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INSTABILITY OF THE SLOPES LINKED TO A NEO-TECTONIC ACTIVITY, MAHOUNA, NORTH-EAST, ALGERIA.

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Abstract: *The Mahouna region located in northeastern Algeria, in a margin considered active; it constitutes a fragmented landscape, extremely varied, with a very complex substratum characterised by a tectonic heritage of several geological units. The sedimentary soil dates from the Permo-Triassic to the Plio-Quaternary. It is distinguished by a structural relief, young, active, due to its geodynamic evolution during the Upper Tertiary (convergence of the Africa- Eurasia plates). The instability of the slopes by the size and extent of the affected masses constitutes a serious threat and pose problems of development of this region. It is recommended on the one hand to discern the different revealers of recent tectonics; and on the other hand, the highlighting of the relationship between neo-tectonic activity and disorder whose main purpose is to improve the geological balance of a region that remains very little explored from the morpho-structural point of view. The multi-source mapping and analysis through the GIS, the deciphering of a mosaic of aerial photos, coupled with the field study, give us new results and show that the construction and the genesis of this relief is closely linked to the neo-tectonic activity, whose activation is confirmed by the disorder, dismemberment and quite significant deformation that affect both ancient and recent geological formations and the morphology of the region.*

Keywords: *Deformation, Instability of the slopes, Mahouna, Neo-tectonic, Structural relief, SIG.*

INTRODUCTION

The Mahouna or Ain Larbi region is part of North Eastern Algeria (Figure 1-a). It is located at longitudes: 7°19' and 7°41' East, and latitudes: 36°13' and 36°30' North. It extends from the town of Guelma in the north to the village of Ain Arbi (formerly called Gounod) in the south and is located between the following three main wadis: Oued Seybouse which penetrates the Guelma plain in the North, Oued Cherf in the South-West and Oued R'bibain the South-East (Figure.1-b). From a palaeogeographical point of view, these wadis correspond to a transition zone between the low valleys of the tell and the high plains region.

Due to its location in an area considered to be an active margin, with medium seismicity, it is also known for significant hydrothermal activity. There is a clear contrast in the geomorphological landscape (mountains, depressions, hills, etc.), with a variety of facies, reflecting the eventful geological and palaeogeographical history and active geodynamic evolution of the region from the end of the Miocene to the present day. Thus, the rugged and tormented relief presents numerous disorders. The instability of the slopes due to the size and extent of the masses affected is beginning to pose problems for the development of this region.

Despite its proximity to Guelma, the study area has remained poorly explored in morpho-structural detail. On the 1:50,000 geological map of the Mahouna [5], no faults have been mapped; whereas mapping and field observation

show that the rugged topography presents many discontinuities. Faced with the increasing lack of detailed and precise geological mapping information (e.g. geological boundaries), which constitutes a major handicap, one of the problems posed in the present work is, on the one hand, the establishment of the various indicators or indicators of recent tectonics and, on the other hand, the highlighting of the relationship between neo-activity and disorders (instability), the main purpose of which is to flesh out the geo-mapping of the region.

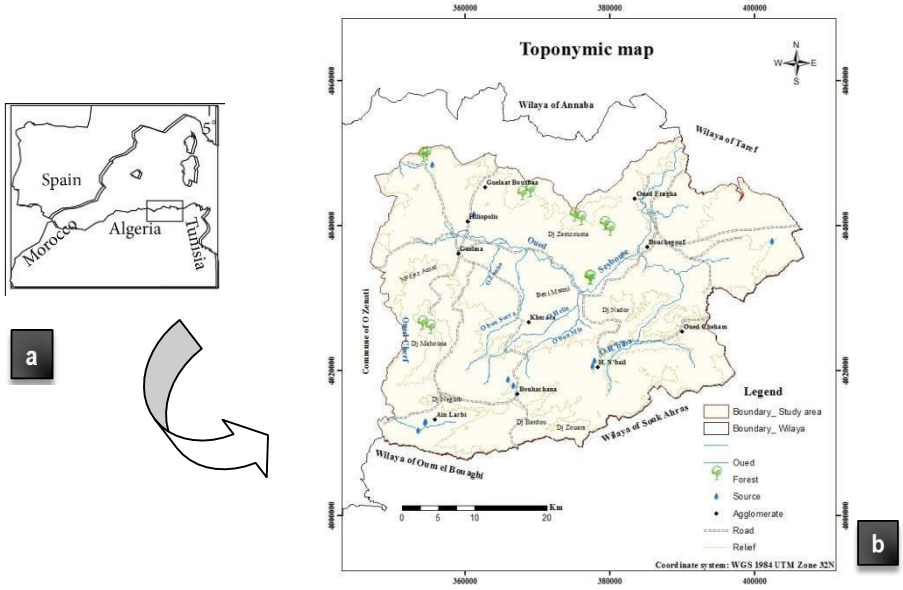


Figure 1. Mahouna or Ain Larbi region is part of North Eastern Algeria and Oued Cherf in the South-West and Oued R'biba in the South-East

MATERIALS AND METHODS

The methodology is based on:
1- Analysis and digital cartographic processing through GIS (hypsometric, hillshade and slope map..), the reading and interpretation are done on a geological background [1] to compare the particular structures and anomalies with the available geological data;
2- Draw a network of lineaments (any object appearing linear or more or less curved) from the general shape of the hydrographic network of the region using the Raskatov method [1] [3] and [13];
3- The deciphering of a mosaic of aerial photos;
4- The field study.

