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The Role of the Morphological Heritage in the Vulnerability of the Natural Environment: Case of the Slopes of the Southern Limit of the Constantine Basin

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Abstarct

The North-East of Algeria has known, these last two decades, the realization of big infrastructures, in particular the East-West highway, dams and transfers on tens or even hundreds of kilometers. However, in all these projects, the choice of routes was often based on topographic criteria, neglecting or ignoring the morpho-geological contexts of these achievements, hence the reactivation of old mass movements over hundreds of meters. As a result, ineffective consolidation and permanent maintenance lead to significant costs and delays. The cases studied in this work show the consequences of not taking into account the morphological heritage in the actions undertaken and the solutions adopted (improvised) after the damage was noticed.

Key words: infrastructure developments, morphological heritage, mass movements, North-East Algeria.

INTRODUCTION

The Constantine basin, constituted by a mio-pliocene filling (sand, clay and conglomerate) (Joleau, 1912; Durand Delga, 1969; Guiraud, 1973; Raoult, 1974; Vila, 1981; Coiffait, 1992; Lahonder, 1987) has known, during the Quaternary, the sinking of a hydrographic network that has emptied the basin in part, hence the appearance of long slopes and / or glacis particularly at the level of its southern limits. Indeed, these areas have experienced a dynamic characterized by widespread mass movements, the majority in the form of mudflows of great magnitude. These paleo-forms have stabilized with time and the climate has probably become less humid (Holocene). This morphological heritage has remained very vulnerable (precarious stability) because its stability has often been broken by human intervention during the realization of infrastructures crossing this area (highway and dam water transfer channels).

The mapping of landslides in Constantine has experienced significant advances in recent decades (Coromina, 2000; Bougdal et al., 2007; Pincent et al., 2008; Calvello et al., 2008; Machane et al., 2008; Guzzeti et al., 1999 and 2005; Guemache et al., 2011; Manchar et al., 2012; Bougdal et al., 2013; Bourenane et al., 2014 and 2016; Achour et al., 2017).

This study deals with three cases (Fig. 1): the first one, focuses on the damage occurred during the realization of the East-West highway at the point of its penetration in the Constantine basin (Tafrent micro basin). The second one concerns the bypass of the city of HammaBouziane realized at the beginning of the 80's, at the origin of a mass movement whose repercussions reached the calcaro-travertine wall of the northern limit of the plateau of Bekira (of a length of about 1Km). The third deals with the damage related to the transfer of water through the northern boundary of the high plains, between Ain Tin and El Melha (Wilaya of Mila) which has encountered very unstable areas (recent and current mudflows) that affect the entire southern edge of the Constantine basin.

Based on the data available in each area (geological, geotechnical or different types of measures) and on a detailed mapping of each site we will try to explain the specific mechanisms in each case to highlight the shortcomings in the feasibility studies of these projects especially regarding the morphological heritage to avoid irreparable.

PRESENTATION OF THE STUDY AREA

The area concerned by this study is located within the Neogene basin of Constantine. It is part of a group of inland basins characterizing alpine Algeria. It is a post-nappe basin that has been filled by a silico-clastic and carbonate series of mio-plio-quaternary age (Vila, 1980; Coiffait, 1992). This receptacle is installed on a substratum pre-structured in nappes and scales of the Tellian, Penitellian and neritic units belonging to the external zones of the Maghrebian chain of eastern Algeria (Vila, 1980; Wildi, 1983).

The slopes that constitute the mio-plio-quaternary filling, are juxtaposed on several kilometers and are constituted by formations with clayey predominance (Coiffait, 1992).

From the morphological point of view, the basin of Constantine is divided, from west to east in three units, in this case and in order, that of OuledKebbeb, that of Smendou and finally that of Mila which remains the most important. These units are inserted between the Numidic chain in the north and the mountains of Constantine in the south (Figure 1).

