CONTRIBUTION OF SPACE REMOTE SENSING AND NEW GIS TOOLS FOR MAPPING GEOLOGICAL STRUCTURES IN THE MEKKAM REGION OF NORTHEAST MOROCCO

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ABSTRACT:
The Paleozoic buttonhole of Mekkam is located in the SE of the town of Taourirt, North Eastern Morocco. The geological framework of this buttonhole is characterized by the presence of terrains of different ages and lithologies. The oldest terrain forms a monotonous schistose bedrock with a flyshoid character of Devonian age unconformably underlain by volcanic and sedimentary formations of probable Upper Visean age, which have not been the subject of detailed structural studies. The objective of this work is to create a structural map based on satellite image processing techniques from space remote sensing. Our methodology uses remote sensing data composed of LANDSAT 8 Oli satellite imagery, taken under favorable weather conditions. Principal Component Analysis (PCA) and directional filtering were applied specifically. Thus, a map was produced using ArcGIS and Rockworks16 software. The application of these techniques allowed us to highlight the presence of lineaments with four main directions: N-S, NE-SW, E-W and NW-SE with a dominance of NW-SE and E-W directions. The interpretation of the obtained map was verified by field missions (measurements of faults, veins, and dykes). The NW-SE and E-W directions correspond in the field to mineralized quartz dykes and veins. The highlighted lineaments are concentrated in the Devonian-aged terrains where the geological material is represented by schists and volcanic rocks. The terrain is characterized by steep and rugged relief, sometimes difficult to access, such as the Sidi Lahcen massifs, the present study will initially help guide mining exploration by determining the geological lineaments in the region Thus, it confirms that remote sensing is an effective and less costly means of structural mapping in arid and semi-arid areas.

Key-words*: Remote Sensing, GIS, Rockworks16, Mapping, Lineaments, Mineralization, Mekkam, Morocco*

1. INTRODUCTION

In remote sensing, lineaments are any straight or curvilinear structure, some of which may have geological significance (fault, dyke, etc.) (Hobbs, 1904; O'Leary et al. 1976). Their study is of crucial importance for the analysis and understanding of the regional structural context. Today, their extraction has become possible thanks to digital processing of satellite images. As their tensor translates into a binary black and white representation on the satellite image, it is easy to extract the lineaments by noise removal. (Han et al. 2018).

In the present study, the Landsat 8 OLI satellite image of the Mekkam buttonhole was used. The extraction of lineaments was carried out using the automated extraction method guided by PCI Geomatica software, aiming to create an initial map of the different lineaments of the buttonhole.

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2. STUDY AREA

The study area is a Paleozoic buttonhole attributed to the Eastern Meseta, located 50 km SE of the town of Taourirte. Access to this buttonhole is provided by road P6052 between Taourirt and Berguent. The dominant climate in the region is arid, with a succession of two seasons: one cold in winter and one hot in summer. Previous works (Médioni,1980; Marhoumi et al. 1983; Chegham, 1985 et Hoepffner, 1987) have described the geological context of this massif, noting a monotonous schistose bedrock with a flyshoid character of Devonian age unconformably underlain by volcanic and sedimentary formations of probable Upper Visean age. The volcano-sedimentary complex known as Ez-Ziroug is in abnormal contact with the granitoids of Soulouina-Hassiane-Diab. These Paleozoic terrains are overlain by Triassic and Quaternary formations (**Fig. 1**).