CONTEXTE GEOLOGIQUE

Geologically, the study area belongs to the Tellian Atlas which is part of the outer domain of the folded Alpine chain of North Africa. Overall, it appears that the region has a strong structural legacy, comprising several landslide sheets, according to J. M. Villa, these are probably the most spectacular landslide sheets known in North Africa [6]. These nappes have an extremely complicated structure of detail; they are generally distinguished by a stacking of pellicular units (Figure 2) with a complex geodynamic history.
The deposits that constitute the territory of this region range from the Permo-Triassic to the Quaternary:

- The Triassic formations are generally evaporites, poorly stratified, present in the study area in numerous outcrops, sometimes occupying large surfaces. The Triassic only outcrops in abnormal positions, either in the form of diapirs or injected along tectonic faults [10], whereas in the Nador N'bail's massif, it outcrops in a normal situation [5], as it occupies the bottom of an anticline;
- The marly and calcareous marl soils (Jurassic - Eocene) form the main part of the Sellaoua unit, they outcrop in the south-eastern corner of the study area, surmounted in places by Tellian series.

- A thick series of limestones, interspersed with marlstones of the Tellian unit sensu stricto, ranging from the Senonian to the Lutetian, located mainly in the centre of the study area.
- The Numidian complex (400 metres high) forms the main part of Jebel Mahouna, overlying the Tellian allochthonous series of the territory.
- The continental detrital, lacustrine and fluvial terrains of the Quaternary Mio-Plio (a thick series beginning with the travertines and ending with the alluvium) are widely developed in the region,covering the whole of the northern part (Guelma Basin), as well as the eastern end (Hammam N'bail's Basin).

From a lithological point of view, it is important to note the extreme complexity of the bedrock:
*Various rocks of different ages; *Stacking of units; *Direct and anomalous contact existing between both ancient and recent formations (Triassic terrains and travertine or tuffaceous formations of the Quaternary).

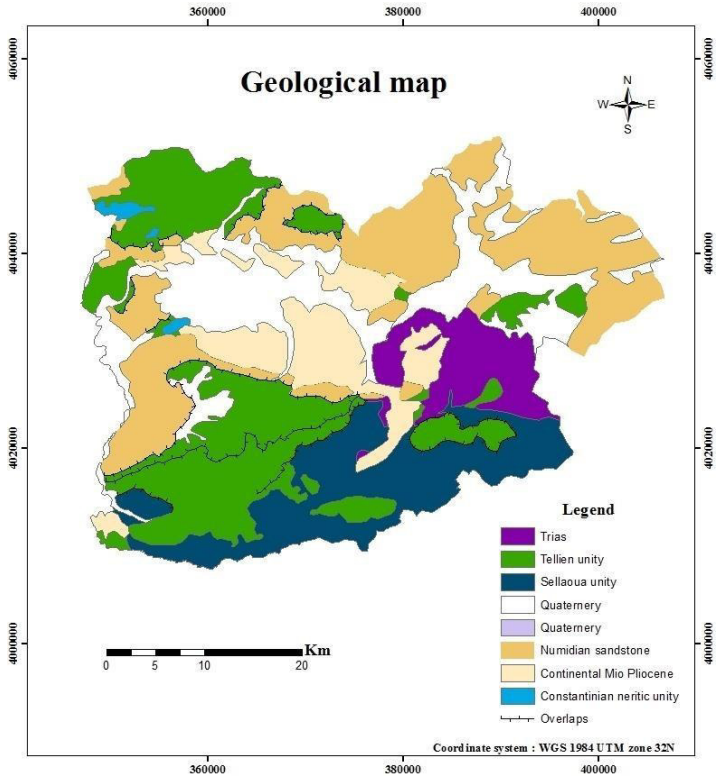


Figure 2. A strong structural legacy of studied region

OROGRAPHIE PARTICULARITIES

On the morpho-structural level, the DEM and the hypsometric analysis (Figures 3 and 4), which show a hierarchical relief by altitude classes, provide a wealth of information on the particularities of the orography of the area (rate of deformation and dismemberment). The reading and interpretation is done on a geological background [1] to compare the particular structures and anomalies with the available geological data;
The study area is made up of a large number of very small regions, each of which is distinguished from the others by more or less striking features.
The relief shows an extreme variety of landscapes. In (Figure 3), three regions can be distinguished by their physical characteristics (mountains, ranges and intra-mountainous depressions); the essential difference lies in altitude and shape. Between the highest peaks (1411 m), and the bottom of the Seybouse valley (90 m),the difference exceeds 1300 m.