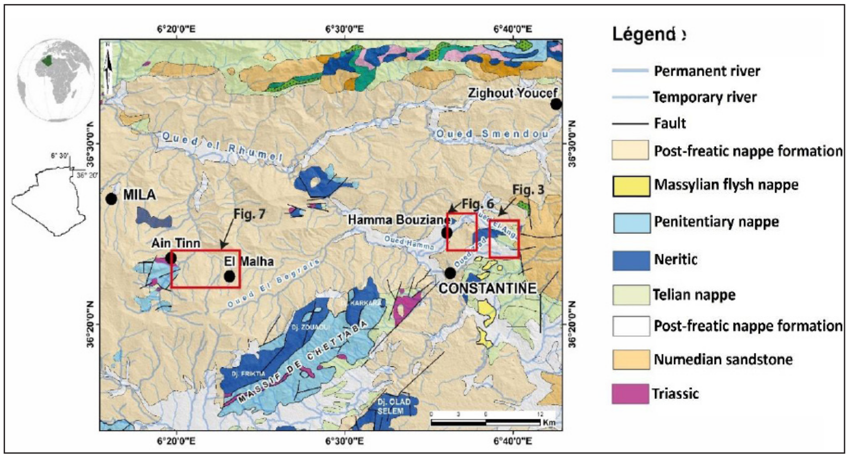

Figure 1. Geological context of the study areas: a- Constantine basin (Extract from Constantine 1/200000). b- Tafrent basin (Extract from El Aria 1/50000). d- Between DjebelAkhal and El Malha (Extract from Constantine 1/50000).

The continental Miocene-Plio-Quaternary came after the nappes filling the Neogene basin of Constantine. Indeed, the Miocene is mainly clayey-sandy and conglomeratic. On the other hand, the Pliocene is represented by lacustrine limestone formations and travertines that occupy summit positions (Coiffait, 1992).

METHODS AND MATERIALS

This work has required the use of topographic and geological maps at small and medium scales where the lack of information at the scale of the slope. The cartographic background used corresponds i) to the topographic and geological maps at 1/50.000 of the sheets n° 73 (Constantine), n° 74 (El Aria), n° 51 (Sididris) and n° 52 (Condé Smendou). ii) as well as the geological map 1/500.000 of northern Algeria. iii) and that of Constantine at 1/200.000.

This cartographic analysis was completed by field observations and analysis of aerial photographs at scale 1:20,000 and multi-date images "google earth". It was supported by some inclinometric and piezometric measurements as well as micro-seismicity recordings and in situ tests (ANA, 2011).

This information allowed us to quantify point displacement velocities that we spatialized after analyzing the morphology and apparent erosion patterns on the slope surface (Crozier, 1986; Guemache, 2011). They finally allowed us to have a global vision of the vulnerability of the slope.

The approach adopted consists in reading, analyzing and monitoring the different factors considered separately or combined at the origin of the instability of the slope. Nevertheless, the morphological heritage remains the main factor at the origin of this instability (slope and surface formations). This precarious instability is broken at the least anthropic action.

Indeed, our work tries to highlight the usefulness of the morpho-geological approach in the identification of the vulnerability of slopes before any intervention (preliminary study).

RESULTS AND DISCUSSIONS

The results obtained confirm our working hypothesis. Indeed, the three cases studied below show the consequences of not taking into account the morphological heritage in the preliminary studies supposed to warn stakeholders of the vulnerability of land affected by the projects.

The Tafrent Area

The structural framework represented by the NW end of Jebel Kellal which is bounded in its northern and western parts by faults of east-west and north-south orientation respectively. Others of lesser importance and slightly different orientation combine to triturate the calcareous substrate. This situation has allowed the installation of a hydrographic network that has become entrenched in the form of a perched basin. As it has favored the karstification of the massifs thus giving resurgences that continuously soak the vulnerable surface formations. It should be noted that the sandstone formations (flysch numidiens) dominating the slope of SW exposure are affected by a dense fracturing showing the two main directions. Thus, they constitute a reservoir that continuously feeds the surface formations located at these feet. In addition, we note that the rejuvenation of the relief has played a prominent role in shaping the current morphology (Vila, 1980; Vila and Coiffait, 1977).