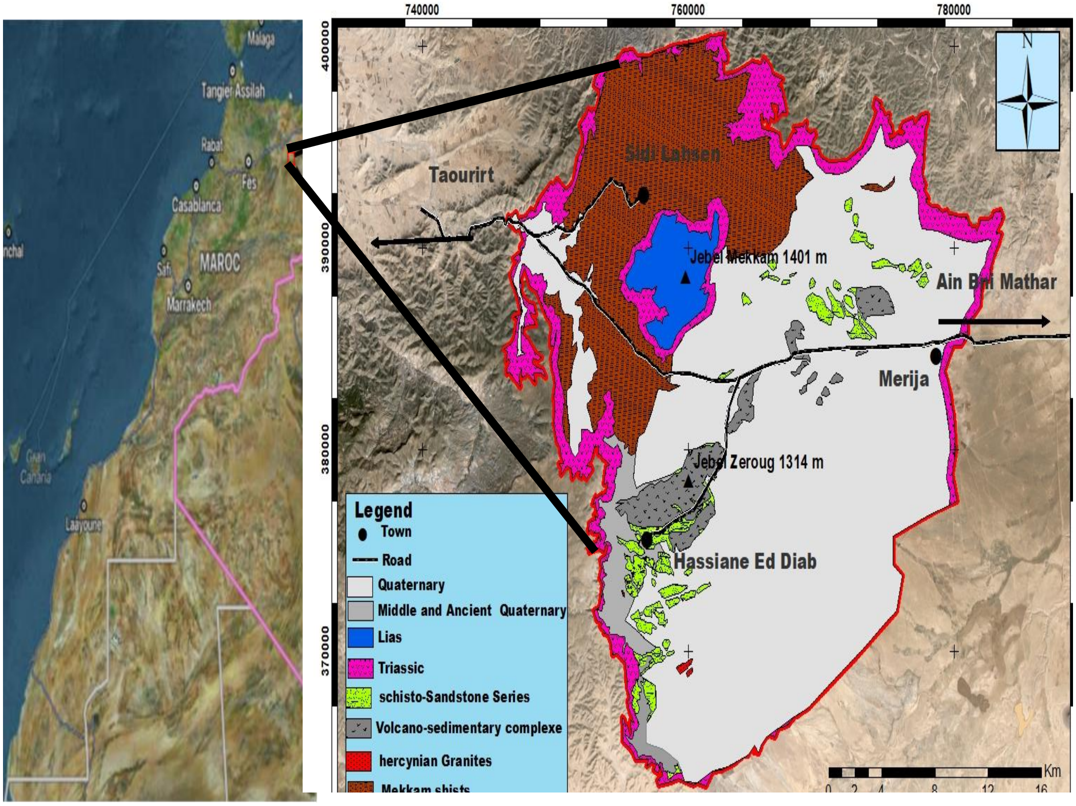

Fig 1. Location and geological map of the Mekkam buttonhole.

3. DATA AND METHODS

The Landsat 8 OLI image was chosen due to its relevance in extracting lineaments (Abdelouhed et al. 2021). The image covers the entire study area, and its acquisition date of 11/08/2019 was chosen to avoid clouds that could obstruct the area. The Landsat images are available on the website « arthexplorer.usgs.gov ». The Mekkam buttonhole, which constitutes our study area, has been delineated on four topographic maps (Taourirt, Ain Bnimathar, Hassiane Ed Diab, and Oued Charfe sheets, at a scale of 1:100000). Consequently, the study area was extracted from the satellite image.

Then, based on digital image processing techniques, an atmospheric and radiometric correction was applied using the INVI 5.3 software. Subsequently, the extraction of lineaments was carried out following four main steps, which are: (1) Principal Component Analysis using INVI 5.3; (2) Filtering using INVI 5.3; (3) Automatic lineament extraction using PCI Geomatica; and (4) Verification and validation of results in the field and using ArcGIS and Rock Works.

3.1. Principal Component Analysis (PCA)

Principal Component Analysis (PCA) is a technique for image transformation based on complex digital processing of statistical characteristics of multi-band data to reduce data redundancy and establish the correlation between frequency bands (Pandey et Sharma, 2019). This technique is widely used by geologists in digital mapping, it reduces the information contained in multiple, sometimes highly correlated bands, into a smaller number of components. These components typically represent around 97% of the total variation in the original data set (Deslandes, 1986). With this analysis, the information presented in 5 or 6 bands is compressed into two or three principal components. Previous work (Hammed et al. 2020; Ba et al. 2020; Tözün et Özyavaş, 2022) have shown that the first three principal components contain over 90% of the spectral information. In our case, the first components CP1, CP2, and CP3 were chosen for the extraction of lineaments. High-quality information was acquired during the applied tests. The new images obtained from the original data provide the opportunity to create color compositions that enable a better visual interpretation. PCA was carried out using INVI 5.3 software, and the results obtained were subsequently used in the sequence followed to locate the lineaments.