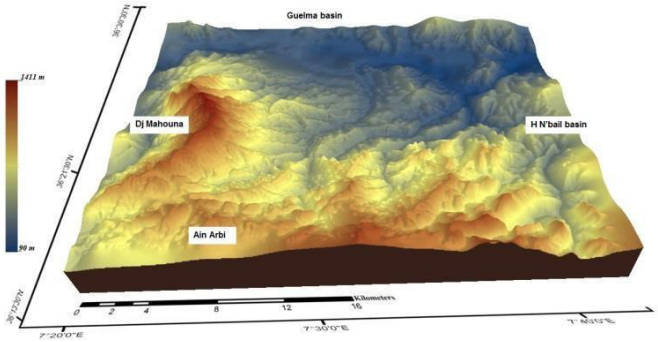


Figure 3. Three regions of the morpho-structural level

The reliefs all belong to the succession of several geological units; their physical differences result from the conjunction of their altitudes, their situations, their shapes, their lithological behaviours and undoubtedly to the persistent tectonic constraints which have a rather important role in the shaping of the relief in particular and the geomorphological evolution of the region in general.

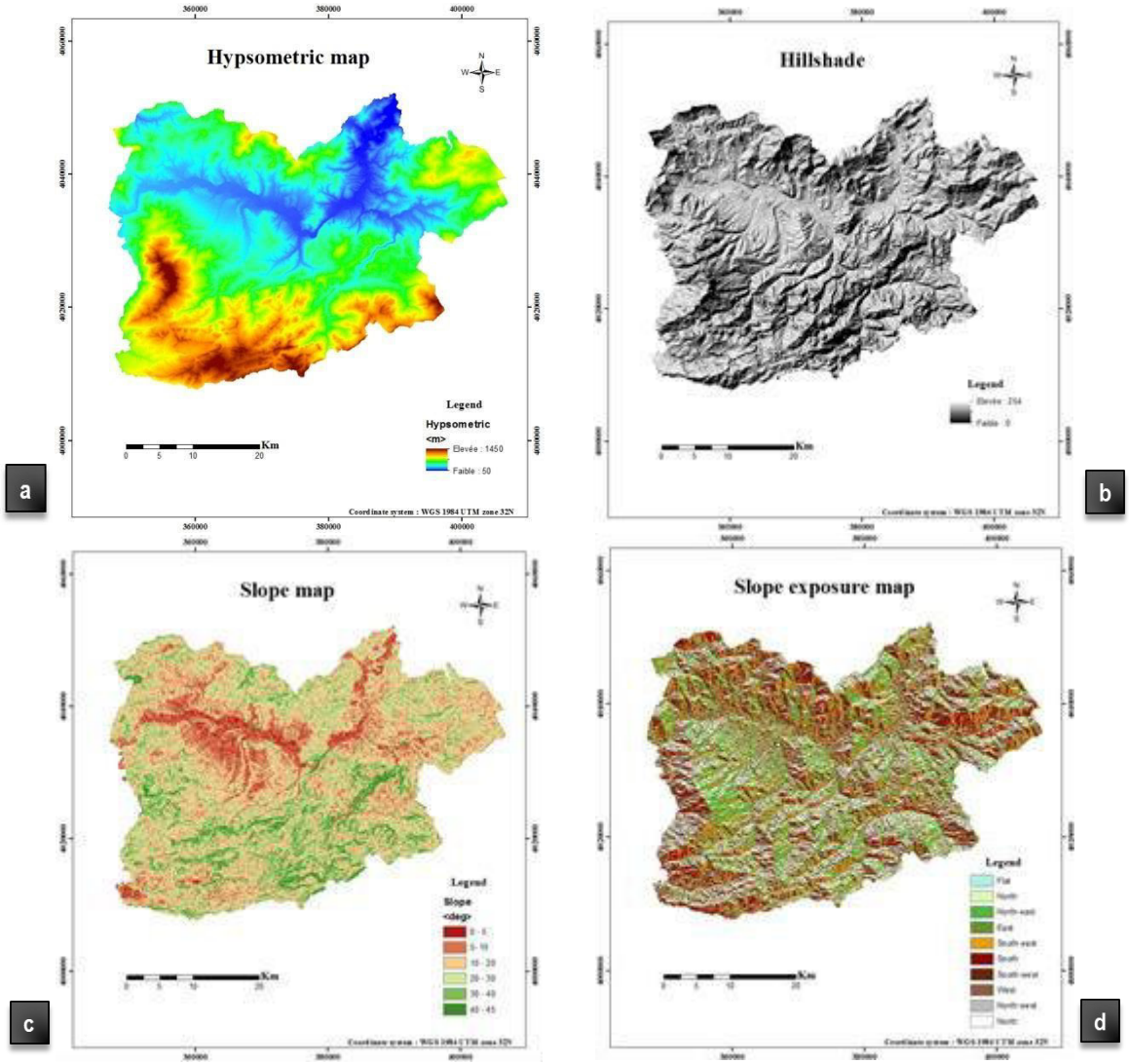


Figure 4. The hypsometric analysis

Due to its geographical situation, the Mahouna is a fragmented area, the nuance is quite clear between the northern part (low areas) and the southern part (high areas) which is composed of less monotonous units, surrounded by topographical and geological discontinuities;

