Active tectonics revealed by isobase surfaces analysis from South Rifian Ridges, Northern Morocco

Tectónica activa revelada por el análisis de superficies isobase de las cadenas del Sur del Rif (Marruecos)

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ABSTRACT

The analysis of isobase maps, as one of surface dynamic parameters, helps understanding the tectonic geomorphology of South Rifian Ridges, Northern Morocco. The automatic generation of morphostructural map of 2nd and 3rd order channels is based on 30-grid Digital Elevation Model into Geographic Information System environment presents good results, supporting previous studies. Comparing to the western ridges, the eastern ones, specially Moulay Idriss massif, evidence neotectonic activity triggered by the presence of evaporites to generate an active fold growth (Dehar en Nsour) and possible zone of subsidence (Volubilis basin). These morphostructures are associated with normal faults reactivated during and after Miocene times. The inflexion of Khoumane river is caused by an WNW-ESE recent fault.

Key-words: *Isobase map, Active tectonics, GIS, South Rifian Ridges, Morocco.*

RESUMEN

El análisis de mapas de isobases se aplica en este artículo como una herramienta para entender la geomorfología tectónica de la parte sur de la cadena del Rif, en el norte de Marruecos. La generación automática de mapas morfoestructurales de cursos de segundo y tercer orden está basado en una red de 30 m del Modelo Digital del Terreno volcado en un Sistema de Información Geográfica. Los resultados muestran que las cadenas orientales, especialmente Moulay Idriss, presentan mayor actividad, a la que ha contribuido la presencia de evaporitas, para formar un pliegue activo (Dehar en Nsour) y una posible zona de subsidencia (Cuenca de Volubilis). Estas estructuras están asociadas a fallas normales reactivadas durante y después del Mioceno. La inflexión en el río Khoumane está también causada por una falla reciente de dirección WNW-ESE.

Palabras clave: *Isobases, tectónica activa, SIG, Rif, Marruecos.*

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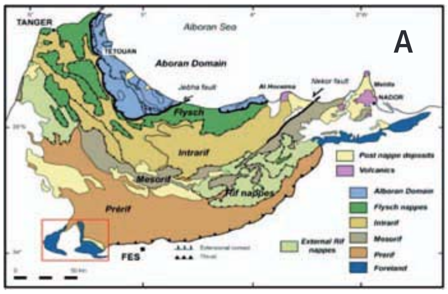
Introduction

Isobase surfaces (Filosofov, 1960; Grohmann *et al*., 2007), isobase maps (Lacika, 1997) or base level maps (Raczkowski *et al*., 1984; Grohmann *et al*., 2011) are important tools providing data about morphostructural evolution. Relief pattern discontinuities and drainage network may be explained by recent terrain movements (Grohmann, 2004).

In large areas containing rivers with variable youthful landforms such as the south rifian ridges (SRR), located at the front of the Moroccan Rif Cordillera (Fig. 1), the construction of isobase maps is useful for the investigation of uplifted or subsidence areas, as well as the amplitude of Neogene movements (Raczkowski *et al*., 1984). However, this concept has never been applied in the SRR. The general structure of the SRR is defined by two thrusting arcs separated by the Volubilis piggy-back basin (Roldán *et al*., 2014). The SRR are interpreted as ramp propagation folds (Haddaoui, 2000; Sani *et al*., 2007; Habibou *et al*., 2012; 2014 a and b, 2016), whose development was related to their southward or southwestward displacement in agreement with NE-SW, N-S and final NNW–SSE compressions, as a result of the present-day African and Eurasian convergence (Chalouan *et al*., 2006). This motion produced tilting and even overturning of the sedimentary sequences in which the thick Jurassic series, mainly carbonatic, form the dominant SRR reliefs, overlying the Triassic evaporites which are absent at surface, and covered, locally, by a marly Cretaceous series in the Eastern Ridges. The Miocene unconformably spreads over several Mesozoic series (Faugères, 1978).

