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Main crustal discontinuities of Morocco derived from gravity data

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ABSTRACT

Sharp linear gradients in maps of potential field data are generally assumed to result from sharp discontinuities or boundaries between rocks having different densities or magnetic susceptibilities and are usually associated with faults or other geological contacts. The computation of the horizontal gradients of the gravity field permits us to localize the limits of such blocks and then the fault locations. The horizontal derivative maxima of the Bouguer anomaly and its upward continuation at several heights show lineaments that could reflect the layout of faults and/or contacts and their dip directions. The application of this method to the Bouguer anomaly map of Morocco (with 19,571 points, using an average crustal density $\rho = 2.67\ g/cm^3$) allowed us to perform a multiscale analysis of the gravimetric lineaments of the country. The obtained structural map is consistent with several faults already identified in previous studies, and highlights five new major subsurface faults systems with location and dip: the Saghro fault system; Bou-Arfa Midelt fault system; Sidi Slimane Mezquitem fault; Ksar El Kebir–Chefchaouen fault and the Rifan West Mediterranean fault. In addition, this study suggests a new shape and localization for the Agadir-Oujda trans-Moroccan major fault with a NE-SW direction and 900 km length, subdividing Morocco into two main domains. The results of this study contribute to the improvement of the regional structural map of the north western part of Africa, which is situated within the convergence zone between Africa and Eurasia.

1. Introduction

A multidisciplinary approach using the gravity method along with geophysical and geological information is essential for the understanding of the nature and behaviour of the Earth's crust (Omran et al., 1999; Jallouli and Mickus, 2000; Lefort and Agarwal, 2000). In Morocco, geophysical studies, mainly seismic and gravity investigations, were carried out in 1971, 1974, 1975 and 1980 in order to study the structure of the crust and uppermost mantle. Using seismic and gravity data, Tadili et al. (1986) mapped the Moho and an intracrustal discontinuity. The latter is located at an average depth of ∼20 km while the minimum crustal thickness is at ∼25 km along the Atlantic and Mediterranean coasts. Beneath the Atlas Mountains, the maximum depth of the Moho ranges from 35 to 40 km. However, Tadili et al. (1986) also noticed that these depth ranges are not uniform and differ from one geological unit to another.

Corchete et al. (2010) showed that the inversion of gravity data is a powerful tool to investigate the structure of the crust and upper mantle. By means of this technique, they revealed the principal structural features beneath Morocco and inferred the existence of lateral and vertical heterogeneity in the area. They also produced a general picture of lithosphere structure from 0 to 50 km depth. Using the results obtained from seismic, gravity, heat flow and geomagnetic surveys, Piqué et al. (1987) detected two main lineaments: (1) a NNE-SSW or NE-SW trend running from Mellila to Agadir and (2) an E-W trend running from Fes to Kenitra. Both trends represent zones of crustal weakness characterized by seismic activity, conductive structure and elevated heat flow. Recent volcanism associated with these trends suggests that they may represent deep-seated fractures giving way to mantle-derived volcanic material (e.g. Mokhtari and Velde, 1988; Rachdi, 1995; El Azzouzi et al., 1999, 2010; Wagner et al., 2003).

In this paper we attempt, by analyzing gravity gradients, to locate the abrupt lateral changes in density of upper crustal rocks that may indicate the presence of major deep seated fractures in Morocco. The approach adopted for this purpose is the application of a multiscale contacts analysis, which permits an enhanced visual interpretation of the gravity field data. The gravimetric gradient analysis (GGA) leads to a better knowledge of these

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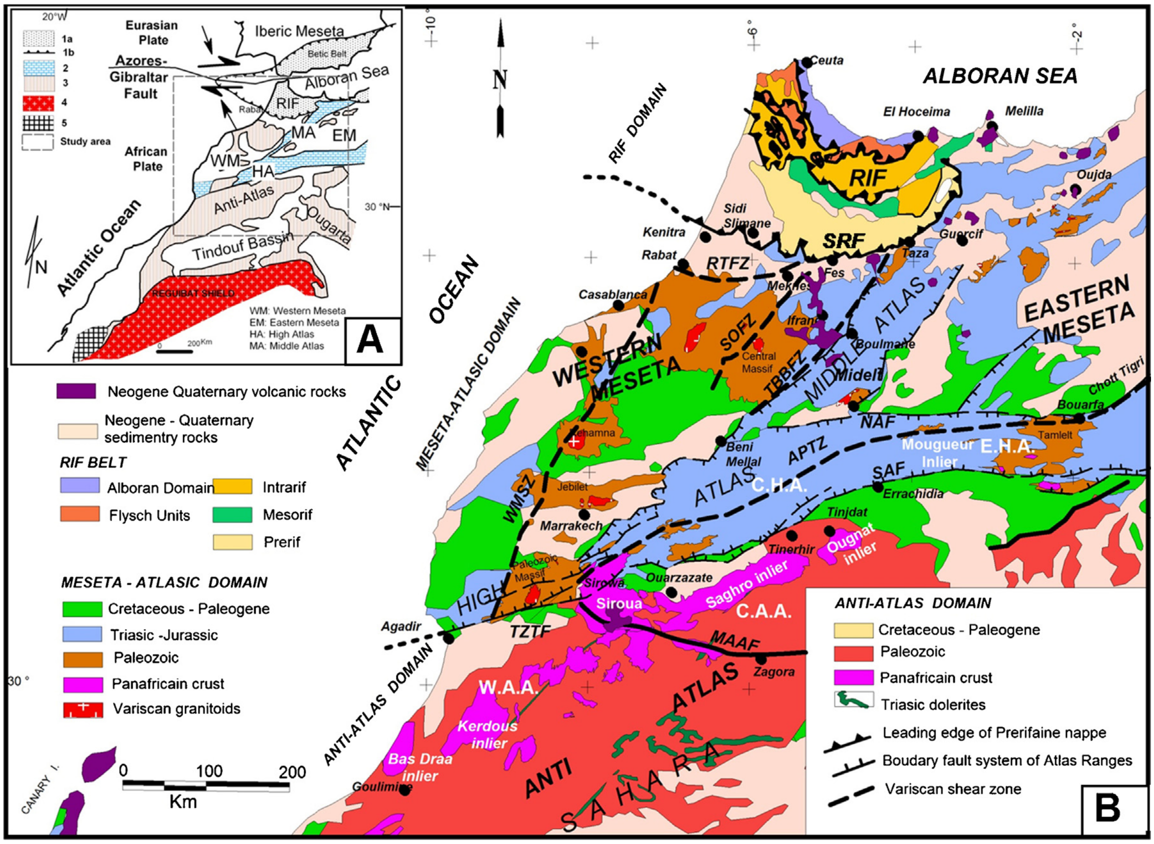

