the Orgaz pluton in the bouguer anomaly values and symmetry. The anomaly is –90 C.U., in the pluton centre.

The model proposed for the geometry in depth (Fig. 2b) shows that this body has an inverted-triangular shape, reaching 7 Km in depth. But in this case with a very strong mushroom shape, and surrounding materials as «roof-pendants» floating on the granite. This pluton is an allochthonous body, actually unrooted, showing an elliptical shape, with an orientation close to that of the late Hercynian folds in this region (Julivert *et al.* 1983).

Valdepeñas-Pozo de la Serna Granite (Bergamín and De Vicente, 1985):

The observed anomaly is of −100 G.U. (−10 mgals) with a wavelength about 15 Km and a very marked «U» shape (Fig. 2c). This make us think that this body has an important development in depth. There are two kinds of models that can explain anomalies as the observed ones (Fig. 2c).

Type I) It shows a downwards convergent contact model with poligonal shaped blocks of Precambrian, Lower Ordovician and Upper Ordovician materials.

Type II) It shows an upwards convergent contact model.

The gravimetric method does not discriminate between the two models, although indicates a rooted granitic pluton and more or less vertical contacts (Fig. 2c).

Plutons to the south of Ciudad Real (Bergamín 1986, Bergamín et al. 1985):

There are three important anomalies in this region related with granitic bodies and independent of those generated by the Hercynian folding structures. We have from west to east:

1) Eastern extension of the Fontanosas Pluton anomaly with a value of −120 G.U. (−12 mgal).

2) Sierra Gorda anomaly, probably produced by a non outcropping granite, its value is −80 G.U. (−8 mgals).

3) Siles anomaly, related too probably with a non outcropping granite, with values between −80 and −90 G.U. (−8 to −9 mgal).

In the last two cases the anomaly is related here to non outcropping granitic bodies because of their elliptical and circular geometries. Their magnitudes and horizontal extension makes them different from the one produced by the Hercynian folding structures and from those produced by recent volcanoes.

The bidimensional models that best fit the observed anomalies have the following geometry (Fig. 2d):

They are three stocks of depth divergent walls, with small horizontal extension probably rooted in depth as they probably extend more than 8 Km under the actual surface.

– The Fontanosas pluton is slightly ENE elongated.

– The Siles pluton (the most eastern) is elongated in the opposite direction, following a N-S trend and showing a greater widening towards its base, 5 Km below, in its south edge.

– Sierra Gorda pluton, located between the two other, is practically equidimensional.

– The last two plutons do not outcrop and the models indicate a roof depth of about 500 m, surrounded by pre-Ordovician sedimentary formations.

– Other hidden bodies of this kind seem to appear, as indicated by other gravimetric anomalies, to the south and east of the zone studied, indicating that the stocks analysed here are not exceptional in this sector of the Hercynian chain.

The Fontanosas, Sierra Gorda, Siles and Valdepeñas plutons define an E NE-W SW lineament related with a belt characterised by thrust faults (inverse strike-slip) and shear zones. In most cases these shear zones are associated with the emplacement plutonic event. This deformation phase probably correspond to Hercynian D3 or D4. In this belt, NNE-SSW trending (N20 to N30) crossed folds are produced which interfere vith the main Hercynian structures. This thrust faults tectonics gradually changed in time towards and extensional regime in only one direction, and towards a final episode of radial extension. The Carboniferous Puertollano basin (Stephanian B and C) is also controlled by this fault tectonics. Both, the fault and the transverse folds trends, control the shape of the granitic bodies.

CONCLUSIONS

a) In the Luso-Alcudian Zone there are greater number of granitic bodies than supposed previously. Some of them have not yet been exposed by the erosion and they can only be located by indirect methods.

b) Several geometric shapes have been found in depth, ranging from very rooted divergent-wall stocks to unrooted convergent-wall stocks. The last ones, represented by the Orgaz and Madridejos granites, correspond both to mushroom-shape bodies as well as dipping.

c) In the Ciudad Real southern area, the deepest bodies, included in pre-Ordovician materials, are different from those included in shallower formations as the Valdepeñas one, indicating a transition to a convergent wall stock.

d) In the Ciudad Real region, the emplacement and the final localization of these bodies is controlled by late strike-slip belts. The intrusions of plutons is through extensional fractures developed by the shear zone, in mode similar to that proposed by Castro (1988) in a close region (Caceres region) of the Central Iberian Zone. This, together with the late crossed folds, determine the main horizontal body elongation.

In the Orgaz granite, the Toledo mylonitic shear zone (T.M.S.Z.) is very important in the actual subsurface geometry of that pluton.

In the Madridejos granite there is a close relationship between plutonism and the hercynian folds. The superimposed folding, of the Late Hercynian deformation phases (D4 or D5) produce a cross-folding with domes and basin structures, in one of which outcrops the Madridejos granite.

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