High areas

To the north of the municipality of the study area, a vigorous massif, bearing the ancient name of the study area: La Mahouna; constitutes the dominant element of the whole territory, both from the point of view of altitude (1411 m) and of the surface area it occupies, it is curved in the shape of an arc, the convexity being turned towards the West; by its general North-South orientation seems to link in some way the Atlasic chain to the Numidic chain [5]. It is characterised by a dissymmetrical, dislocated and dismembered aspect. Indeed, its particular shape, its position and its relation with the Guelma basin in the North, make it interesting from a morpho-structural point of view (fig.4- a, b, c and d);

- A brutal flooding is observed in its northern termination, near the Medjaz Amar region. The passagefrom the mountain to the Guelma basin follows a significant slope (over 40°);
- The ridge line shows virgations and discontinuities;
- Linear scarps, orthogonal to the ridge direction, are numerous, possibly fault scarps, often with decaying kinematics;
- A piedmont of considerable dimensions stands out in the NNE part, inclined between the massif and the plain, developed for the most part on very thick detrital accumulation materials (Mollasse de Guelma), resulting from the erosion of the massif upstream. This can certainly be explained by the Plio-Quaternary surrection of the mountain as a result of the orogeny and therefore implies the intervention of an active structural control. Thus, the important fact to mention is the weight of the filling materials which still favours the subsidence of the basin to the north.

The Mahouna massif becomes narrower at its southern end, where we can note an oro-hydrographic lineament (Oued bou Zender), oriented roughly East-West, corresponding to a structural contact between the Numidian unit to the North and the Tellian Sensu-stricto unit to the South. It is likely that this lineament extends further eastwards in a NE-SW direction to limit the monoclinal reverses of the limestone.

An alternation of steep limestone and marl with a significant thickness of the Ypresian-Lutetian [5] favours the clearing of structural forms by differential erosion to form the ranges and reverses of the monoclines, but also active tectonics responsible for the construction of the latter; the most characteristic ones can be seen in the central part, at the level of the Khezara region and to the south of the Mahouna massif.

Even further west, the Nador-N'bail's anticline reaches 1108 m and appears as an anticline, centred on Koudiat en Guataya in a SW-NE direction. Most of it is made up of Triassic gypsiferous formations, except in a few places where Neogene terrain and fragments of Eocene limestone are hidden.

Morpho-structurally, this anticline has a particular morphology and a rather dissymmetrical aspect. While the south-eastern flank is more or less regular, the north-western flank, which is longer, is characterised by a significant dissection: It is subdivided by large erosion zones into several morpho-structural entities (mega-blocks): kef el Mouza, koudiat Eratba, kef lahraiche, kef Mourad...etc.; These mega-blocks are often deformed in the form of virgations at the level of their terminations;

The north-western limit corresponds to an oro-hydrographic lineament (oued Seybouse), characterised by a steep and rectilinear cliff in a NE-SW direction, as well as a large incision of Oued bou Mia (oued Melah in its upstream part) which limits the massif to the east, where the Triassic formations are intertwined; the tectonic nature of these lineaments is obvious.

Another interesting structure stands out between the sandstone massif of the Mahouna and that of the Nador N'bail's: the massif of the béni Marmi; a thick flyshoid series, clayey and sandstone, rests unconformably on the marls of the middle Eocene [5], culminating at more than 460 m and dominating the Guelma plain like a spur. This structure presents two directions: NE-SW then it becomes NNW-SSE in its extension towards the plain. This change of direction is explained by a series of gullies that run through it and have just dislocated the ridge line. It is bordered by a particular linearity of the Oued bou Sorra in its western part and limited by the Oued bou Mia from djebel Nador. Thus a flooding, a lowering of the ridge line and a slight virgation can be seen in the NNW end. This leads us to believe that the evolution of this structure is controlled by tectonics.

To the south, a mountainous group, represented by the massifs of the Sellaoua Unit, surmounted in places by the Tellian formations: the syncline of Dj Zouara (1292 m) whose summit line is intersected by a very important linear escarpment, exceeding 1500 metres in length, with an East-West direction, marking in our opinion the location of an important fault; the syncline of Dj Bardou (1261 m) with an Eocene core; Dj Zoubia (1173 m), Dj Neguib (1133 m), of triangular shape whose crest line forms an angle of 90° with two directions, NW-SE then abruptly, it becomes NE-SW and finally, Rous el Mzaïr (1081 m) presents a complexity of beds, with very varied facies, Large central depressions with low relief (up to 50 metres), dug into the black, bituminous marlstone formations of the Eocene, where we note the presence of two sub- parallel faults with vertical components, running NW-SE; All these massifs are asymmetrical, dislocated and present anomalous directions, except the last one (Rou el Mzaïr) which keeps the Atlasic direction (NE-SW).

Low areas

The Hammam N'bail's intra-mountainous basin constitutes a rather elongated ellipse whose major axis is oriented approximately SSW to NNE, it extends in a continuous way, over a length of approximately 15 kilometres and a width varying from 2 to 3 kilometres. It corresponds to a Miocene fluvio-lacustrine mega-sequence, containing polygenic conglomerates with carbonate pebbles [4].

