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Combined use of remote sensing and GIS in the extraction of structural lineaments in the Cretaceous basin of Errachidia-Boudnib (south-east Morocco), hydrological implication

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Abstract: ***Linear analysis is an interesting approach for hydrogeological mapping in the Cretaceous basin of Errachidia-Boudnib, this analysis was carried out by interpreting the ETM + images acquired by the Landsat 7 satellite. In our study, features of geological interest detected during the interpretation process were digitized using GIS software. Before extraction begins, various processes are applied to the satellite image. Lineament synthesis maps have been produced by combining four methods; filtering techniques that allow mapping a larger number of lineaments, color compositions, ratio bands and main component analysis (PCA) and lineamenst density, so the highest densities obtained are oriented (NE-SW to ESE-WNW). In the study area, the knowledge of structural lineaments is very interesting for identifying zones favourable to groundwater circulation. A spatial statistical analysis of the lineaments was performed to detect their frequency and main direction.***

Keywords: Cretaceous basin of Errachidia-Boudnib, Landsat 7 ETM +, GIS software, Lineament, Groundwater circulation.

I. INTRODUCTION

The mapping of structural lineaments (fractures) is an essential component in hydrological research. Lineaments are linear or curvilinear and are associated with geomorphological characteristics and/or a variety of structures [11, 7] such as faults, fractures, folds and lithological contacts. They lead to topographic depressions, the water system and vegetation anomalies. Mapping by conventional methods monitoring defects in the field does not identify all existing lineaments. The experience has demonstrated the value of remote sensing data for linear mapping and identification [12] of geological structures. Also, the synoptic view provided by the satellite images, with a high spatial resolution, gives an easier linear analysis. However, not all lineaments are automatically geological structures [11]. Indeed, the roads, waterways are also considered as lineaments. The aim of this study is to map the Structural Lineaments in the Cretaceous basin using filtering techniques applied to different processed images.

The resulting map will be used for geodynamic analysis of the area and be a help to hydrological exploration.

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II. MATERIALS AND METHODS

A. Area Descriptions

The Cretaceous basin of Erachidia-Boudnib is part of the structural unit of the South Atlasic Trench. It is limited to the North by the South Atlasic accident and to the South by the outcroppings of the Anti-Atlas and the Hamada of Guir. This Cretaceous basin extends over an area of 13 000 km^2. The average altitude is between 1000 and 1100 meters and is accentuated to the west towards the Imider sill [4]. Geographically to the north of the basin is a high mountainous area (1300 m maximum altitude). It is crossed by the South Atlasic accident and shows anticlines which separate the Errachidia-Boudnib basin from the High Atlas, a central zone with sedimentary filling, mainly Cretaceous of tabular shape or slightly inclined towards the North and often surmounted by quaternary regs. This domain is divided into three sectors; in the West, the Ziz and Rheris plains and plateaus can be distinguished; in the center a gutter between the High Atlas and the Guir valley, in the East extends the Guir-Bouanane plain; in the southern edge of the basin, the sedimentary series is less thick, it is discordant on the Paleozoic formations. Altitudes are relatively low compared to northern outcrops (Fig 1).

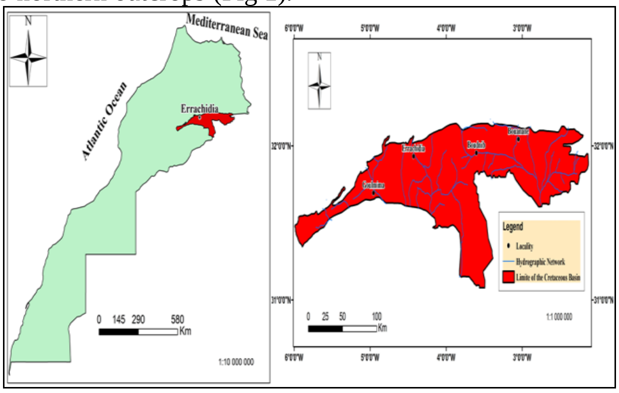

Fig.1: Geographical situation of the Cretaceous basin of Errachidia-Boudnib in relation to Morocco.