3.2. Directional filtering

Directional filtering is crucial for lineament extraction. It helps improve the visualization of the image by eliminating noise present in the image data, making interpretation easier (Amrani, 2007; Abdelouafi, 2007; Ezzine et al. 2011). Its principle is manifested by a rectangular window (3x3, 5x5, 7x7…) that moves line by line and column by column to calculate the new value of the central pixel (Amrani, 2007). In geology, we are interested in irregularities or interruptions in imaging textures, which can reveal the presence of faults, dykes or veins. (Ezzine et al. 2011). Sobel directional filtering is based on convolving the image with a small kernel in both vertical and horizontal directions. It calculates the gradient of the image intensity at each point and gives the direction of the possible increase from light to dark (Al-Djazouli et al. 2019). In our case, this filtering is applied to the different main directions, which are: N-S, NE-SW, NW-SE et E-W, by adopting the different windows (3x3, 5x5, 7x7, 9x9…). The 5x5 window proved to be the most favorable for the Landsat 8 image with a spatial resolution of 30 m x 30 m that we adopted. The results obtained from the filtering are presented in **Figure 2**.

3.3. Automatic lineament extraction

The lineaments were automatically extracted from the images obtained through directional filtering using the "line" option in PCI Geomatica software. The reliability of this method has been confirmed in comparison to manual lineament extraction, as assessed through a comparison conducted by Hung et al. 2005. This technique is faster and simpler, relying solely on the quality of the image used A higher number of lineaments is revealed, as well as smaller structures. The principle of this method is based on an algorithm designed to work with the « PCI Geomatica » software. to obtain a final map in vector format by following three essential steps: (1) edge recognition, (2) thresholding and (3) curve extraction (Kiran et Ahmed, 2014 ; Pandey et Sharma, 2019).