Fig. 1. (A) The structural domains of Morocco and location of the study area. 1a: Rif–Betic belt; 1b: southern and northern front of the belt with Atlantic probable extension; 2: Atlasic belt (HA, High Atlas; MA, Middle Atlas). 3: Palaeozoic terrains. 4: West-African craton (Archaean and Eburnian). 5: Mauritanides allochthons. (B) Structural domains of Morocco and main structural limits: SRF, South Rifan front; RTFZ, Rabat–Tiflet Fault Zone; WMSZ, Western Meseta Shear Zone; SOFZ, Smaala–Oulmès Fault Zone; TBBFZ, Tazekka–Bsabis–Bekrit Fault Zone; APTZ, Atlas Palaeozoic Transform Zone; SAF, South Atlas Fault; NAF, North Atlas Fault; TZTF, Tizi n'Test Fault. MAAF, Major Anti-Atlas Fault.

main structures. The outcome of this study will contribute to the improvement of the regional structural map of the north western part of Africa, located at the triple junction between the African continent, the Atlantic Ocean and the active Alpine plate collision zone (Michard et al., 2008). This wide area is tectonically complex, with moderate to large earthquakes mainly associated with the convergence between Africa and Eurasia along the Azores Gibraltar Fault (Fig. 1 inset).

2. Geological and tectonic overview

Morocco is located in the NW corner of Africa, the outcropping terrains spanning ages from Archaean to Quaternary. They record a variety of tectonic systems: from sedimentary basins to metamorphic fold belts, controlled by crustal structure. The most important orogenic movements are superimposed; this entails the control of the youngest structures by the oldest ones as attested by significant examples such as the Atlas Palaeozoic Transfer zone (Piqué and Michard, 1989), the South Atlas Fault, the major Anti-Atlas Fault and some detected structures like the Agadir-Nekor trans-Morrocan fracture zone (Aït Brahim, 1986) and Fes to Kenitra contact (Piqué et al., 1987). These Palaeozoic faults have an important role in controlling the younger structures during Mesozoic–Cenozoic times and delimit the main structural domains of Morocco (Fig. 1 inset). This study attempts to detect the gravity signatures of major deep seated structures predominating in Morocco. Abbreviations are listed in Table 1.

2.1. The structural domains of Morocco and their limits

The structural domains of Morocco (Fig. 1), from south to north, are the Anti-Atlas and the northern limit of the Saharan domain; the Meseta Atlasic domain and the Rif domain (Choubert and Marçais, 1956; Michard, 1976; Saadi, 1982; Piqué et al., 1983).

The Anti-Atlas and the northern limit of the Saharan domain belongs to the West African craton (WAC), which outcrops mainly in the Reguibat shield (Villeneuve and Cornée, 1994) and can be locally recognized in the inliers “boutonnières” of the Anti-Atlas Belt (Ennih and Liégeois, 2001). These Archaean and

Table 1
List of abbreviations used in the text and figures.

Gravimetric gradient analysis (GGA)
West African craton (WAC)
Rabat–Tiflet Fault Zone (RTFZ)
Western Meseta Shear Zone (WMSZ)
Tazekka–Bsabis–Bekrit Fault Zone (TBBFZ)
Atlas Palaeozoic Transform Zone (APTZ);
Saghro fault system (SFS)
Goulimine fault (GF)
Agadir-Oujda trans-Moroccan Fault (AOTMF)
Bou-Arfa Midelt Fault (BAMF)
South Rifan fault (SRF)
Sidi Slimane Mezquitem fault (SSMF)
Kenitra Sidi Kacem Fault (KSKF)
Ksar El Kebir–Chefchaouen fault (KCF)
Rifan West Mediterranean fault (RWMF).
Beni Arous fault (BAF)