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Topography and drainage system evolution in the ''Volubilis basin'' (South Rifain Ridges, Northern Morocco)

Topografía y evolución de los sistema de drenaje en «cuenca de Volubilis» (Cadenas sud-rifeñas, Marruecos)

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ABSTRACT

The Volubilis piggy -back basin, located at the front of the Rif belt, northern Morocco, is a subsided area, as a continuation of the deformational orogenic ridges, related to the present-day African and Eurasian convergence. For the first time, by morphotectonic studies, we analyzed the topographic evolution and drainage systems response. Our results proved the influence of active tectonics in the drainage network and topography of the Volubilis basin. The young phase is indicated by a less dissected planation surface comparing to the ridges, as well as by the ε-shaped hypsometric curve of the khoumane river. This latter drains the continuation of the basin and the eastern arc, where the tectonic activity is mostly concentrated. Based on swath analysis, the general trend of tilting was characterized and was attributed to the recent tectonic movement combined with folds growth of the ridges.

Key-words: *Volubilis piggy-back basin, topographic evolution, morphotectonics, South Rifian Ridges, Morocco.*

RESUMEN

La cuenca de piggy-back de Volubilis, situada en el frente del Rif es una área deprimida localizada en el frente del cinturón orogénico, formado a su vez en relación con con la convergencia entre Africa y Eurasia. Este estudio morfotectónico novedoso analiza por primera vez la topografía y la respuesta de los sistemas de drenaje a la tectónica. Nuestros resultados demuestran una influencia de la tectónica reciente en la topografía. Los indicios de la fase más reciente están en relación con una superficie de erosión menos disecada en relación con las zonas elevadas, así como con la curva en del perfil del río Khoumane. Este último drena la continuación de la cuenca y arco oriental, donde se concentra la mayor parte de la actividad tectónica. A partir del análisis de perfiles swath se ha caracterizado el patrón general de basculamiento, relacionado con los movimientos tectónicos recientes y levantamiento de cadenas.

Palabras clave: *Cuenca piggy-back de Volubilis, evolución topográfica, morfotectónica, cadenas sud-rifeñas, Marruecos.*

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Introduction

The Volubilis piggy-back basin is located between two curved thrusts that form the South Rifian Ridges, northern Morocco. It has a sub-circular morphology and an approximate extension of 450 km². Since the middle Miocene-early Tortonian, the basin formation has been associated with the activity of these movable arcs, whose southwestward displacement is related to the present-day African-Eurasian convergence (Roldán et al., 2014).

Neotectonic features in the Volubilis basin reveal active subsidence of the basin and presence of active folds surrounding the basin related with deformation in the orogen associated to the present-day convergence between the African and Eurasian plates (Amine and El Ouardi, 2017; Amine et al., 2020 a & b). In this work, we analyze the topography evolution of the Volubilis basin to infer

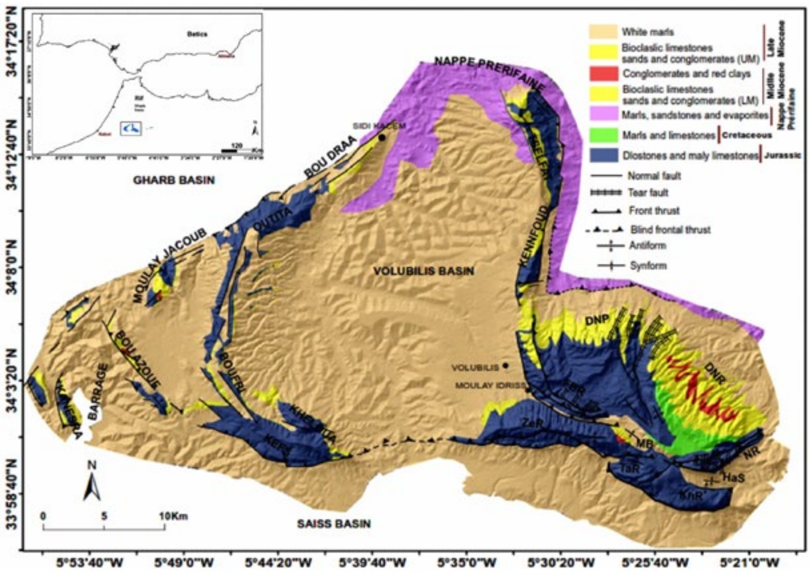

Fig. 1. Geological map of the Volubilis Basin (modified from Roldán et al., 2014 and Faugères, 1978). DNR-Dehar en Nsour; NR-Nesrani; KnR-Kannoufa; TaR-Takerma; Zer-Zerhoun; FBR-Fert El Bir and MB-Moussaoua Basin. Ver la figura en color en la web.

