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Magnetic evidence of a crustal fault affecting a linear laccolith: The Guadiana Fault and the Monchique Alkaline Complex (SW Iberian Peninsula)

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ABSTRACT

Magnetic anomalies can help reveal the structure of the upper crust in regions with intermediate or basic igneous rocks, and their continuity is essential to determine the position of crustal faults. The southwestern Iberian Peninsula constitutes the foreland of the Betic Cordillera and is characterized by an elongated E-W dipole extending 200 km toward its external zones. The anomaly is related to the outcropping Monchique Alkaline Complex, characterized by rocks of moderate magnetic susceptibility (0.029 SI) intruding into the metapelitic host rock of the South Portuguese Zone. Analysis of aeromagnetic and field magnetic anomalies serves to constrain the geometry of this laccolith. Toward the east, the magnetic dipole has a 60 km long N-S sharp boundary that coincides with the southern part of the Guadiana River. Field magnetic and gravity anomalies confirm the presence of this structure. It is produced by a sharp step in the elongated anomalous body, with an E downthrown block, interpreted as the offset produced by a deep N-S crustal fault—the Guadiana Fault. Therefore, the Guadiana River has three long linear segments near its mouth, locally coinciding with a N-S trending joint set, that support the presence of this major fault. To date, no evidence of this tectonic discontinuity, coinciding with the Spanish-Portuguese border, has been reported. Magnetic research is essential for understanding the structure of wide regions intruded by intermediate and/or basic igneous rocks.

1. Introduction

Geophysical methods are essential for determining crustal structures in covered regions and in areas of complex geological features. Magnetic studies over continental areas conventionally focus on mineral exploration and on establishing regional geologic and tectonic frameworks. The trends of magnetic anomalies are directly linked to the geometry of the magnetic rocks and, therefore, to the deformation undergone (e.g. Blakely and Simpson, 1986). Magnetic methods are useful to study the upper crust in regions with intermediate and basic igneous rocks because of related major magnetic anomalies. They are very relevant in the analysis of large linear batholiths, such as the Cretaceous gabbro intrusion along the Antarctic Peninsula, related to the Pacific Margin Anomaly or West Coast Magnetic Anomaly, and more than 1500 km long (Garrett, 1990). In recent times, some magnetic studies have been applied in the analysis of specific faults that produce the sharp juxtaposition of rocks with different magnetic properties (e.g. Pilkington, 2007). Aeromagnetic data reveal a large strike-slip fault in the northern Willamette Valley, Oregon (Blakely et al., 2000) and the location and structure of the Seattle fault zone, in Washington (U.S.) (Blakely et al., 2002); as well as a left-lateral strike-slip fault in the Libyan Sirte Basin (Saheel et al., 2011), and several buried tectonic lineaments in the Kutahya-Denizli region (western Anatolia) (Bilim, 2007).

In the specific case of a fault downwardly displacing a thin anomalous magnetic layer, a sharp fall-off of magnetic effects would coincide with the fault trace (Reid, 2003). High resolution magnetic surveys make it possible to detect and model geometries of faults affecting thin magnetic bodies such as magnetic sedimentary strata or laccolith formed by magnetic rocks. For example, the faults that offset the Albuquerque basin fill, in New Mexico (U.S.) feature a layer with magnetic properties and have a clear aeromagnetic expression (Grauch et al., 2001; Hudson et al., 2001).

The southwestern most part of the Iberian Peninsula corresponds to the external zones of the variscan orogen, and comprises

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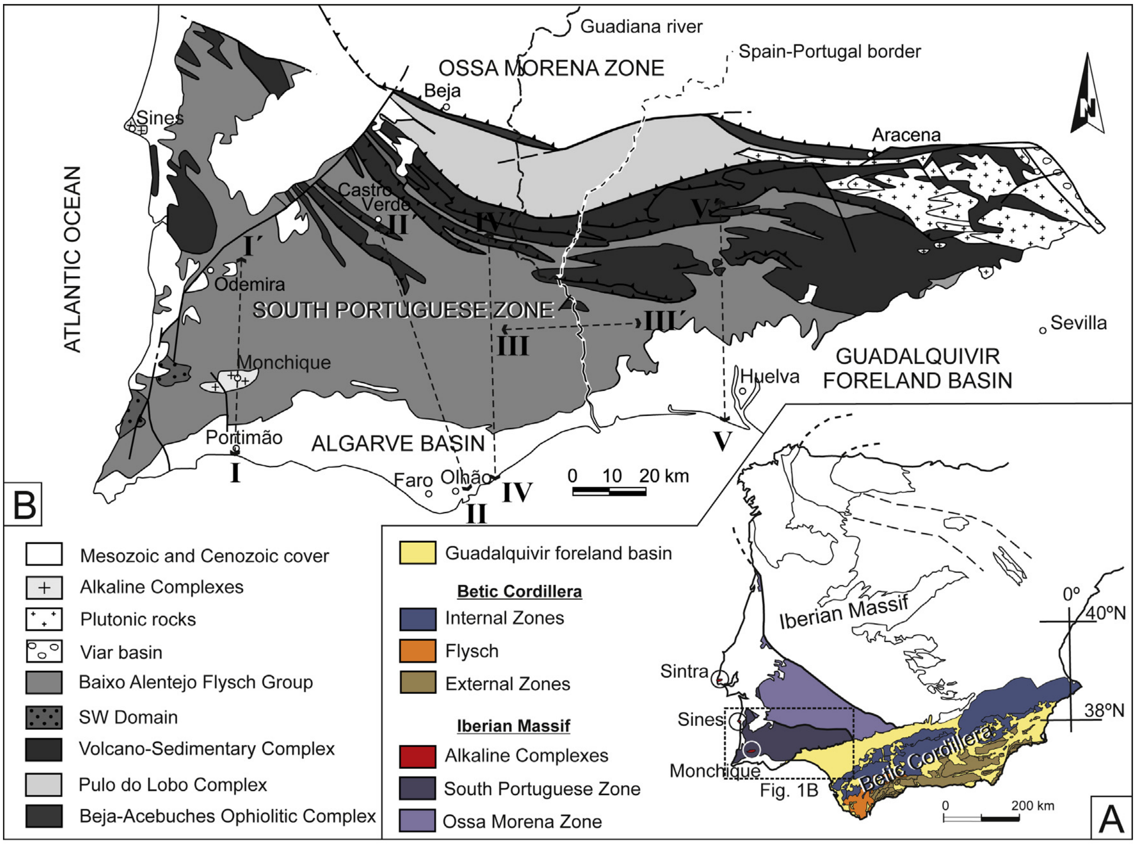

