Fractured rocks influence on hydrological flow in of the Agourai plateau, Middle Atlas, Morocco: Inferences from Isobase lineaments and field data

Influencia de las rocas fracturadas en el flujo hidrológico en la meseta de Agoura, Atlas Medio, Marruecos: Inferencias a partir de lineamientos de Isobases y datos de campo

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ABSTRACT

This study provides new data of hydrological flow direction in the Agourai plain, Tabular Middle Atlas, north central Morocco. Given its major economic interest in term of agricultural production, the analysis of fracture networks remain essential for a good management of water resources. Mapping fractures network, using isobase maps combined with field data reveal three groups of fractures oriented N-S, NE-SW and NW-SE. the latter was poorly described and lies with the setting of three main springs in the area. Fractures analysis in the Bouchermou spring, confirm the predominance of NW direction, which control of the water flow in this area.

Key-words: *Isobase lineaments, Water circulation, Agourai plateau, Tabular Middle Atlas, Morocco.*

RESUMEN

Este estudio proporciona nuevos datos de la dirección del flujo hidrológico en la llanura de Agoura, Atlas Medio Tabular, Marruecos central norte. Dado su gran interés económico en términos de producción agrícola, el análisis de las redes de fracturación sigue siendo esencial para una buena gestión de los recursos hídricos. El mapeo de la red de fracturas, utilizando mapas de isobases combinados con datos de campo, revela tres grupos de fracturas orientadas N-S, NE-SW y NW-SE. este último fue mal descrito y se encuentra con el establecimiento de tres manantiales principales en la zona. Los análisis de fracturas en el manantial de Bouchermou, confirman el predominio de la dirección NOROESTE, que controla el flujo de agua en esta zona.

Palabras clave: *Lineamientos Isobase, Circulación del agua, Meseta de Agoura, Atlas Medio Tabular, Marruecos.*

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Introduction

Fractured reservoirs are becoming more important in the exploration of groundwater and geothermal fluids. Understanding circulations require characterizing fracture networks affecting a rock reservoir. With the increase of water needs and the climate changes the management of water resources is one of the major environmental issues in Morocco.

The highly fractured and karstic landscape of the Agourai plateau (El Ouardi *et al*., 2018) belongs to the tabular Middle Atlas, between the Rif and the folded Middle Atlas, in north-central Morocco (Fig. 1). Fractures favor the water flows through a series of Springs of emergence and discharge, with fairly large flows (Aïn Maarouf, Aïn Boujaoui, Aïn Bouchermou). However the water pathway and the complex fractures network organization are poorly constrained.

We focus on the direction of hydrological flow by mapping fractures network, using isobase maps combined with field data to improve the knowledge of the hydrogeological behavior of fractures in the Bouchermou spring area.

Geological setting

The Agourai plateau is located at the NW side of the Folded Middle Atlas (Fig. 2). The plateau is drained by two rivers (Oued El Kell and Oued Rdom). The main lithologies in the área Liassic limestone and dolostone . Gorges are the main fluviokarst forms, typically developed in semi-aride climate conditions. They are slightly deformed and are limited only to the Upper Triassic-Lower Jurassic rocks, corresponding to red silty clay intercalated by basalt. They are structured in drag folds occurring in Jurassic limestone, especially near NE-SW oriented major faults (Fig.1). Fractures affecting the Liassic limestone have the same orientation, defining many blocks in the Agourai Plateau, which shows sometimes half-grabens, containing continental Mio-Plio-Quaternary sedimentation (Bouya, 2014).

Methodology

The isobase maps analysis (Filosofov, 1960; Amine and El Ouardi 2017) consists of highlighting fractures and lineaments