To the north, the Neogene basin of Guelma corresponds to a wide open lenticular depression, about 25 kilometres long from west to east and varying in width from 3 to 10 kilometres. This wide valley, where the town of Guelma is located, is limited to the south by the northern end of the Mahouna massif and the much less important Bni Marmi massif, which is the last buttress of the Atlas chain [5]. Finally, it is closed to the South-East and to the East by the Nador-N'bail's massif. The Guelma basin is largely filled by evaporite deposits from the terminal Miocene, partially or totally covered by travertine deposits from the Pliocene and Quaternary. The ORGM (1984) is applied several geophysical methods in order to better define the structural arrangement of this basin. The results of the geophysical work revealed that the Guelma basin is divided into two blocks: a collapsed block and a raised block. These two blocks are separated by first order tectonic faults and present two general directions: an almost East-West direction and a North-West-South-East direction.

In summary, the structuring effects of a recent post-orogenic tectonics are well marked on the current relief pattern; to this effect, some anomalies have been drawn:

- Clear dissymmetry between the flanks of the djebels such as dj Mahouna, dj Zouara, Rous el Mzair, dj Nador... etc;
- Deformations, significant twists at the level of the ridge lines of the majority of the massifs;
- Some massifs are subdivided into several morpho-structural units by topographic and/or geological discontinuities;
- Detachment of mega-blocks and the presence of recent scree in the vicinity of the Mahouna sandstone massif and the limestone ranges;
- Kilometre-long scarps are probably fault lines;
- Linear incisions appeared on the irregular slopes under the effect of intense erosion;
- Rectilinear orographic limits could coincide with tectonic accidents such as the southern limit of Jebel Mahouna;
- Remarkable abrupt erosion.

HYDROGRAPHIE ANOMALIES

The hydrographic network is a component of the complex geomorphological system, which is very sensitive to exogenous variations, particularly climatic variations and active tectonic deformation [6]. The region is characterised by a continental Mediterranean climate; the average rainfall, which varies between 500 and 800 mm/year, is a very important climatic factor, conditioning the seasonal flow and directly influencing the watercourse regime. The study region belongs to the catchment area of the middle Seybouse (catchment area N°14): the Seybouse, which drains the Guelma basin to the north, is fed by an important independent

hydrographic network between the Atlas chain of the Tell to the south and the Numidian chain to the north [5].
The hydrographic analysis (Figure 5) shows that the watercourses represent a dense hydrographic network, of dendritic type with rather complex branches in certain parts. The watercourses do not follow a uniform direction and they have undergone disturbances and disorganisation manifested by meandering or sinuosities, and these are guided by the morpho-structures of the terrain crossed and reflecting the variety of heterogeneous geological formations from the point of view of facies.

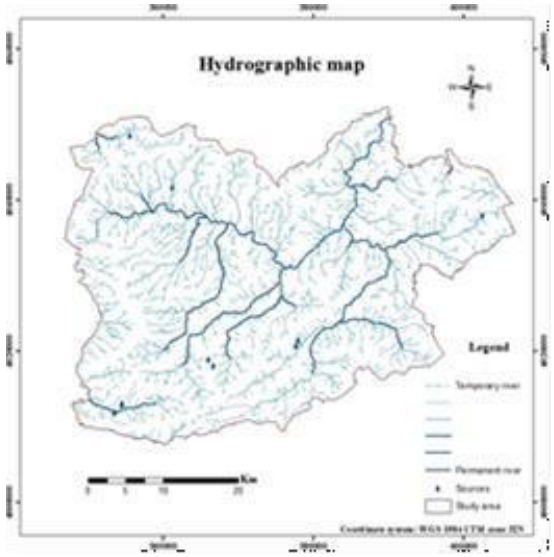


Figure 5. The hydrographic analysis

The northern system: the Seybouse valley
The general aspect of the sinuous course of the Seybouse valley is E-W with two different and asymmetrical banks; At the level of the mouth of O bou Sorra in the Seybouse we notice a progressive change of the direction of the valley to the NW-SE until Koudiat bou kasrouba which obliges the valley to make adiversion towards the East, by crossing the gorges of Nador and by crossing several geological formations (the steep triassic formations of Nador, the liasic formations of koudiat bou Kasrouba and the more recent quaternary grounds), then suddenly, the direction of flow becomes NE-SW with a rectilinear and linear aspect, this perfect linearity, already mentioned above on the hypsometric map, corresponds indeed to an accident.
Thus, there are two distinct constrictions in the valley (fig. 6-c): the first (1) at the level of the Nador massif and Koudiat Bou Kasrouba and the second (2) at the level of Bni Marmi and the mega dejection cone of Jebel Zemzouma;