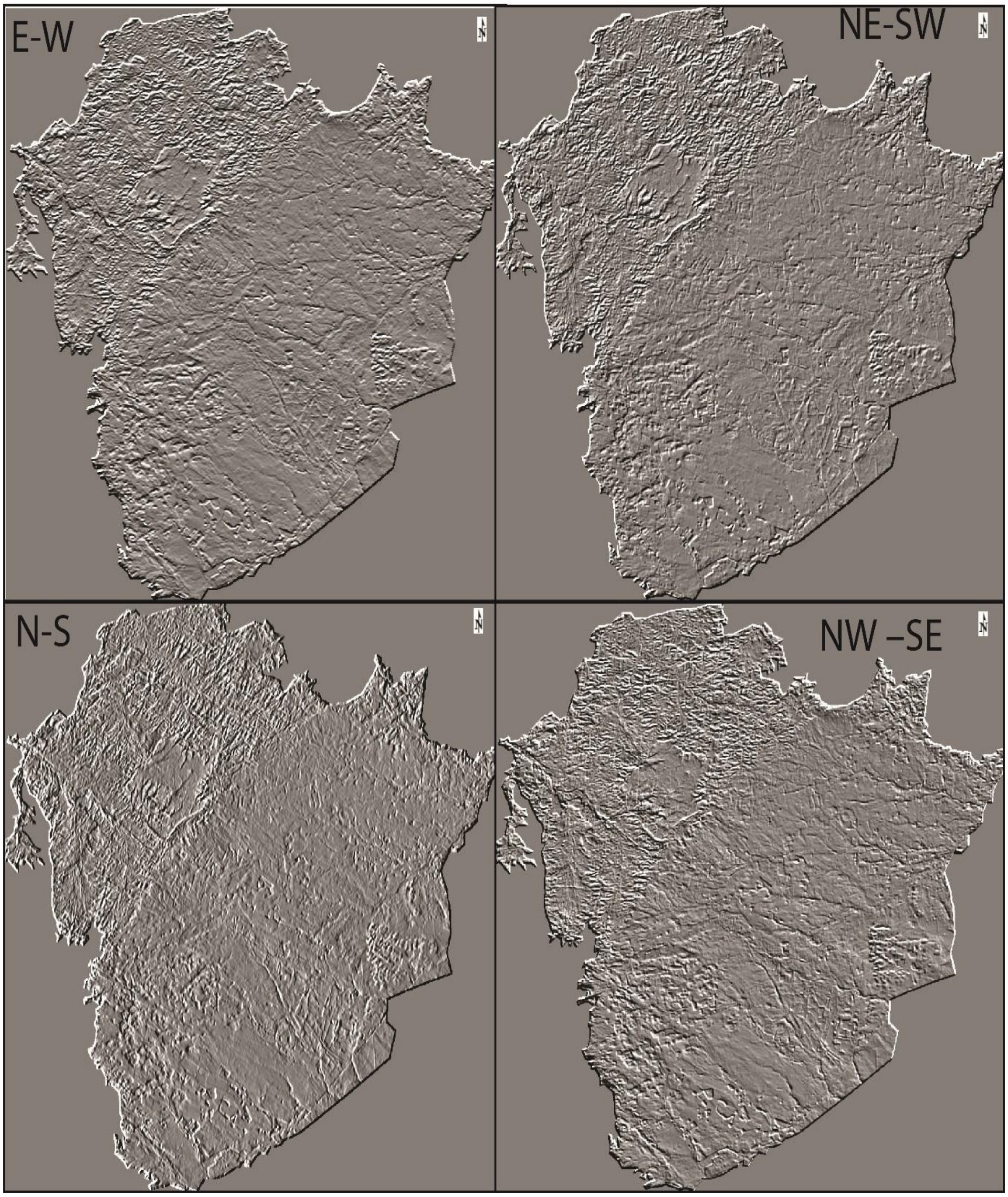

Fig. 2. Directional filtering.

3.4. Verification and validation of results

These steps were applied in our case to the four images obtained through filtering. The Arc GIS software allowed for the combination of the four images to create a synthetic map without distinguishing between lineaments of geological significance (faults, veins, dykes, and lithological contacts) and man-made lineaments (roads, tracks, and high-voltage lines). Field verification was conducted to distinguish between different types of lineaments. Then, a statistical study was conducted to quantify the lineaments and establish the directional rose diagram of the dominant directions using the "Rock Works" software.

4. RESULTS

The lineament map produced is shown in **Figure 3**. Anthropogenic lineaments have been subtracted. Overall, the results obtained from digital processing of satellite images are in line with existing data. New geological structures are revealed in comparison with previous work of Chegham, 1981 and d'Hoepffner, 1987. A second confirmation of the numerical results was provided by four field missions. During which we recorded the measurements of the various directional families of the structures observed, as well as their locations. The nature of the lineaments is varied, it corresponds to either faults, dykes or mineralized quartz veins, the number of faults is predominant.

The interpretation of the results allowed us to highlight the following observations: (1) The structural complexity of the Mekkam sector, where we can distinguish the existence of four main directions. N-S, NE-SW, E-W, NW–SE (**Fig. 4**) with the dominance of the E-W direction and the NW-SE direction; (2) The frequency of lineaments shows that the Sidi Lahsen schistose terrain in the north is affected by more faults and dykes than the terrain of the Hassiane Diab volcano-sedimentary complex in the south; (3) The existence of several directions in the same sector most probably shows that the study area underwent successive phases of orogenic deformation.

Field missions confirm the presence of eruptive rock dykes (**Fig. 5**). With directions that are generally E-W, quartz veins running NW-SE (Hassiane-Diab) and E-W (Sidi Lahcen) These are consistently associated with different types of mineralization, including Pb-Zn-Ag and W, Ba, some of them have been exploited or are currently under exploitation. Our field work has led to the discovery of new mineralized veins not reported in the literature, which can be used to delineate and estimate their mineral resources.