Fig. 1. Mapa geológico de la cuenca de Voluibilis (modificado de Roldán et al., 2014 y Faugères, 1978). DNR-Dehar en Nsour; NR-Nesrani; KnR-Kannoufa; TaR-Takerma; Zer-Zerhoun; FBR-Fert El Bir y MB-Cuenca de Moussaoua. See color figure in the web.

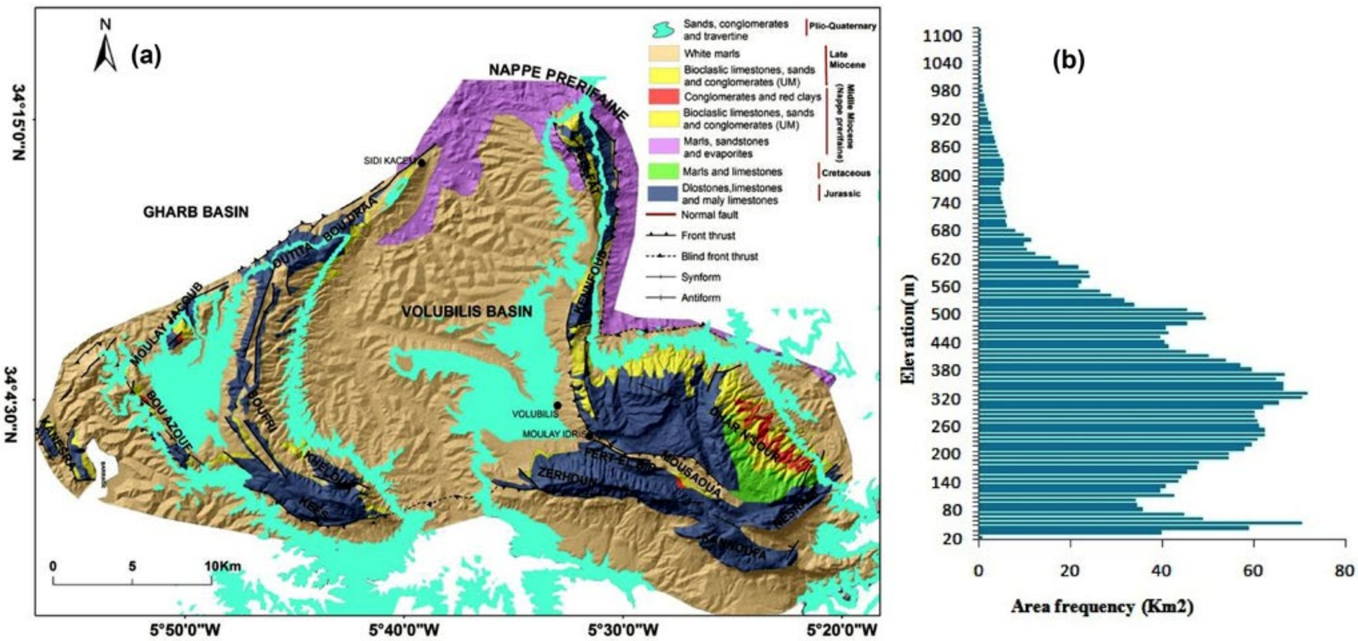

Fig. 2. (a) Automatic extraction of the indissected outcrops (b) Histogram of elevation versus area frequency. Ver la figura en color en la web.

Fig. 2. (a) Extracción automática de afloramientos no incididos. (b) histograma de altitud frente a superficie. See color figure in the web.