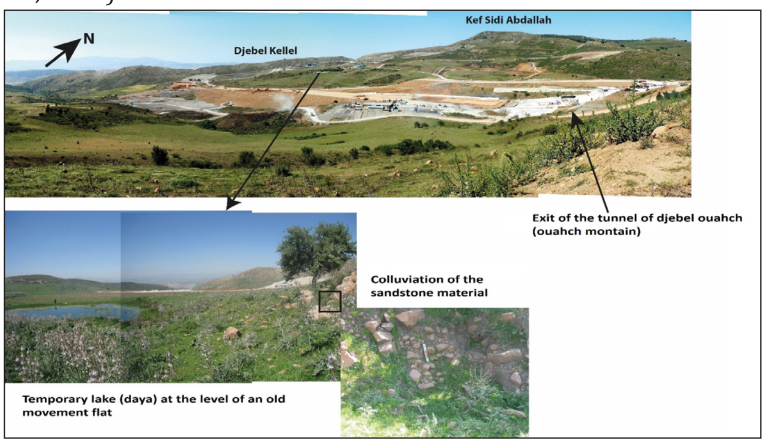

Figure 2. Panoramic photo of the slopes of Tafrent and their morphology.

The basin thus individualized has undergone a filling of ancient Quaternary age (Saletian). This level has been dismantled by the hydrographic network over large areas (Figure 3). The latter were filled in by contributions coming, for the most part, from the clay-sandstone escarpments of the Numidian flysch. This basin is drained by the OuedAanga which shows a rectilinear Talweg (probably following a fault line). It is deeply inscribed by sweeping the ancient Quaternary level. Its embankment was sufficient to create two opposite slopes NE and SW. The NE exposure shows, on the aerial photo, a darker tone indicating a significant and more or less generalized thickness of the superficial formations. On the other hand, the SW exposure shows forms of paleo valleys that have undergone a fairly thick filling mainly from the sandstone front (Numidian flysh) that fed this slope. Thus, this slope is covered by very localized surficial formations (ANA, 2011; Manchar et al, 2012; Achour et al., 2017). Thus, the overall configuration of this environment favors mass movements (in places) that affect vulnerable areas in the Tafrent basin. This basin was crossed in its amant part by the East-West highway over its entire width (about 2 Km) crossing perpendicularly all areas of precarious stability hence the triggering of mass movements of great magnitude. This instability was accentuated by excavation and embankment operations (Figure 4). This situation caused a significant delay and considerable expense for an unconfirmed stabilization of the slope.

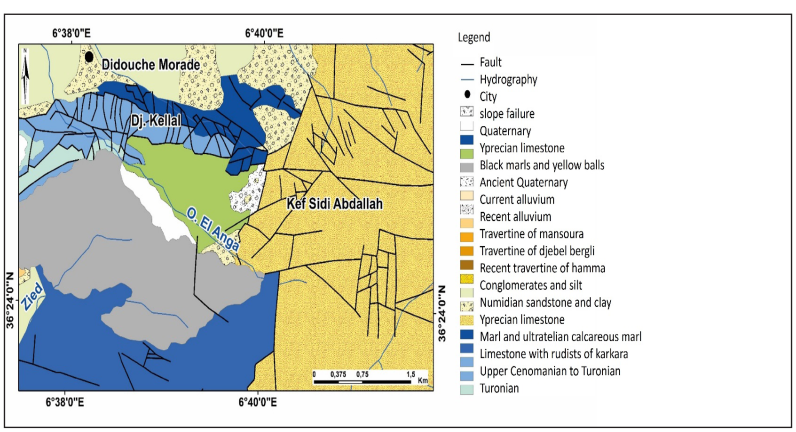

Figure 3. extract of the geological map (El Aria and Constantine at 1/50000eme) modified.

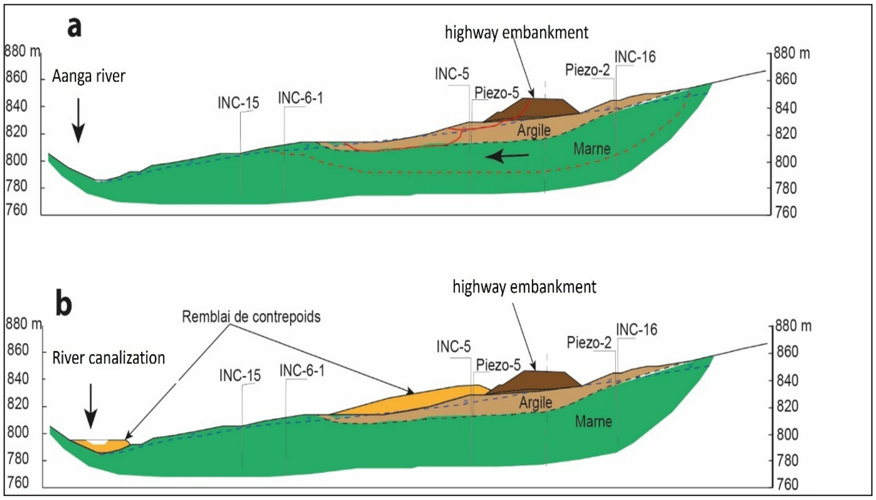

Figure 4. Interpretative section on the NW slope of Tafrent intersected by the highway: a- Fracture lines (1- Fracture line at the base of the superficial formations. 2- probable depths of the fracture line affecting the marl substratum) b-counterweight reinforcement on the landslide bead.