Methodology

In order to simplify and accelerate the construction of isobase map in SRR, the automation process was carried out as a first step of tectono-geomorphological analysis. The automatic extraction of the drainage network from the Shuttle Radar Topography Mission (SRTM) DEM (~30m resolution) was done in ArcGIS software and was compatible (visually verified) with topographic maps at scale of 1:50,000, produced by the Morrocan ministry of agriculture in 1942. The Strahler ordering (1952) was established and the first-order drainage (the more recent river) was eliminated, because the "noise" could prevent the identification of a scarp or other topographic



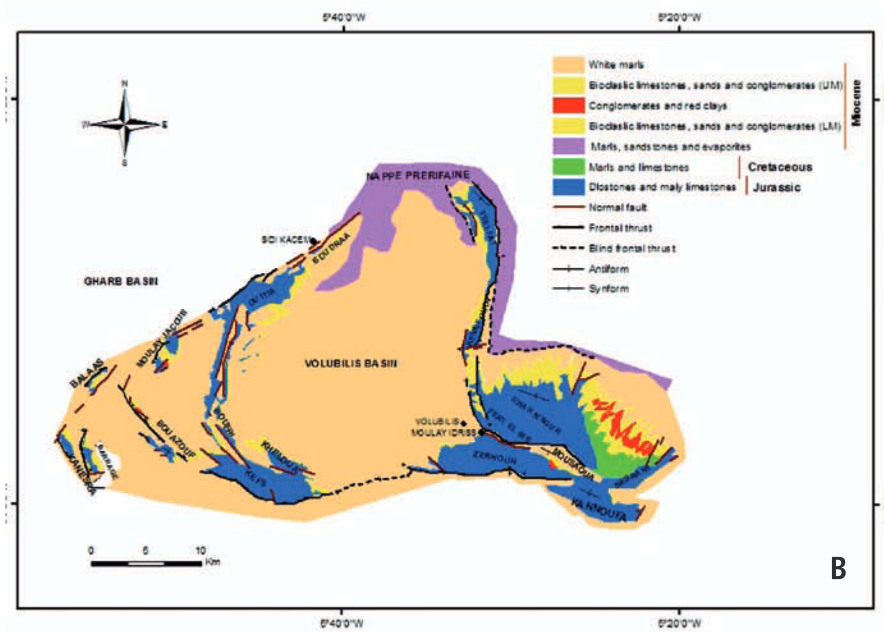


Fig. 1.- Geological setting of the study area. (A) Geological setting of the Rif Cordillera with location of the investigated region. (B) Geological map of the South Rifian Ridges and Volubilis basin (modified from Faugères, 1978). See color figure in the web.

Fig. 1.- Situación geológica del área de estudio. (A) Esquema de la cordillera del Rif con la ubicación de la región estudiada. (B) Mapa geológico de las cadenas del sur del Rif y la cuenca de Volubilis (modificado a partir de Faugères, 1978). Ver figura en color en la web.