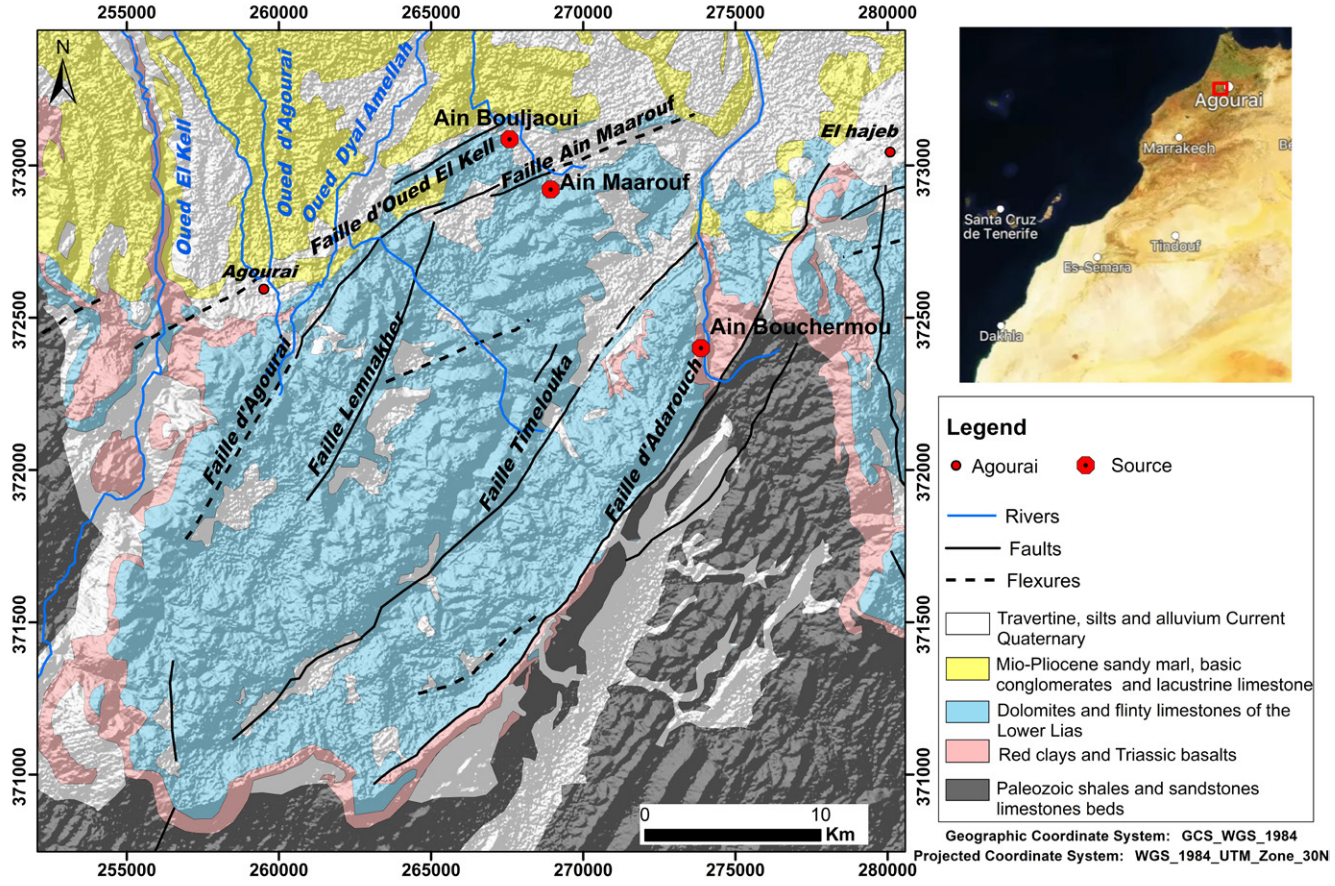

Fig. 1. Simplified geological map of the Agourai plateau. See color figure in the web.
Fig. 1. Mapa geológico simplificado de la meseta de Agoura. Ver figura en color en la web.

and their orientation in homogeneous lithology. We attributed the height of the contour lines to the hydrographic network, after its extraction using the D8 method, from the digital terrain model (DEMs) (Fig.2), via the ArcGis 10.3 software. Firstly, we carried out the interpolation to obtain the isobase surfaces which allow us to obtain isoline curves (isolines). Then, from the second and third order isolines, we drew fractures in comparison with the structural and lithological map of the region. Their determination is based on the deformation of these curves due to a tectonic disturbance (Grohmann *et al*., 2011).