The southern system: the mountainous area
The southern part includes two sub-catchments: one in the south-west corresponding to the O. Cherf (which rises south of Guelma), and the other in the south-east, represented by the O. R'biba, whose upper course (the upstream part) is successively called O. Mellah and O. Zouara. These last streams flow in a particularly hilly region, at the bottom of wild, deep valleys with steep walls; between the two sub-basins, the secondary tributaries and the talwegs of the Seybouse valley have a different course and a bizarre appearance expressing the morphological complexity of the terrain; those coming from the north-eastern slope of Dj Mahouna have a NE-SW direction (O. Zimba), others coming from steep limestone ranges of the Tell atlasic chain, show several directions: (O.bou Sorra E- W, O.bou Mia N-S and O.Helia NE-SW), the latter, with altitudes varying from 150m to 800m, has undergone disturbances during its course and has changed its direction six times; and finally, O. Melah, descending from the Nador massif, with a flow following the E-W direction, but after its confluence with O. bou Mia, it abruptly takes the S-N direction. In fact, the structural directions that emerge are: the N-S and the E-W.
Sometimes we see semi-circular structures (the upstream part of Dj Nador) which are very interesting from a

morpho-structural point of view; however, we believe that these structures deserve further study, as this could shed light on the current tectonic evolution of the region and the sub-surface or even semi-deep structures; in fact, these structures can be associated with:

a. A network of stall systems;
b. Deep or semi deep intrusive structures;
c. A halokinetic phenomenon (diapirism).

Given the geological nature, structural heritage and hydrothermal activity of the region, all three possibilities have their place.

In addition, the application of the Raskatov decryption method (Figure 6-a).and detailed observations on the secondary oueds and their tributaries also reveal quite significant disturbances:

- Linear flows over hundreds of metres in some cases;
- Abrupt changes in their course due to the presence of accidents;
- Abandonment of beds (confirmed by aerial photographs);
- Abrupt stop of some streams before joining the main stream (Figure 6-b). This explains in most cases the permeability of the cover crossed (alluvial formations) added to the small quantity of running water (temporary tributaries);
- Perpendicularity (angularity) of oueds etc.
- Strangulations of the Seybouse valley (Figure 6- c);
- High hydrothermal activity and frequency of water sources.

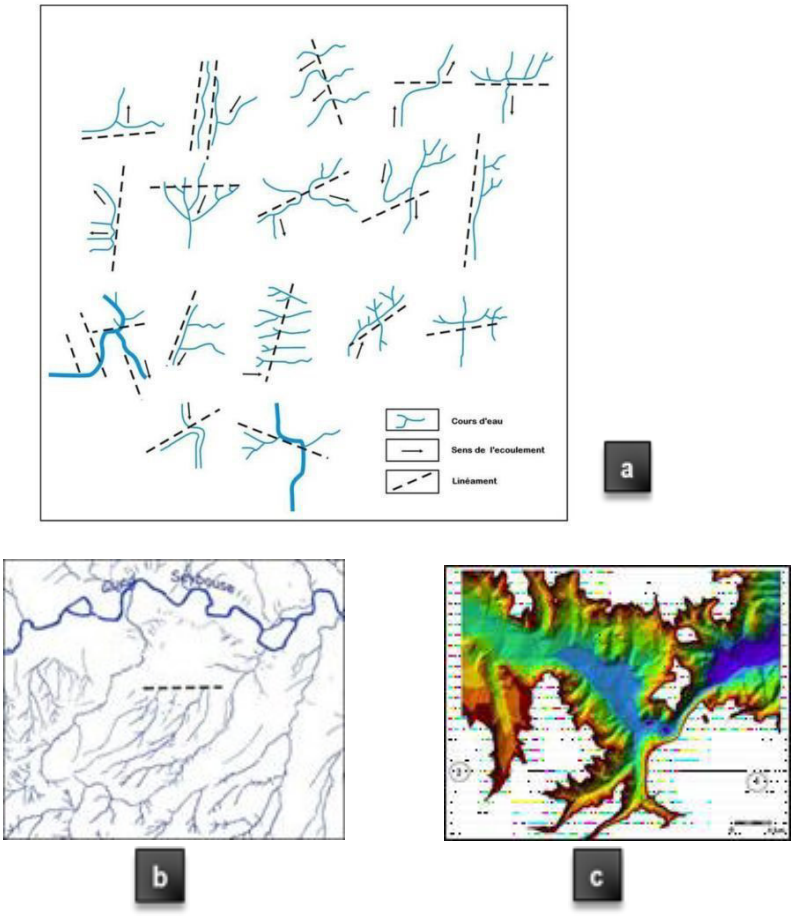


Figure 6. The geological nature, structural heritage and hydrothermal activity of the region

Thus, the important fact to note is that most of the watercourses are temporary and their regime is torrential and aggressive; Guelma, situated at an altitude of 290 metres, at the foot of the sandstone massifs, on a plain (essentially filled in by more than a hundred metres of terrigenous and powerful alluvial deposits from the Quaternary period, according to boreholes), is considered to be a superficial water table, and floods, torrential floods and gullies are the main facts each time it rains. These hazards constitute a major risk, where the torrential crisis will be doubly devastating, as the settlements will be affected not only by flooding, but also by torrent migration and embankments. If houses are located on the new course of the river, they will eventually be destroyed.

The susceptibility of the slopes to erosion varies according to the degree of fragility of the terrain (highly fractured Numidian sandstones, friable marl and limestone formations and Triassic terrain), the fracture rate of the terrain and the degree of slope.