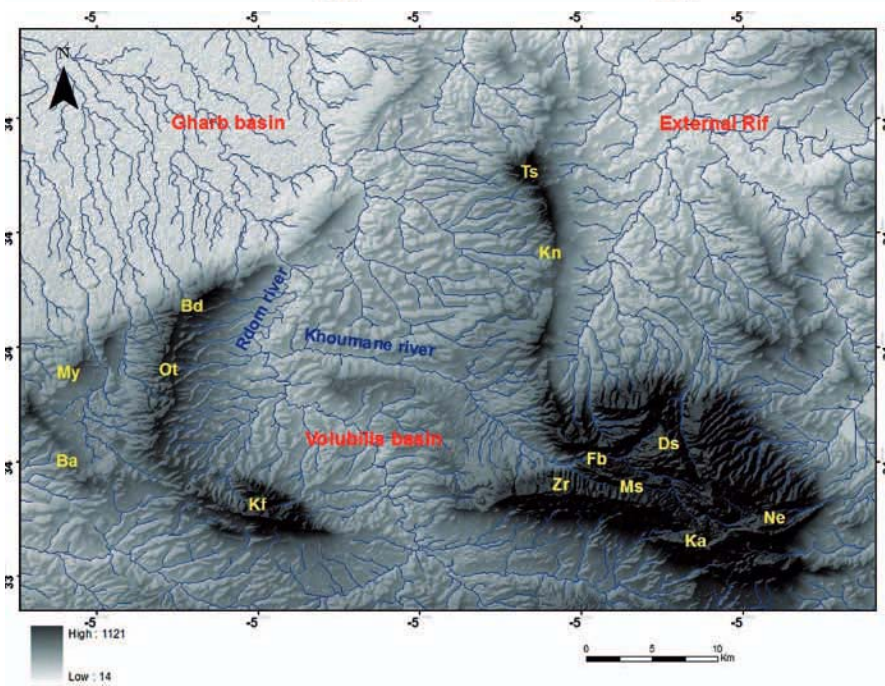


Fig. 2.- Shaded relief image with extracted drainage network of the study area. Fb, Fert el Bir ridge; Zr, Zarhoun ridge; Ds, Dehar en Nsour ridge; Ms, Moussaoua syncline ;Ka, Kannoufa ridge; Ne, Nesrani ridge Kf, Kefs ridge; Ot, Outita ridge; Bd, Bou Draa ridge; TR, Trhatt ridge; TS, Tselfat ridge; Kn, Bou Kennfoud ridge; My, Moulay Yacoub; Ba, Bou Azouf. See color figure in the web.

Fig. 2.-Imagen sombreada del relieve en la cual se ha extraído la red de drenaje del área de estudio. Fb, cresta de Fert el Bir; Zr, cresta de Zarhoun; Ds, cresta de Dehar en Nsour; Ms, sinclinal de Moussaoua; Ka, cresta de Kannoufa; Ne, cresta de Nesrani; Kf, cresta de Kefs, Ot, cresta de Outita; Bd, cresta de Bou Draa; TR, cresta de Trhatt; TS, cresta de Tselfat; Kn, cresta de Bou Kennfoud; My, Moulay Yacoub; Ba, Bou Azouf. Ver figura en color en la web.

features related to erosional–tectonic events (Grohmann *et al.*, 2011). Contours derived from the DEM, as a source of elevation, were incorporated at the location of 2nd and 3rd order streams (Golts and Rosenthal, 1993; Grohmann, 2004). This creates points where streams cross elevation contours, interpolated with Regularized Splines with Tension (Mitasova and Hofierka, 1993; Mitasova and Mitas, 1993; Hofierka *et al.*, 2002).

As a result of this, isobase map can be seen as a smoothed version of the original topographic surface without the influence of the first Strahler order stream erosion. Aligned and elongated isolines (smooth lines that connect points where individual thalwegs are crossed by contours of the same elevation) as well as sharp topographic changes, compression or spreading affecting contours may reflect lithological changes or tectonic dislocations. Approximate faultline area is recognized by isoline inflexions (Grohmann *et al.*, 2011) that usually cannot be inferred from the present-day topography.

Isobase map is a spatial distribution of stream height from which the dynamics of stream Strahler orders (1952) and topographic variations can be studied. Streams of similar orders seem to be related to similar geological events and correspond to similar geological age (Golts and Rosenthal, 1993).

Results

Although important ridges have good morphostructural delimitation, the isobase configuration shows three contrast models (Fig. 3).

High isobase values with closely spaced isolines occur in the eastern arc, especially in Moulay Idriss massif (Zr, Fb and Ds) in which Ds shows the most irregular concentric model of isolines due to the possible recent and /or active tectonic influence.

Medium isobase values distinguished by medium isobase density are observed in the western arc and some morphostructures located in the eastern arc (Ms, Ne, Kn and Ds eastern flank), while the widely spaced isobases with lower values are noticed in Volubilis basin and peripheral areas revealing depressions and an obvious erosional control (Fig. 2).