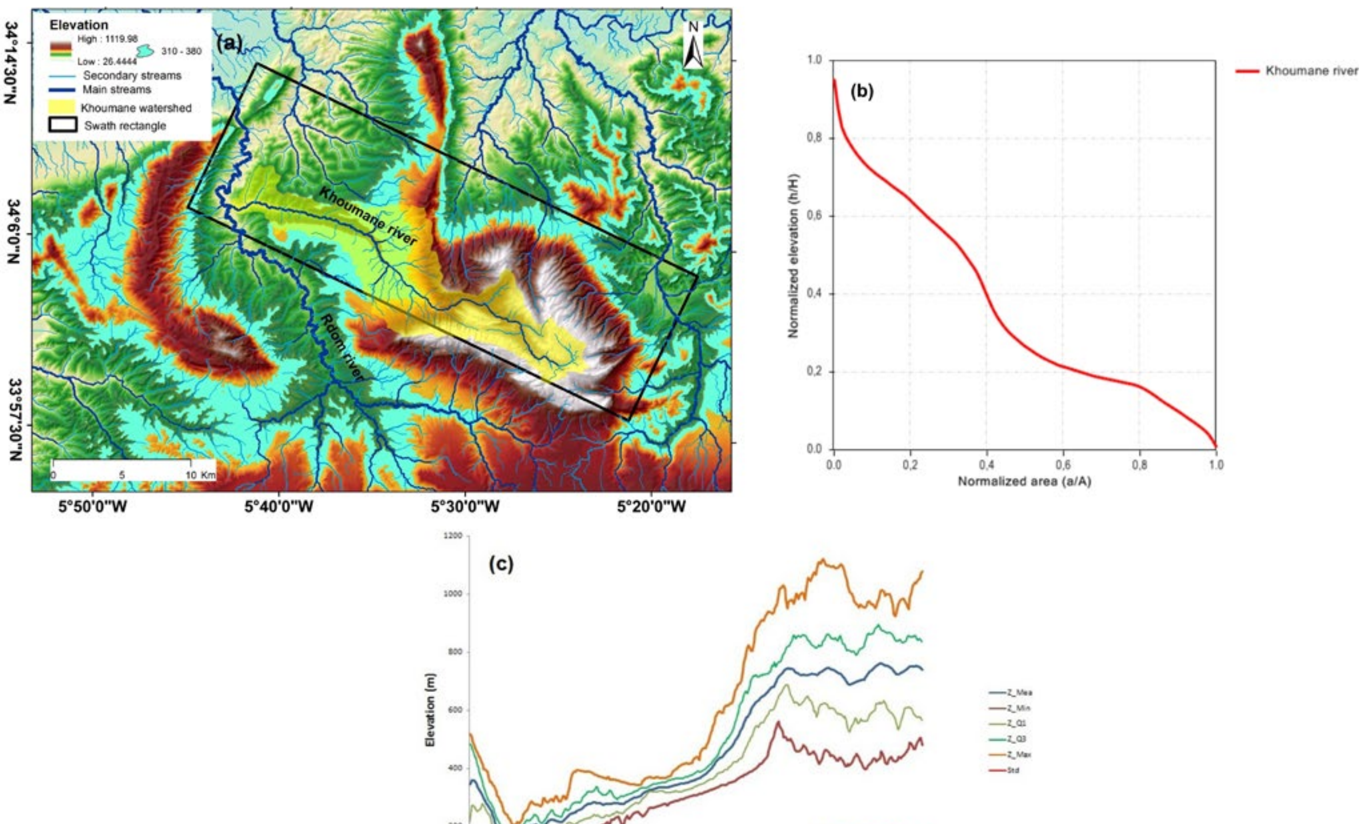

Fig. Fig. 3. The selected elevation of less dissected area and the swath location, (b) hypsometric curve and (c) Swath profiles along the Khumane course. Ver la figura en color en la web.

Fig. 3. La elevación seleccionada del área menos disecada y la ubicación de la franja, (b) curva hipsométrica y (c) Perfiles de franja a lo largo del curso Khoumane. See color figure in the web.

how the recent tectonics influence on the spatial variations of erosion, the tilting of units and the drainage system.

Geological setting

The plates motion produced tilting and even overturning of the thick carbonatic Jurassic series, forming the dominant South Rifian Ridges reliefs.