B. Methodology

In this work, the images used are Landsat 7 ETM+ (Enhanced Thematic Mapper) satellite images. The diversity of spectral channels (8 spectral bands) offered by this satellite provides the interpreter with a wealth of spectral information, thus facilitating the identification of territorial objects for different applications (see table below).

For geological studies, this type of image has the great advantage of bringing out the structures and discriminating between lithology because of the low solar angle, the absence of spatial details and the regional coverage (185 km x 185 km). The approach adopted for the extraction of geological information useful for this study can be divided into two

levels: Preprocessing and enhancement of visual quality to improve the interoperability of images, extraction of geological information using appropriate techniques (filtering and mathematical morphology).

Table 1: Spectral characteristics of Landsat 7 ETM+ bands

Band	Spectral Band	Resolution
1	0.45 – 0.515 µm (blue)	30 m x 30 m
2	0.525 – 0.605 (green)	30 m x 30 m
3	0.63 – 0.69 µm (red)	30 m x 30 m
4	0.75 – 0.90 µm (near IR)	30 m x 30 m
5	1.55 – 1.75 µm (SWIR)	30 m x 30 m
6	10.4 – 12.5 µm (TIR)	60 m x 60 m
7	2.09 – 2.35 µm (SWIR)	30 m x 30 m
PAN	0.50 – 0.90 µm	15 m x 15 m

III. RESULTS AND DISCUSSION

A. Preprocessing and image quality enhancement

The objective of this stage of the treatment is to eliminate deformations due to conditions and improve the interoperability of these images. With respect to the deformations related to the acquisition geometry, we used the maps topographic to 1/100,000 covering the entire area as a reference topographic for the geometric correction of satellite images used allowing thus satisfactory localization accuracy. Then, the multi-spectral bands of 30 m resolution were resampled to 15 m after fusion with the band 15 m panchromatic. This merger makes it possible to bring more detail at the level of the spatial resolution by combining the spectral richness of multispectral bands and the spatial fineness of the panchromatic band of this type of images. In order to better discriminate between geological formations, other channels have been generated by ratios between specific spectral bands, these ratios are: Mineral clay which corresponds to the ratio (channel 5 / channel 7); Mineral ferrous which corresponds to the ratio (channel 5 / channel 4). These ratios have demonstrated their usefulness in geological studies, particularly by their ability to enhance the difference in rock reflectance. They also minimize signal disturbances caused by the passage of waves through the atmosphere. The final image used is therefore a combination of the 7 nominal bands and the two generated ratios (fig 2).

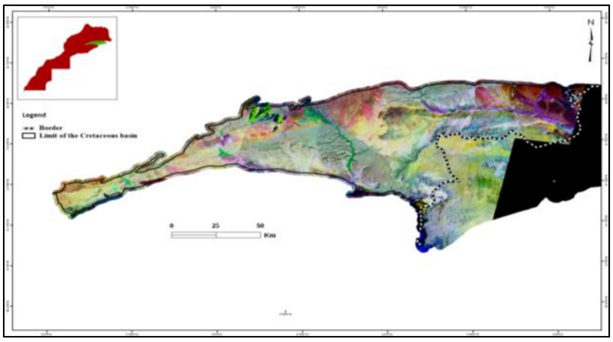

Fig.2: Landsat image mosaic covering the study area

B. Filtering and mathematical morphology technique

In order to condense spectral information and make it easily exploited by a principal component analysis (PCA) had been performed on the operator [5]. This has enhanced multispectral image quality by eliminating redundant data contained in the different channels. We calculated the first three main components from 7 spectral bands of the input image. Indeed, the structures in the ACP1 image are more visible than in the multispectral image [8, 10].

In order to reduce subjectivity in the process of extracting lineaments from satellite images, we have adopted a semi-automatic approach based on the automatic analysis techniques and our knowledge of structures. This approach consists in the enhancement of the geological (structural) features of the image used (ACP1). This has been done through the use, sometimes combined, of spatial filters linear and non-linear (directional gradients, Laplacian filters, Sobel operators and Prewitt) [13]. Filtering results are systematically improved by techniques such as of mathematical morphology in order to better highlight areas (pixels) marking high spatial frequency passages corresponding to potential lineaments. Lineament mapping is performed directly on linear structures identified on the various binary images by using as support a final image with 9 channels in different colored compositions. It is also important to note that a Digital Terrain Model is used to better understand the geomorphology of some of these structures [1, 3].