Most isolines indicate a NW-SE to NNW-SSE direction adapting to the Tortonian NE–SW compressional deformation

(Fig. 3), excluding Ds which shows trends in NNE-SSW and N-S in response to the Pliocene to Quaternary NNW–SSE compression.

From a morphotectonic point of view within the SRR morphostructures, lineaments (Fig. 4) are coherent with geological contact and existing normal faults showing trends in NE-SW, N-S, E-W and NW-SE directions. They have determined the area where overlaps were developed with a propagation involvement of ramp anticline folds (Habibou *et al.*, 2014 a and b; 2016).

Discussion and conclusions

Based on previous works (Golts and Rosenthal, 1993, Raczkowski *et al.*, 1984; Grohmann *et al.*, 2011), spatial distribution of isobase values characterize erosional surfaces related to tectonic-erosional events, mainly the most recent one. Thus it is possible to correlate lithological changes with their erosional properties using isobase lines. In Northern Tunisia, Slama *et al.* (2015) have stressed, within Teboursouk isobases, that rugged morphostructures (hard rocks with a lower erodibility) are associated with high isobases, whereas the lower ones are related to brittle morphostructures (soft rocks with a higher erodibility). As previously analyzed the two SRR arcs include Jurassic limestone with lower erodibility, correlated with high to medium isobases, except of the (Ds) eastern flank and (Ms) represented respectively by Cretaceous and Miocene series (mainly marly and highly erodible) (Fig.1). The Miocene observed in Volubilis basin shows the most widely isolines. Therefore (Ms) and (Ds eastern flank) should be represented by lower values (Figs. 1 and 3). The increase values of isobase and their association with high erodibility rocks may be related to an active halokinesis influence, argued by the presence of gypseous marl into (Ms) and El Hamma thermal source on the western wedges of the deep evaporitic diapir of (Ds).

Previous studies have shown that narrow isobases are related to a decrease thickness, while larger thickness is correlated with widely spaced isobases (Raczkowski *et al.*, 1984). In addition, subsided areas display long distances between isolines (Filosofov, 1960). As mentioned above, Volubilis basin is characterized with wide isolines therefore with thick Miocene series (Figs. 1 and 3), confirmed by the simultaneous infill toward the center of the basin, associated with the development and the propagation of ridges (Roldán *et al.*, 2014). However the closely spaced isoline pattern represented by Moulay Idriss massif is characterized by the most important thickness of Jurassic and Miocene sequences mainly in (Ds) (Faugères, 1978; Haddaoui 2000). This anomalous picture could be explained by the recent tectonic activity whithin Moulay Idriss massif.

The constructed isobase map allows depiction of anomalies. They are used to investigate possible tectonic structures that left recent signatures in the landscape (Grohmann *et al.*, 2011). Major identified lineaments (Fig. 4) trend in NW-SE and NNW-SSE are compatible with the Tortonian NE-SW maximum compression direction that leads the southwestward tectonic wedge escape of SRR.