The stratigraphic pile is composed by: (1) Triassic evaporates, which do not outcrop at surface and facilitate the propagation of the ridge folds, (2) a thick carbonatic Jurassic series, which forms the dominant South Rifian Ridges reliefs, (3) a marly Cretaceous series present only in the Eastern Ridges, and (4) Miocene rocks, unconformably overlying the Mesozoic rocks, which constitute the main sedimentary materials of the basin (Faugères, 1978) (Fig.1).

Methodology

The Digital Elevation Model (30m) was used to extract morphotectonic features such as surface roughness and hypsometry combined with swath profile analysis, into ArcGis 10.3 environment. Results were then verified in the field to identify tectonic features and activity signature.

The hypsometric curve identifies the geomorphic evolution of drainage basins. It represents the relative proportion of the watershed area below a given altitude (Strahler, 1952). In this study, the hypsometric curve of the Khoumane catchment was calculated with the aid of CalHypso extension for ArcGIS tool (Pérez-Peña et al., 2009a).

The surface roughness (SR) or vertical dissection measures how much an area deviates from being totally flat. It is calculated as the ratio between the analyzed topographic surface (TS) and the corresponding flat surface (FS) (Grohmann, 2004; Andreani et al., 2014): SR=TS/FS.

Flat areas refer to SR value close to 1, which increases with incision, as the surface becomes irregular producing highly deformed surface.

Swath profiles show topographic variation along the swath by maximum, mean and minimum elevations across the swath width. The swath was deliminated with the definition of a baseline and the X, Y coordinates. Using the swath calculating macro of Telbisz et al. (2012), the statistical parameters were calculated for categories, also plotting the result on diagrams.

Results and conclusions

Figure 3a shows how the Khoumane river is crossing the eastern anticlines experiencing high uplift rate (Amine et al., 2020a) and the Volubilis basin. The river shows an abnormal ESE deflection, into the basin to gain the Rdom river. This pattern might refer to the differences in the levels of uplift in the area (Fig. 3a).

1 Hypsometry and surface roughness

In an attempt to interpret the warping river course, the hypsometry of all the studied area (Fig. 2b) and the hypsometric curve of the Khoumane were obtained (Fig. 3b).

Edges of harder rocks (310m-380m) are accumulated in a planation surface, into the basin and show less dis-

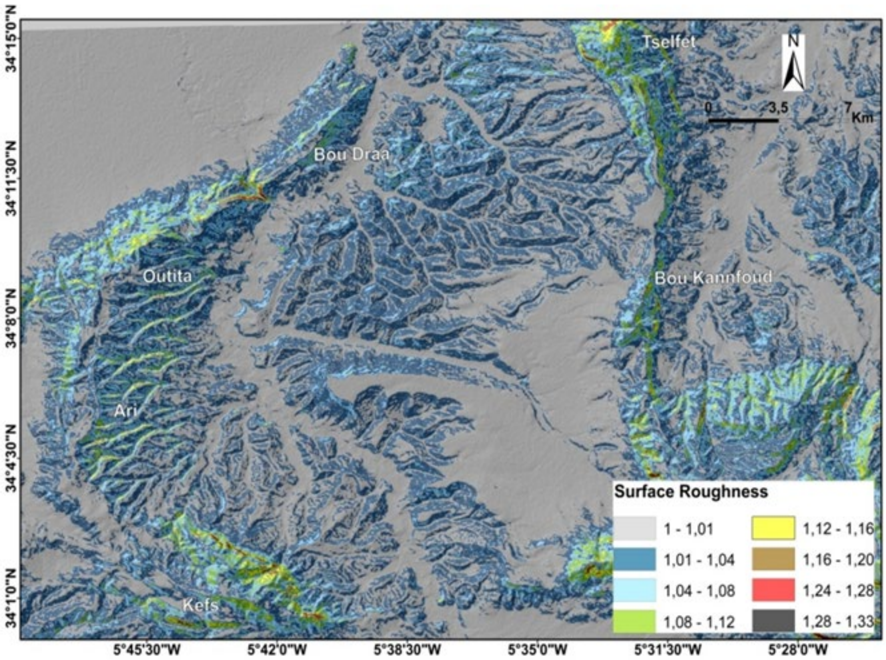

Fig. 4. Surface Roughness of the studied basin. Ver la figura en color en la web.
Fig. 4. Rugosidad superficial de la cuenca estudiada. See color figure in the web.