Fig. 1. Geological setting of the studied area. (A) Regional geological setting including the Sintra, Sines and Monchique Massifs. (B) Geological setting of the South Portuguese Zone and the Algarve Basin.

the South Portuguese Zone and the Algarve Basin (Fig. 1). This region constitutes the Betic Cordillera foreland, which extends below the Guadalquivir foreland basin and beneath the external zones of the cordillera. It is characterized by large linear magnetic anomalies (Socias and Mezcua, 2002) (Fig. 2) that can also be observed offshore, in the nearby Gulf of Cádiz. These magnetic anomalies have been related to large basic bodies (Dañobeitia et al., 1999) associated with the alkaline intrusions that affected the region during the Cretaceous (Bernard-Griffiths et al., 1997; Féraud et al., 1982; Rock, 1982). The Monchique Alkaline Complex is the most voluminous one, and the only one exclusively intruding Paleozoic rocks (Miranda et al., 2009). Surface geological data do not reveal the presence of large N-S variscan or alpine faults, although a set of fractures with this orientation is recognized in the Gulf of Cádiz (Lopes et al., 2006).

The aim of this research is to combine geophysical and surface geological data in order to determine the extension of the Monchique alkaline laccolith along the Southwestern Iberian Peninsula and discuss the nature of its boundaries. Its outcrop is related to a wide magnetic dipole that extends eastwards several hundreds of kilometers in a region where only metapelitic rocks crop out. A sharp magnetic discontinuity across the Guadiana River reveals, for the first time, the presence of a probable crustal fault, the Guadiana Fault. This regional research may improve our understanding of major covered faults through the integration of magnetic, gravity and geological methods.

2. Geological setting

The studied area is located in the southwesternmost part of the Iberian Massif, corresponding to the South Portuguese Zone and the Algarve Basin (Fig. 1). This area constitutes the western foreland of the Betic Cordillera.

The South Portuguese Zone represents the external zones of the variscan orogen and was formed by an accretionary prism over oceanic crust during the Pangaea formation. It comprises Devonian and Carboniferous rocks, some of them affected by very low grade metamorphism (Pinheiro et al., 1996). Its northern boundary is determined by an ophiolite. During variscan thin-skinned tectonics, three fold episodes and later thrusts involved structures of SW vergence, followed by a late fracture phase (Mantero et al., 2011; Silva et al., 1990). Therefore, deep seismic refraction and reflexion (Díaz and Gallart, 2009) profiles indicate that crustal detachments are delineated within the variscan cover. The South Portuguese Zone is divided into the following structural and stratigraphic subdomains from north to south: the Beja-Acebuches Ophiolitic Complex, the Pulo do Lobo Domain, the Volcano-Sedimentary Complex and the Southern Domain (Oliveira, 1990; Silva et al., 1990). The studied area is located in Southern Domain, and is mainly formed by metapelitic rocks.

Since early Cretaceous, large magmatic episodes occurred along the west margin of the Iberian Peninsula, probably associated with the motion of the Iberian plate above a mantle plume (Merle et al., 2009). Onshore, the main subvolcanic complexes of late Cretaceous age are NNW-SSE aligned and include the massifs of Sintra, Sines and Monchique (Fig. 1A). Although there is no surface evidence, a large NNW-SSE crustal structure (the Sintra-Sines-Monchique fault) has been proposed as a weakness that facilitates magma ascent (Ribeiro et al., 1979). The Monchique Alkaline Complex is the largest and youngest complex, and it is located in the Southern Domain of the South Portuguese Zone, north of the Algarve Basin. Rock (1978) describes this massif as a subvolcanic laccolith emplaced into late Carboniferous marine sediments. The age of the