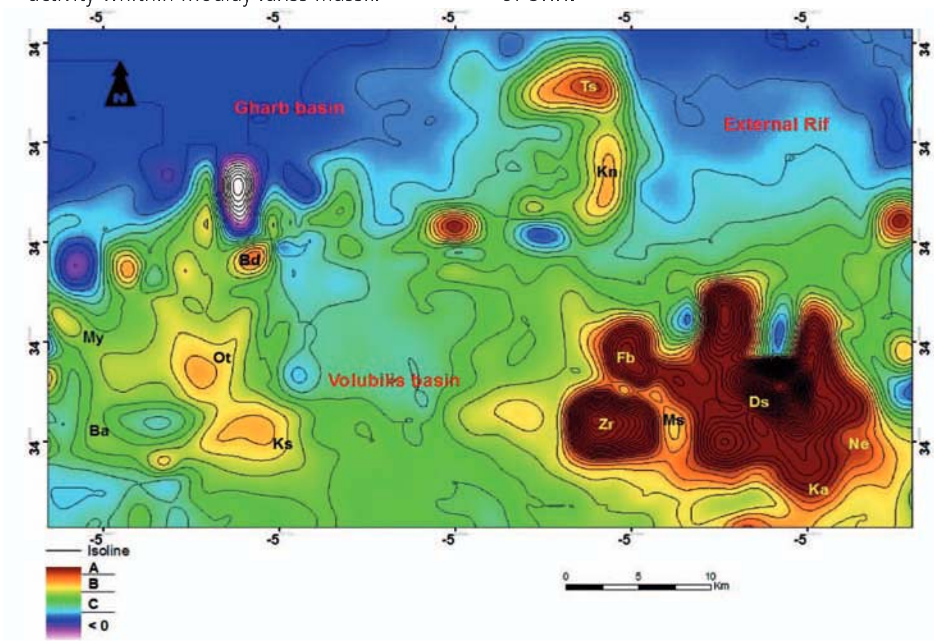


Fig. 3.- Isobase map of 2nd and 3rd order valleys. (A) High, (B) Medium and (C) Low. See color figure in the web.

Fig. 3.- Mapa de isobases de los valles de segundo y tercer orden. (A) alto, (B) medio, (C) bajo. Ver figura en color en la web.

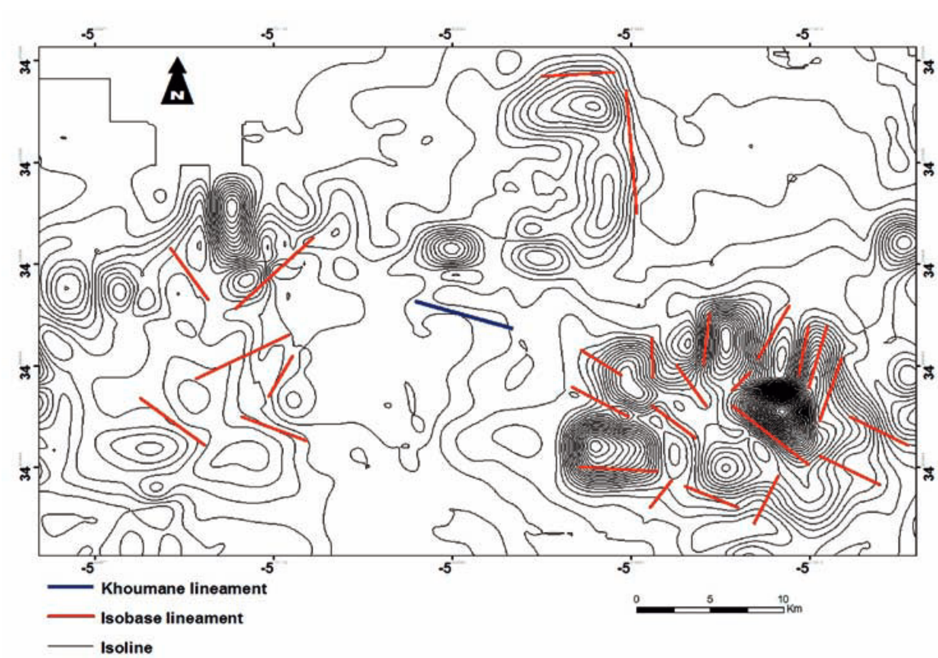


Fig. 4.- Morphotectonic interpretation of contour configuration.

Fig. 4.- Interpretación morfotectónica de la configuración de isolíneas.

It is remarkable that (Ds) display different lineament directions in NW-SE, causing its structure (Haddaoui, 2000), N-S and WNW-ESE to NE-SW conducting, probably, its uplift in agreement with post Miocene compression which varies slightly from N-S to NNW-SSE (Bargach *et al*., 2004).