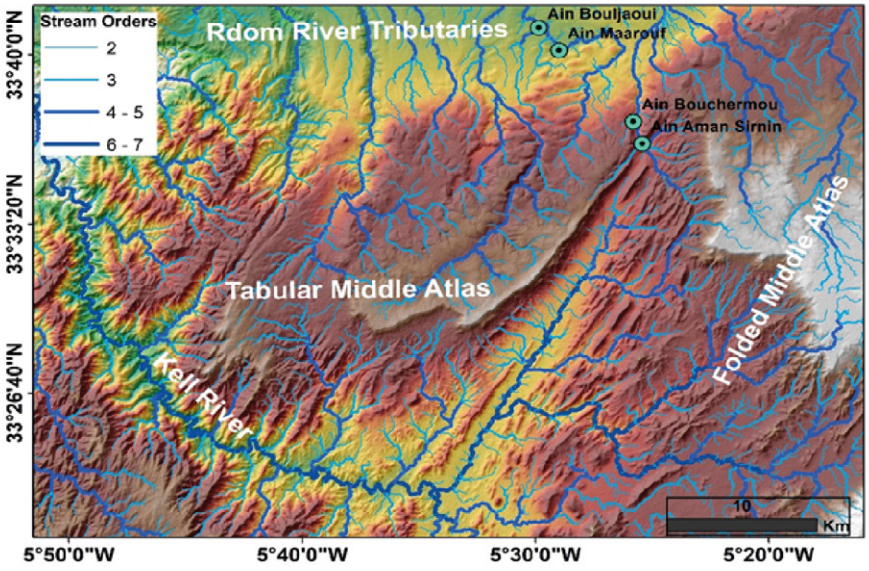

Fig. 2. DEM of the Agourai plateau showing the main drainage network in the area. The green circles are the location of the sources. See color figure in the web.
Fig. 2.- DEM de la meseta de Agoura que muestra la principal red de drenaje de la zona. Los círculos verdes localizan la situación de las fuentes. Ver figura en color en la web.

Results and conclusions

Isobase maps

Isobase lineaments show three main directions (Fig. 3). The dominant and oldest are NE-SW oriented fractures and are interpreted to be inherited from the Hercynian basement and reactivated during the Triassic-Liassic times controlling the Atlas rifting. Their following reactivation during Miocene and Quaternary times has also been previously mentioned by several authors (Charrière, 1990; Hinaje, 2004; Bouya *et al*., 2014).

The NW-SE oriented lineaments coincide with the alignment of three spring sources (Aïn Maarouf, Aïn Boujaoui and Aïn Bouchermou) and would be linked to a recent extensive tectonic phase attributed to the upper Tortonian – Messinian (Hinaje, 2004; El Fartati *et al*., 2023) (Fig. 3). These fractures often correspond to

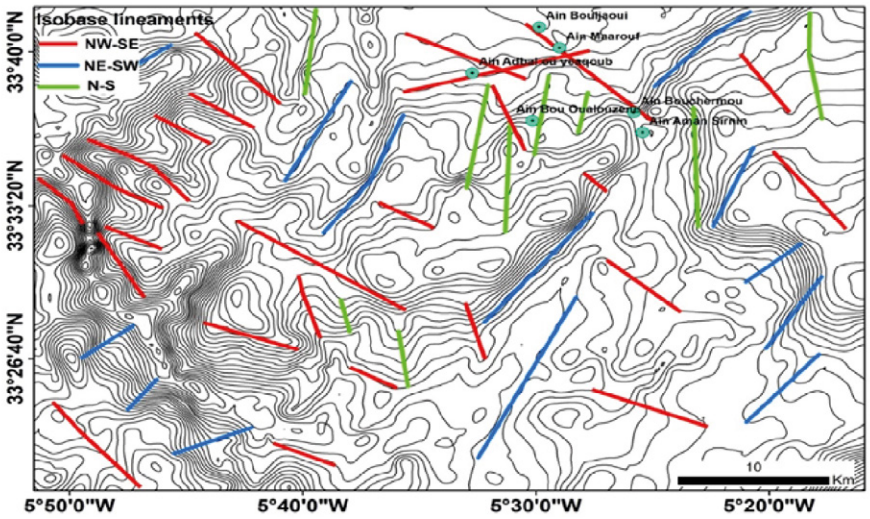

Fig. 3. Isoline map of the the Agourai plateau and main isoline lineaments. See color figure in the web.

Fig. 3.- Mapa isolíneo de la meseta de Agoura y principales lineamientos isolíneas. Ver figura en color en la web.

normal faults serving as water drains and along which groundwater flows from the Agourai plateau towards the Saiss basin, and thus allowing the supply of the aquifer. They also follow underground karst (Fig. 4D, E) alignments (El Ouardi *et al*., 2018).