The Northern Slope of Djebel Kellal (at the exit of the Tunnel)

The crossing of the Tafrent basin ends with the breakthrough of a Neritic limestone bar in the form of a Tunnel. The latter opens onto the large Mio-Pliocene basin of Constantine. Its southern limit shows a juxtaposition of a series of alluvial cones of multi-decametric dimensions resulting from the disintegration of the sandstone formations of the Numidian flysch overhanging them.

This morphological heritage of precarious stability was not taken into account when choosing the route of the east-west highway. Indeed, the volume and thickness of these formations did not allow the anchoring of structures or earthworks, hence the very expensive improvised solutions (oversized viaducts) (Figure 5).

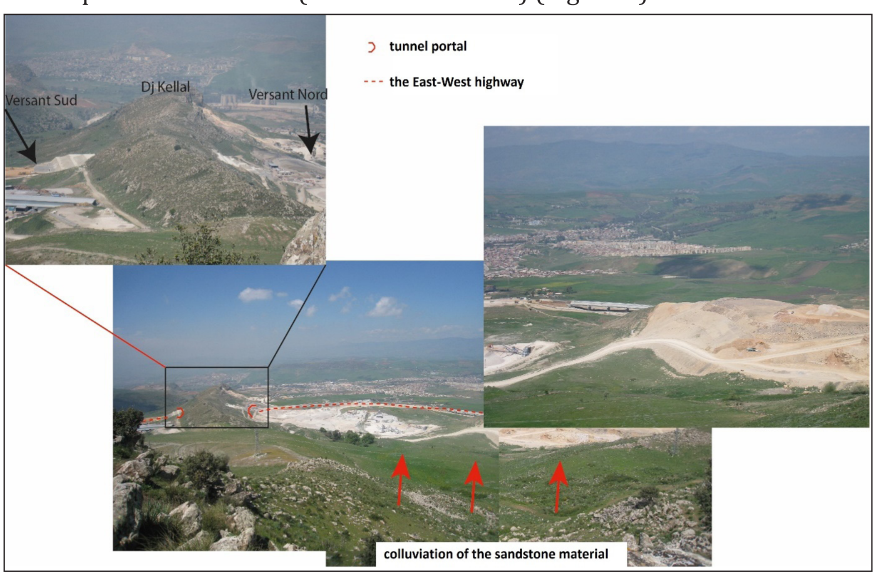

Figure 5. The boundary between the Quaternary Tafrent Basin and the Mio-Pliocene filling of the Constantine Basin, which are represented by the southern and northern slopes of the Dj. Kellal respectively.

The NW Side of Bekira

This slope has shown a very important instability during the opening of the bypass of the city of HammaBouziane on the road Constantine Skikda (RN 3), in its part located at the foot of lacustrine limestone Bekira; particularly during the construction of the station Hamma in the 1940s. It is known that the stabilization lasted for years. Also the road was stabilized by using a dense vegetation by Eucalyptus (tree allowing the anchoring of the formations on

4 m approximately). These operations, along with continuous maintenance, have made it possible to fix the unstable formations in a satisfactory manner. In addition, in the early 1980s, it was decided to bypass the town of Hamma in the continuity of the unstable slope. Indeed, without any prior studies and without taking into account the instabilities (historical) occurred during the previous work mentioned above. (Figure 6).