A NW-SE anomaly which turns to WNW-ESE (Figs. 1, 2 and 4) over Khoumane river without any associated variation in lithology may be originated by a recent WNW-ESE dipping fault.

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References

Bargach, K., Ruano, P., Chabli, A., Galindo-Zaldivar, J., Chalouan, A., Jabaloy, A., Akil, M., Ahmamou, M., Sanz De Galdeano, C. and Benmakhlouf, M. (2004). *Pure and Applied Geophysics* 161, 521-540.

Chalouan, A., Galindo-Zaldivar, J., Akil, M., Marin, C., Chabli, A., Ruano, P., Bargach, K., Sanz de Galdeano, C., Benmakhlouf, M., Ahmamou, M. and Gourari, I. (2006). In: *Tectonics of the Western Mediterranean and North Africa* (G. Moratti and A. Chalouan, Eds.). Geological Society, London, Special Publication 262, 101-118.

Filosofov, V.P. (1960). *Brief Guide to Morphometric Methods in Search of Tectonic Structures*. Saratov University Publishing House, Saratov (in Russian).

Faugères, J.C. (1978). *Les Rides sud rifaines, évolution sédimentaire et structurale d'un bassin atlantico mésogène de la marge africaine*. Thèse Doctorat d'Etat, Université de Bordeaux I,

Golts, S. and Rosenthal, E. (1993). *Geomorphology* 7, 305–315.

Grohmann, C.H. (2004). *Computers & Geosciences* 30, 1055–1067.

Grohmann, C. H., Riccomini, C. and Alves, F.M. (2007). *Computers & Geosciences* 33, 10–19

Grohmann, C. H., Riccomini, C. and Chamani, M. A. C. (2011). *Hydrology and Earth System Sciences* 15, 1493–1504.

Habibou, E. H., Bouya, N., El Ouardi, H. and Mercier, E. (2012). *Mineralia Slovaca* 44, 65- 70.

Habibou, E. H., El Ouardi, H., Habibi, M. and Mercier, E. (2014 a). *Geologia Sudetica* 42, 23- 24.

Habibou, E. H., El Ouardi, H., Habibi M. and Mercier, E. (2014 b). *Geogaceta* 56, 19-22.

Habibou, E. H., El Ouardi, H., Habibi, M. and Eric Mercier, E. (2016). *Arabian Journal of Geosciences* 9/3, 232-245.

Haddaoui, Z. (2000). *Influence de la géométrie d'un bassin Jurassique sur la propagation des chevauchements néogènes: Géodynamique méso-cénozoïque des rides sud-rifaines (Maroc). Modélisation géométrique et numérique*. PhD. thesis, Université Mohammed V, Rabat.

Hofierta, J., Mitasova, H., Parajka, J. and Mitas, L. (2002). *Transactions in GIS* 6, 135-150.

Mitasova, H. and Hofierka, J. (1993). *Mathematical Geology* 25, 655-657.

Mitasova, H. and Mitas, L. (1993). *Mathematical Geology* 25, 641-655.

Lacika, J. (1997). *Geomorphology* 110 (Supplement), S159–S177.

Raczkowski, W., Wójcik, A. and Zuchiewicz, W. (1984). *Tectonophysics* 108, 51–69.

Roldán, F.J., Galindo-Zaldivar, J., Ruano, P., Chalouan, A., Pedrera, A., Ahmamou, M., Constán, A. R., Sanz de Galdeano, C., Benmakhlouf, M., Lopez-Garrido, A.C., Anahnah, F. and González-Castillo, L. (2014). *Journal of Geodynamics* 77, 56-69.

Sani, F., Del Ventisette, C., Montanari, D., Bendkik, A. and Chenakebet, M. (2007). *International Journal of Earth Sciences* 96, 685-706.

Slama, T., Deffontaines, B. and Turki, M. M. (2015). Earth *Science Informatics*, DOI 10.1007/s12145-015-0208-4.

Strahler, A. N. (1952). *Geological Society of America Bulletin*, 63, 1117–1142.