Field analysis in the Ain Bouchermou

The Ain Bouchermou spring is located exactly in the stratigraphic contact zone between the upper red clays of the Triassic and the dolomitic limestones of the Liassic. This source is located on the extension of a small fractured thalweg-oriented NE-SW. The fracturing analysis in 4 microtectonic station show 3 families of fractures: NW-SE, NE-SW and N-S (Fig. 4A).

The Liassic carbonatic formation shows a brecciated (Fig. 4C) appearance and a roughness on the surface characteristic of karst landscapes. This brecciation can be of two origins: i) Frequent activity in high friction fracture zones; ii) synsedimentary origin linked to environmental. Certain zones are brecciated and are aligned along major fractures affecting the carbonate formations (Fig. 4C).

Bou-chermou source area is located in the continuity of the NW-SE oriented thalweg (Fig. 6), which is crossed by a major fault in the same direction and which would be the main draining fracture in the site.

These fractures are all connected and therefore play an important role in the circulation and water supply, which can explain the significant flow of this resurgence. Results can be explained by the proposed 3D model (Fig. 6) making it possible to link the geology of the Bouchermou sector and the analyzed fractures in the Liassic limestones surroundings the spring in the Agourai plateau.

Fig. 4. (A) and (B) Faults and several diaclases and joints families in the Jurassic outcrops of Agourai plateau. (C) Brecciated and ruiniform appearance of the liasic limestones in Bouchermou. (D) and (E) Karstification phenomenon in the liasic carbonate rocks around the source of Bouchermou.

Fig. 4.- (A) y (B) Fallas y varias familias de fracturas en los afloramientos del Jurásico de la meseta de Agourai. (C) Apariencia brechificada y ruiniforme de las calizas liásicas en Bouchermou. (D) y (E) Fenómeno de karstificación en las rocas carbonatadas liásicas alrededor de la fuente de Bouchermou.

Author Contributions

Mouljebouj, S: Formal analysis and writing, Amine, A: Analysis supervision and révision, EL-Ouardi, H: geological field work and analysis, Haddane, R, Kouia,T and Ouargaga,

A : methodology analysis.

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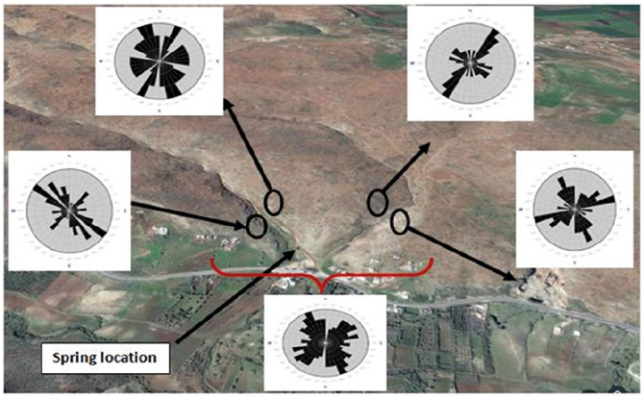

Fig. 5. Google earth image of the analysed fractures locations in the Agourai plateau and representative rosettes.
Fig. 5.- Imagen de Google Earth de las ubicaciones de fracturas analizadas en la meseta de Agoura.

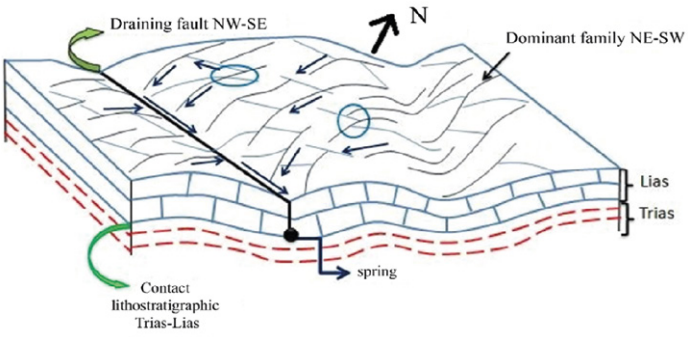

Fig. 6. Plan view of orientation and connectivity of fractures controlling the overall direction of flow, in Ain Bouchermou spring area.
Fig. 6.- Vista en planta de orientación y conectividad de fracturas que controlan la dirección general del flujo, en el área de manantiales en Bouchermou

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