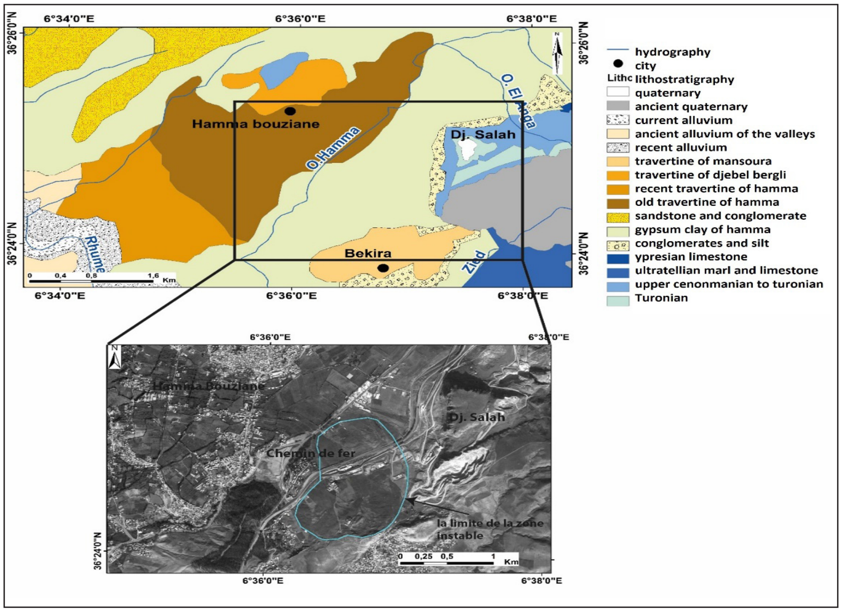

Figure 6. Geological context of the El Hamma-Bekira region (extract from Constantine and ElAria 1/50000).

The Vulnerability of the Western Slope of Bekira

This slope is made up of fairly thick Quaternary formations in the form of colluvium which essentially drape the downstream part of the slope (Figure 6). On the other hand, the upstream part is covered by a juxtaposition of mudflows that can reach 3 to 400 m in length. The substratum is made up of silty-clay formations of Mio-Pliocene age.

However, the slope is dominated by lacustrine limestones playing the role of water reservoir feeding the slope in a continuous way. The Upper Cretaceous limestones of Djebel Salah also participate in this supply. This situation allows to maintain a dynamic by mass movements (muddy flow) in the upstream part of the slope at the foot of the calcareous cliffs. As it allows a preferential circulation at the base of the superficial formations.

This observation is confirmed by the presence of springs in the bed (10 l/sec) of the Wadi delimiting the foot of the slope. Halfway down the slope, at the foot of the mudflows pass the railroad line (Constantine-Skikda).

The Bypass at the Origin of the Rupture of a Precarious Balance

The clearing work carried out at the foot of the slope created a call to the vacuum at the origin of a series of niches of tears that reached the upstream of the slope in a few weeks affecting several hectares and destabilizing the railway line over a length of about 1 km. This situation did not alert the project manager until the instability spread to the entire slope. As a result, the work was suspended calling for further studies to solve the problem, which created considerable delays.

The Slope Jebel Akhal El Malha

This slope represents the southern limit of the Constantine Mio-Pliocene basin (Figure 7) overlooking the pumping station site (located at the edge of the Beni Haroun dam lake). Therefore, the transfer was initially planned to cross over 2 km of the indicated slope. After investigation it turned out that the slope is affected by recent and current mass movements (landslides and mudflows). (Figure 8).