SLOPE INSTABILITIES: Morphological manifestations

The disorder and the ground movements at the level of the study area are frequent and occupy important surfaces, they constitute true active morphological elements which have a dominating role in the evolution of the slopes, indeed, these movements are well controlled by factors of natural order: irregular climatic conditions, heterogeneous lithology, tormented and uneven topography but most often, they are closely related and in a direct way by the active structural context of the area (powerful regional tectonics).Moreover, these instabilities are beginning to cause problems and damage in urban areas and disruption of road traffic.

Here are some fairly common morphological features that have been identified (fig.7 and photos):

- **Mass movements**: in Jebel Mahouna, the hummocky slopes associated with gullying (slides, flows), recent or reactivated, are almost common. With variable volumes and thicknesses, on a steep slope, always higher than 45° (fig.4-c and d), along a breaking surface; To this effect, a typical example was drawn, the national road N°80 was several times damaged by the resumption of movements, thus, to take the road of the wilaya N°123 connecting Guelma to Aïn Larbi, that is to say about forty kilometres, constitutes a real expedition because of the dilapidated state of the road due to landslides; Thus, the bare slopes are strongly dissected by gullying because of the fragility of the terrain (highly fractured sandstone, friable marl and calcareous formations or triassic argillo-gypseous terrain); Jebel Nador offers curious examples of erosion of this kind where the claws of an intense gully form a fantastic landscape.
- **Rock instabilities and scree**: rock instabilities are a phenomenon that often forms the prelude to rock falls and landslides, sometimes considerable at the foot of the mountains; the most obvious are those affecting the limestone and marlstone ranges of the Bou Hachana region and represent a potential threat to property and people along National Road N° 80. The scree is strongly present at the foothills of the Oligocene sandstone ledges, and the Tellian limestone ranges could testify to previous tectonic activity;
- **Torrential incision**: numerous torrents flowing down from the sandstone massif constitute a recurrent factor of imbalance; it is well known that the steepness of the slopes exerts a decisive geodynamic influence; on the two slopes of dj Mahouna, the erosive force of the temporary and aggressive torrents is considerable, not only because of the violence of the displacement of their waters, but above all because of the materials of all sizes that they carry;
- **Solifluctions and blisters**: marly musty soils often have topographic flats, solifluosions, blisters, etc. on the surface.
- **Faults:** some of the Numidian sandstones or the limestone ranges are affected by a whole series of accidents (faults, breaks...) of variable directions;
- **Eluvial and colluvial formations**
- **Halokinetic phenomenon.**