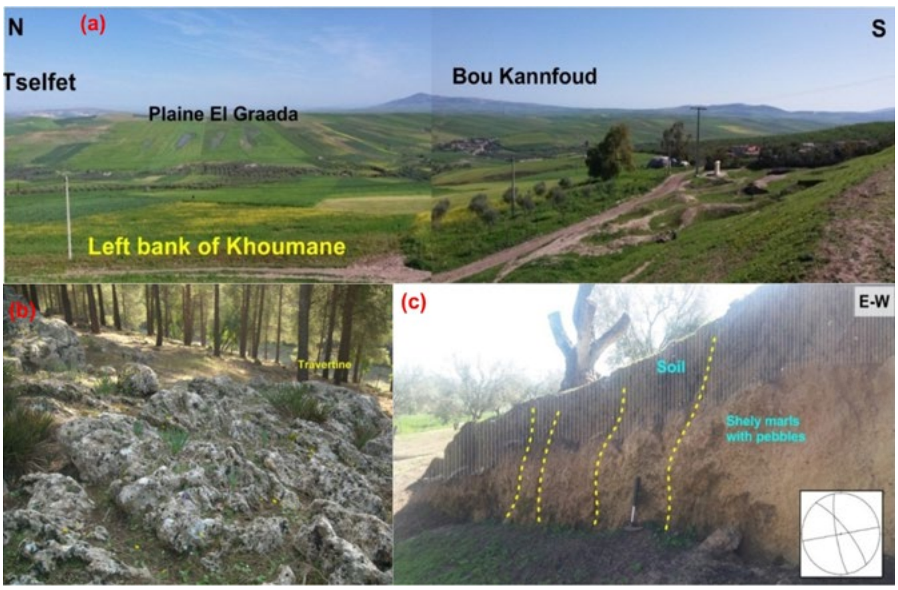

Fig. 5. (a) Panoramic view of the Volubilis baisn, (b) traverine outcrops and (c) active fractures affecting Quaternary soil observed in the eastern side of the basin. Ver la figura en color en la web.
Fig. 5. (a) Vista panorámica de la cuenca de Volubilis. (b) afloramientos de travertino. (c) fracturas recientes afectando a un suelo Cuaternario en el sector oriental de la cuenca. See color figure in the web.

section when compared to the ridges (1070m-520m), where it is more pronounced (Fig. 2b). This flat area is well highlighted by lower values of surface roughness (SR =1) (Fig. 4). The rugged outcrops correspond to Plio-Quaternary detrital deposits (conglomerates and travertines) (Figs. 2a; 5b).

They are mostly accumulated in the southeastern side of the basin (Figs. 5a), rise from the eastern folds towards the centre, and then warped (Fig. 2a).

This movement correlates with the deflection of the Khoumane river (Fig. 3a). The corresponding complex-shaped hypsometric curve (Fig.3b) indicates two young phases in the Fert El Bir fold (Fig.1) (Amine et al., 2020a) and along the basin planation surface, which is argued by active fractures affecting Quaternary soil with Plio-Villa-franchian continental conglomerates (Fig.5c) that we interpret to be associated with the folds of the western and eastern arcs of the South Rifian Ridges. Their reactivation under Pliocene shortening is still active in response to the Africa-Eurasia convergence (Chalouan et al., 2006; Amine et al., 2020a).

2 Swath profiles along the Khoumane river.

Swath profiles show tilting of these sediments coinciding with river warping to reach a recent course (maximum elevation = 400 m in Figure. 3c). The presence of a young phase of rugged sediments over highly dissected marls might be explained by a cuesta or by the Khoumane fault scarp (Amine & El ouardi., 2017).

The structural evolution of the South Rifian Ridges show active structures accommodating the Southwestern motion of the Rif belt with respect of stable Nubia (Amine et al., 2020a) and are responsible for the deformation through proximal basin development. It provides an explanation of drainage network evolution, which was useful for the interpretation of the Volubilis topography development. The growth of folds controlled the drainage and tilting of plio-Quaternary deposits. The latter are remnants of fluvial sediments in the southern part of the basin and form a planation surface with a cuesta morphology, instead of a plain (El Graada plain (Fig.5a) that needs to be studied in detail in future works.

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