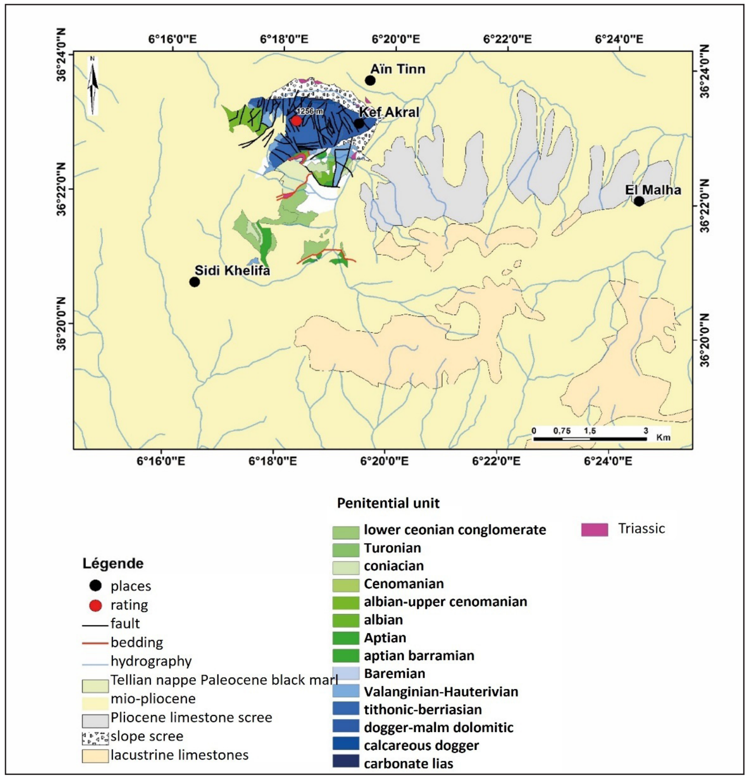

Figure 7. Geological context of the Jebel Akhal- El Malha area (map based on Vila, 1980 and Constantine 1/50000th).

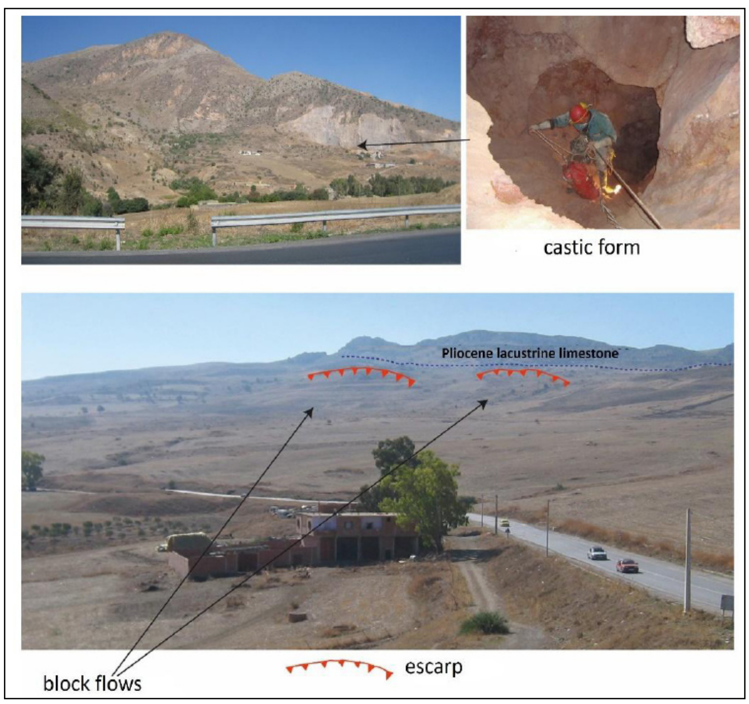

Figure 8. Panoramic photos illustrating the karstic forms of the massif of DjebelAkhal and the slope going towards El Malha.

This situation imposed much more thorough investigations using mainly mechanical drillings up to 50 m deep. With installation of inclinometers and piezometers, in situ and laboratory tests and inclinometer readings. It is to be noted that the ground movements have, as a whole, a rather rapid displacement at a depth not exceeding 5 m (Figure 9). However, in exceptional cases, landslide footings (fracture surfaces) can reach a depth of 20 m. This situation made it difficult to cross the slope without triggering mass movements in formations of precarious stability.

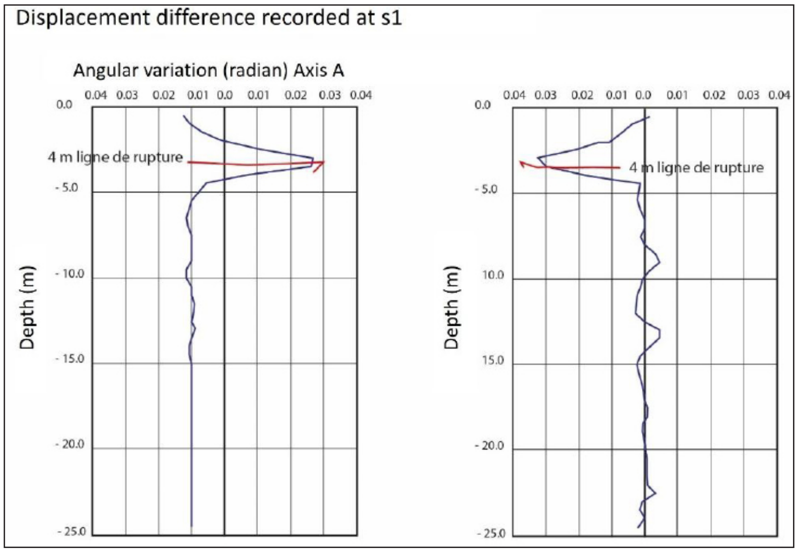

Figure 9. inclinometric measurement showing a displacement at about 4.5 m depth.