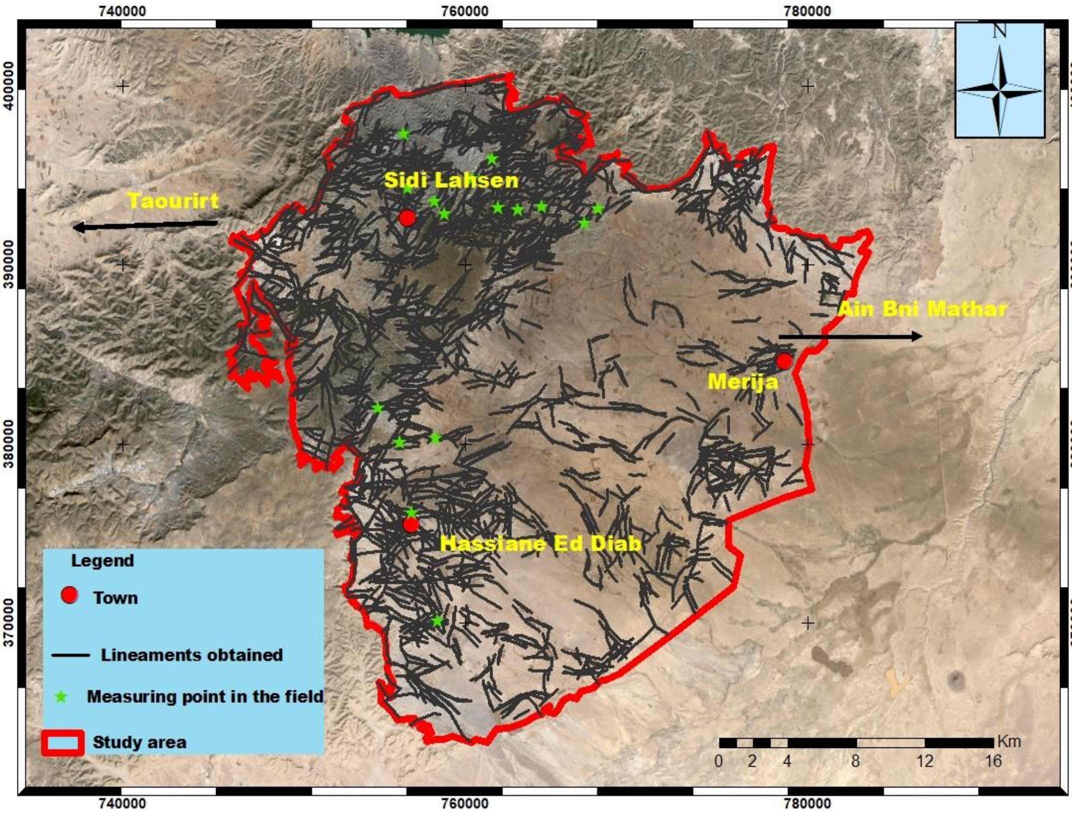

Fig. 3. Map of lineaments obtained.

To understand the distribution of lineaments and define their characteristics, a statistical analysis was carried out using "Arc Map & Rock works" software. The first is used to calculate the length of each lineament and the second to create the directional Rose. These two software programs were used to calculate the number of lineaments and to determine their direction over the total area of the Mekkam buttonhole, i.e., 855,21 km^2. 1624 lineaments were identified in all directions. Lineament lengths vary from 0.9 km to 7 km. We distinguish 4 classes:

-class 1, NW-SE direction, represents 28% of total lineaments.
-class 2, direction E-W, represents 26% of total lineaments.
-class 3, running N-S, accounts for 23% of all lineaments.
-class 4, direction NE-SW, also represents 23% of total lineaments.

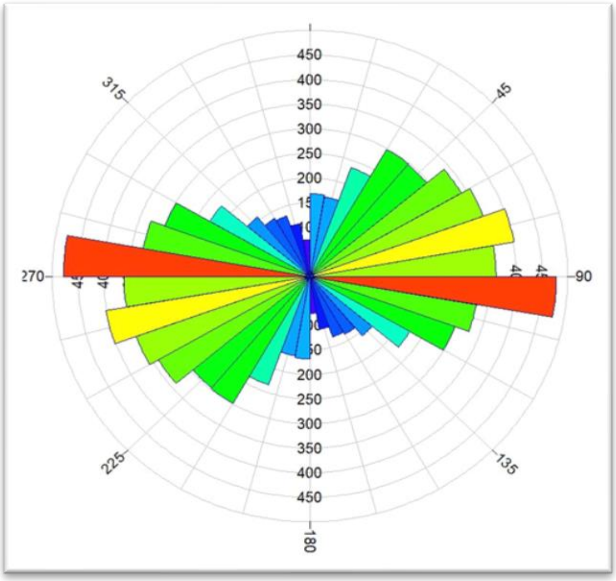

Fig. 4. Rose Diagram.

5. DISCUSSION

On a regional scale, the structural complexity and number of faults and dykes in the Debdou-Mekkam zone is linked, as pointed out by Chegham (1985) to character polyphase of the deformation. According to this author, shists of the Devonian age have undergone at least three phases of deformation that have generated various types of folds and anchizone metamorphism. Hoepffner's (1987) tectonic analysis revealed two episodes of deformation, D1 and D2, attributable to the Eovaric (Breton) phase. D1 corresponds to the initial structuring of the Debdou-Mekkam schists, where the folds have a homogeneous NW-SE direction. D2 is attributed to a deformation episode that probably occurred during the Eovaristic phase (Breton), anterior to the Upper Viséen deposits and characterized by folds running N 120 to N 150. The post-Westphalian D3 phase is superimposed on the two preceding episodes. The multitude of geological lineaments that we have extracted and presented on the map is the signature of this tectonics and the rheological response of the terrain to deformation.