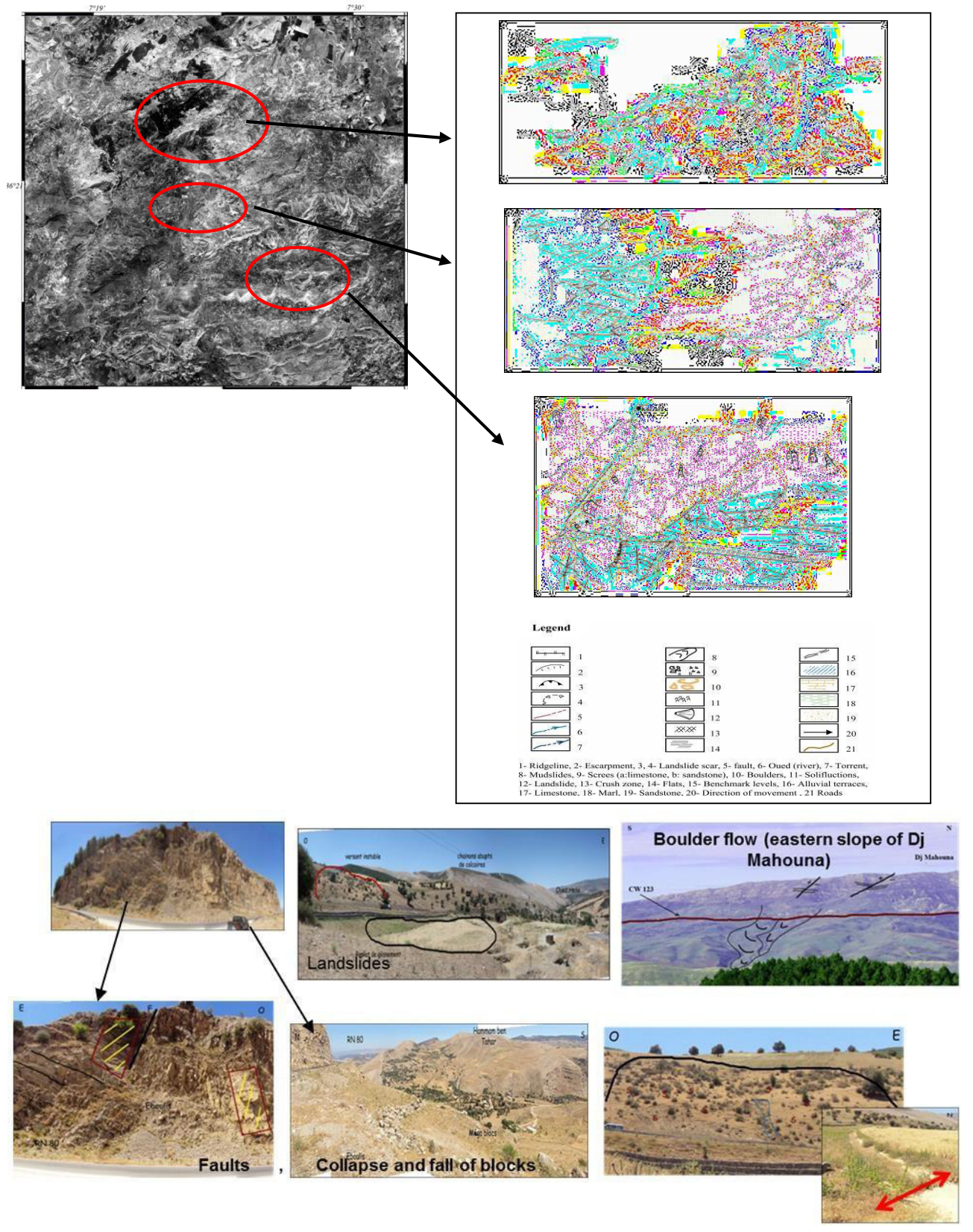
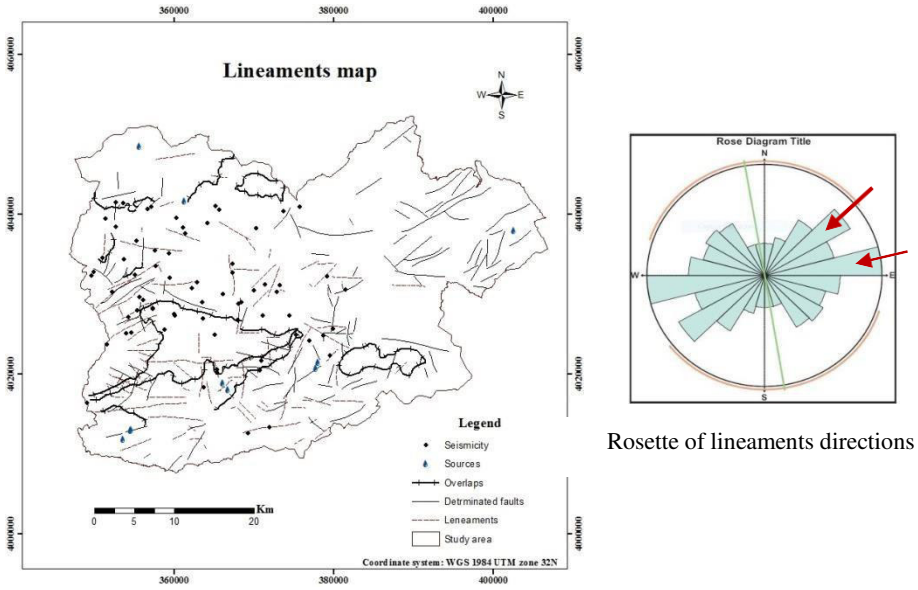


Figure 7. Mosaic of aerial photos of the entire southern part southern part of the study area

RESULTS AND DISCUSSION

More than one hundred oro-hydrographic lineaments (Figure 8) are reported from all the maps made but only the major lineaments are mapped on a toponymic background of the region; Three major directions emerge from the lineament map: NE-SW, NW-SE and N-S; Two structural directions: NE-SW and NW-SE are well marked on the hypsometry and hydrographic network by their alignment and influence the hydrographic system of the region.

The N-S directions are less visible. The typological analysis of the lineament map has revealed an uneven distribution of the tectonic fracture network. This is certainly explained by an uneven distribution of stresses and also by recently deposited materials covering a large area of the study area.



Rosette of lineaments directions

Figure 8.

Also, two typical examples have been drawn:

- Corridor N-S of Kef er Riah: at the level of this corridor, it is important to note: The existence of a hot source. A flap of triassic marl stretched and laminated, The presence of quaternary travertines in direct and abnormal contact with the previous formations. There is no doubt that these structures appear (without doubt) in favor of a fold-fault. These are convincing indications of the active nature of this sector and the reactivation of deep tectonic structures.
- Corridor E-W (eastern slope of Jebel Mahouna): the watershed of Dj Mahouna, provided by a corridor borrowed by an important fault (dexterous drop) of NE-SW direction, this fault draws in thelandscape by kilometer escarpments, affecting the Numidian sandstone of Oligocene; Indeed, severalsliding bodies (sinking-sliding) of large areas and different typologies, are manifested at the level of the NE slope of Mahouna, they are always close to rivers and streams; they are real active morphological structures that have a primary role in the evolution of the slope.

CONCLUSIONS AND RECOMMENDATIONS

The various results obtained from this work can be summarized as follows:

The morphological manifestations of an active deformation, affecting a structural relief, young are well marked at the level of the area of study; the oro- hydrographic irregularity (discontinuities, torsion, decoupling, escarpments of linear faults, the existence of thermal sources etc.), the slope instabilities and the deformation of an important sedimentary stock; certainly constitute one of the most manifest evidence.

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