C. Main structural features

The broad tectonic features of the region reflect that the study area can be divided into two distinct zones. The first zone, which is located at the border of the High Atlas and the Cretaceous basin, is strongly structured. The second zone, which corresponds to the Cretaceous basin is slightly deformed. This distinction is also materialized by the difference in terms of abundance of faults (fig 3).

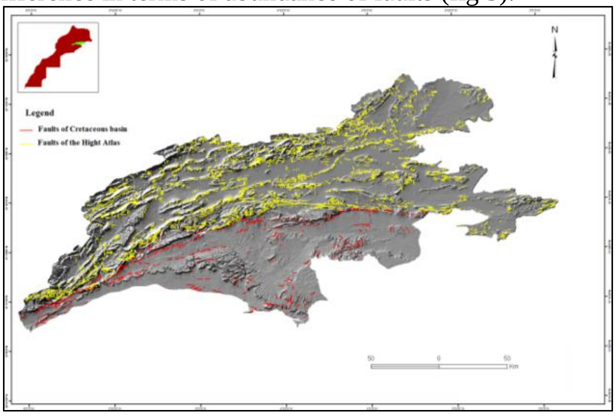

Fig.3: Global view of the difference in deformation (faults) in the High Atlas and the Cretaceous basin

Indeed, in the direction of the anti-atlasic foreland, we suddenly pass to a domain structurally calmer and where the atlasic tectonics is relayed by a deformation flexible. This is underlined by the existence of a vast synclinal depression of direction ENE-WSW which occupies the center of the Cretaceous basin and which continues in the South by a large tabular or slightly sloping structure, especially to highlight large pleated structures (Fig 4).

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This succession of anticlinals and synclinals results in the existence of several potential areas of convergence and accumulation of groundwater.
Especially if the power of these formations within
depressions is important. Given the lack of additional information on the actual dimension of these basins, particularly the absence of sub-surface data, had been sketched out in detail. to bring out the geometry of these structures which probably correspond to a surface manifestation of deep faults (Fig 5). These basins, with an atlasic orientation, present a strong potential for water convergence to the axial zones (Fig 6).
This aquifer system is affected by multiple faults that have certainly important hydrogeological implications. These faults constitute drains that facilitate the flow of groundwater on the one hand between the High Atlas and the Cretaceous basin in particular in the areas not blocked by Triassic clays, and on the other hand between the layers of the same aquifer and between different aquifers (fig 7).

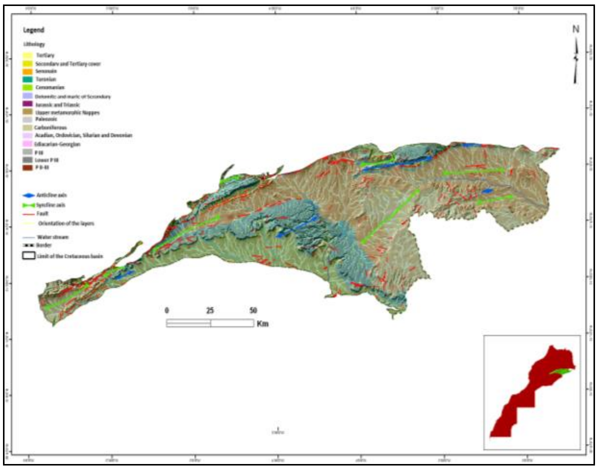

Fig.4: Map of the geological structures of the study area based on satellite images