This vulnerability confirmed, the decision makers opted to stop the transfer through the slope and choose a second route that crosses this time a limestone massif in this case Jebel Akhal (Figure 8), in the form of a Tunnel. However, after starting to dig the tunnel, the company discovered a karstic network of a height often exceeding 2 m (Fig. 8). Thus the progress of the excavation was certainly rapid and the completion probably took less time than expected. However, during the first pumping operations, the leaks that occurred in the tunnel could not be sealed quickly, resulting in the discharge of a very large quantity of water (pumping station with a flow rate of 23m3/s) into the fractured galleries. This quantity that rushed into the faults caused a series of earthquakes measured by stations controlled by the CRAAG (CRAAG, 2007). These recorded earthquakes have reached the number of 736 events over 10 days of recordings (from 4 to 13/12/2007). They are characterized by their low magnitudes (maximum 3.6) and their low depths (< 7 km on average) (Abacha, 2009). The distribution of the swarm cloud allows us to trace the active fault in a SE NE orientation crossing the southern flank of the DjebelAkhal massif (Figure 10).

Taking into account the vulnerability of the slope, this activity can generate mass movements. It should be noted that these swarms have caused cracks in the houses of nearby settlements (Ain Tinn, El Malha and Azzaba).

Indeed, the testimony of the inhabitants of the area speak of a period of 3 months of aftershocks. It is clear that the preliminary studies have not sufficiently estimated the vulnerability of the two routes to draw attention to the risks involved in crossing the slope and the massif.

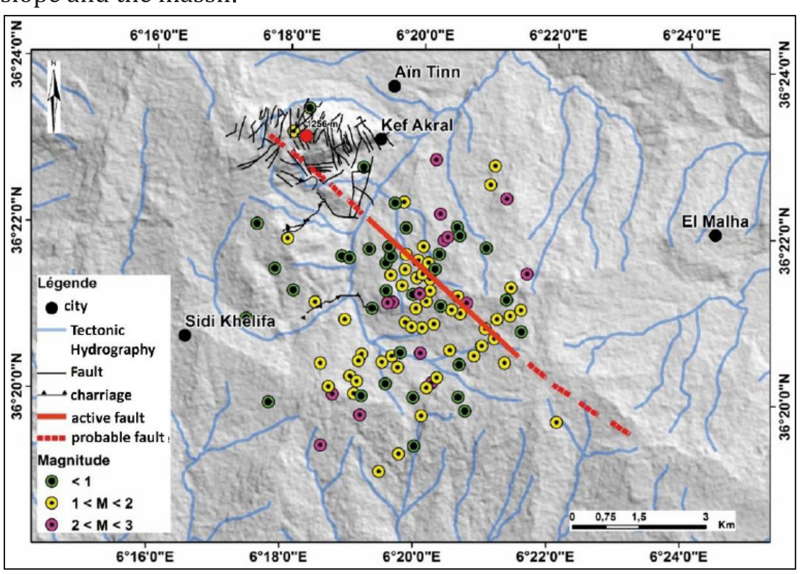

Figure 10. Induced seismicity and active tectonics at Jebel Akhal

CONCLUSION

The existing geological mapping is often on a small and medium scale and only superficially interested in recent formations (Quaternary). These formations are the source of the damage that appears when the work begins. Indeed, in the three cases studied, the same scenario is repeated. The preliminary study is based on small or medium scale geological maps and is mainly interested in the topography of the site. As a result, it ignores all the superficial formations that condition the dynamics of the slopes. Thus, it cannot predict the damage likely to occur during the first modifications made to the site morphology. These results confirm that not taking into account the behavior of the morphological heritage inevitably leads to disorders that are often significant and cause delays and significant additional costs. This work allows us to draw necessary lessons that allow us to avoid the destabilization of these fragile environments.

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