Our results provide new information that confirms the polyphase nature of the structural history in the area studied. On the map obtained, the accidents are located in the Paleozoic terrain of the Mekkam buttonhole. In Mesozoic and Cenozoic terrains, lineaments are less frequent or even absent, recent cover masks the deeper Paleozoic fault and dyke network.

On a large scale, according to Lagarde (1989), the overall deformation of the Moroccan Meseta was followed by the emplacement of late-Hercynian syntectonic granitoids. In our study area, we note the presence of a multitude of mainly microdiorite dykes and mineralized veins attributed to this tectonic phase. All the lineaments extracted by satellite image processing are in overall agreement with the geological data observed in the field.

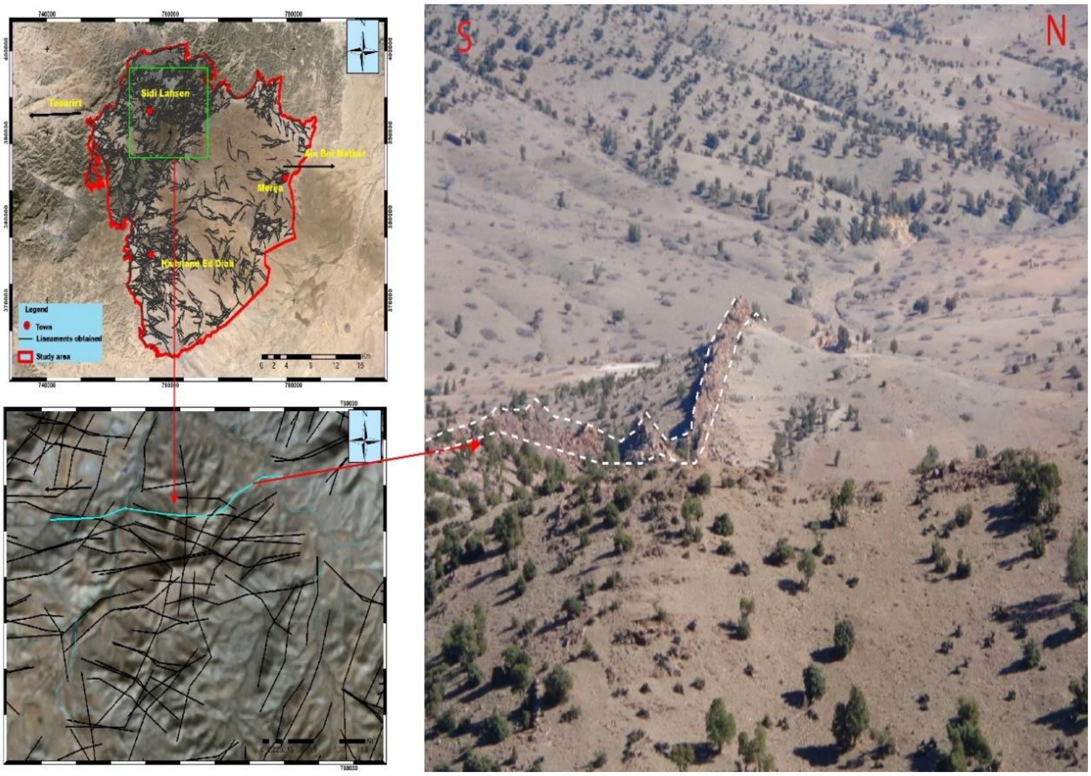

Fig. 5. E-W Dyke at Sidi Lahcen.

6. CONCLUSIONS

Our approach, based on remote sensing image processing and geological field surveys, has enabled us to map geological lineaments in a difficult-to-access area.

Four preferential directions, N-S, NE-SW, E-W and NW-SE, have been identified, corresponding in the field to mineralized dykes and veins, or even faults.

A database of all lineaments has been established that can be used for mineral exploration in the region.

Spatial remote sensing data combined with field work offer an encouraging approach to structural studies. These tools make the task easier and contribute to a better understanding of structural contexts.

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