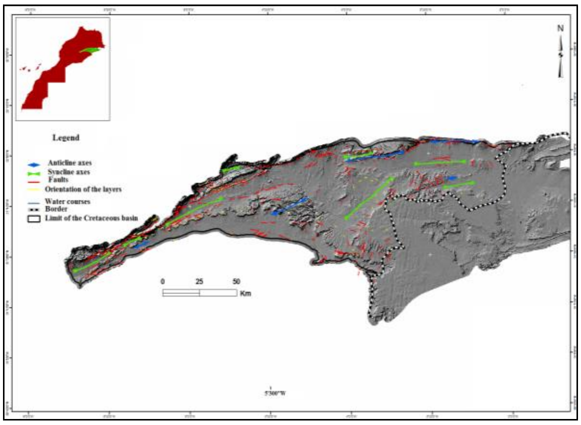

Fig.5: Geomorphology of the geological structures in the Cretaceous basin

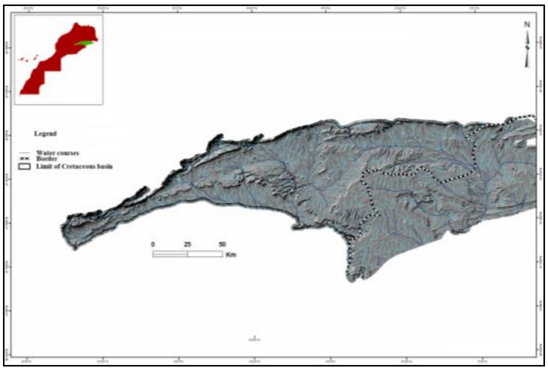

Fig.6: Map of the hydrographic network in the study area

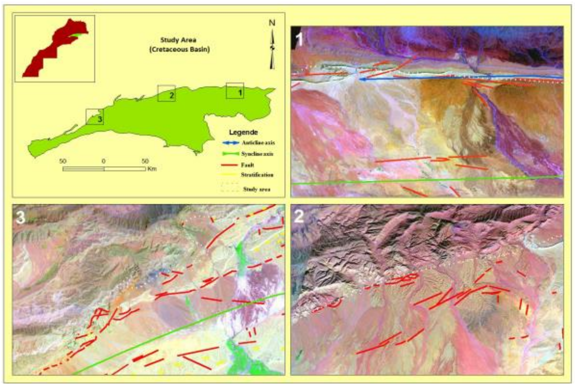

Fig.7: Example of faults affecting the northern part of the study area

D. Statistical and directional analysis

Statistical analysis of lineaments allows a better understanding of the network geometry of lineaments and the identification of the main directions at the regional level [9, 6]. We used the method of directional rosettes which are proportional to the cumulative length of the lineaments by classes of 10 degrees. At the scale of the study area, the rosette diagram shows that the directions are NE-SW to ESE-WNW oriented according to atlas directions of this part of the Cretaceous basin. The passage zone from the High Atlas to the basin Cretaceous presents a clear evolution in the change of the direction of the faults going from NE to ESE-WNW (Fig 8). Indeed, in the Rheris basin, the dominant faults are NE-SW oriented. In the Ziz basin, the rosettes show that the dominant faults are those with an overall ENE-WSW (atlasic) direction. In the Guir basin, the clearly dominant faults are ESE-WNW oriented. This goes hand in hand with the changes in orientation that the High Atlas chain is undergoing by from NE-SW in the west to E-W in the east. It is important to note that N-S directions are relatively more abundant in the northern part of the study area in contact between the High Atlas and the Cretaceous basin. These faults certainly present a strong hydrogeological potential for this zone.

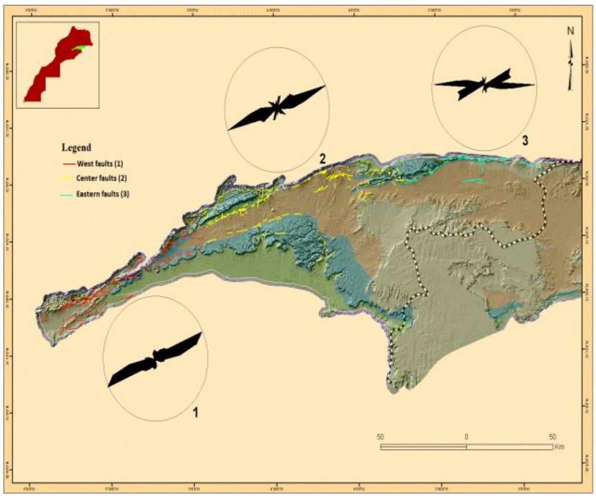

Fig.8. Directional rosettes of the faults in the northern part of the study area

E. Lineament density analysis

In order to better understand the spatial distribution of the faults extracted from the images a density map is generated [2].

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This map shows the magnitude of this unit area and allows a better analysis of the connectivity of the elements. Structuring in this zone: frequency, spacing and crossings between faults.

Thus, a 5 km^2 mesh is chosen for the calculation of this density. This map, represented between

three classes (low; medium and high) shows that the network density faults on a regional scale perfectly matches the organization of the structures major geological formations (NE-SW to ESE-WNW). The cross-referencing this density maps with geological maps shows that the strong densities underline the contact zone between the High Atlas and the Cretaceous Basin (fig 9).

The hearts of the synclinals materialized by more recent deposits which leaves assume that linear structures may be masked by these formations and would be difficult to put into evidence from satellite imagery alone. In order to contribute to the identification of new indicators on possible nutrition of the Errachidia-Boudnib basin from Jurassic aquifers, we considered useful to investigate the links between atlasic structures and N-S faults that are assumed to exist have an

important role in groundwater flow to the basin. Our method is based on the identification of crossings (junctions) between this type of fault and those favouring longitudinal drainage. Analysis of the density of these junctions shows that in the contact zone (High Atlas-Basin), certain zones present a strong potential than other

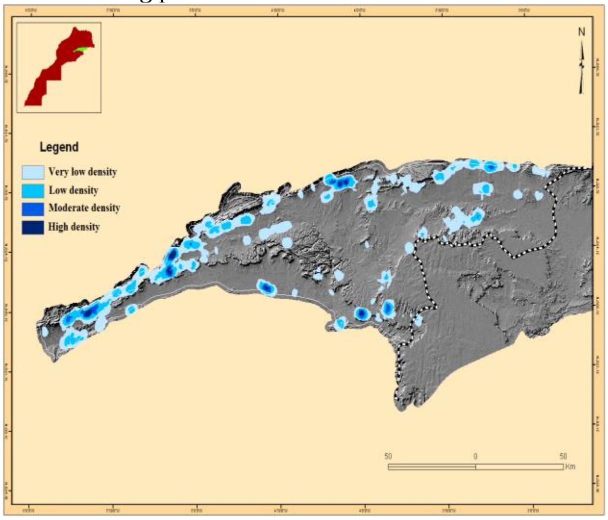

Fig.9: Map of the fault density in the study area

IV. CONCLUSION

The use of satellite images has enabled us to complete our geological knowledge with field visits to the atlas structures (fold axes and faults).These structures are in conformity with the geodynamic context previously known on the atlasic chain. Overall, the directions are NE-SW at the western end of the study area, N 70 in the central part and E-W to the east. The major structural features of the region were also confirmed by analysis of their density distribution. The superimposition of the fracture network on existing cartographic documents shows that fractures are relatively more abundant on anticlinal wrinkles (heart of Jurassic anticlinals) than in the bottoms of synclinals (predominantly Cretaceous). Moreover, analysis of the magnitude of the lineaments shows that the high densities corroborate with the lengthening of the main atlas faults, particularly at the boundary between the High Atlas and the Cretaceous basin. In this contact zone the densities are relatively higher in the western part. As regards the hypothesis of a possible recharge of the basin of Errachidia- Boudnib from the Jurassic aquifers of the High Atlas, and knowing that the triasic faulted anticlinals are zones favourable to longitudinal drainage, we based ourselves on the density of the nodes between faults (atlasic and N-S) to search for indicators favouring this recharge. This analysis allowed us the following conclusions:
- The zone located NE of Tazougeurt presents a high density of crossings between faults, which would favour communication between aquifers upstream and downstream;
- The SW end of the study area and the Tahemdount area also have high node densities. The great drainage potential towards the basin is to be sought in the possible fault communications, all the more so as the Jurassic formations meet directly on those of the basin without the contacts being blocked by the ascent of the Triassic terrains.

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