MORPHODYNAMIC AND STRUCTURAL ANALYSIS OF TAMDA LANDSLIDE DAM (MIDDLE ATLAS, MOROCCO)

Allal LABRIKI*

Natural Resources Geosciences Laboratory (LGRN), Department of Geology
Faculty of Science, Ibn Tofail University. BP 133, 14000. Kenitra. Morocco.

Mohamed Amine ZERDEB

Faculty of Sciences and Techniques of Tanger, University of Abdelmalek Essaadi, Morocco.

Issam MAJID

Natural Resources Geosciences Laboratory (LGRN), Department of Geology
Faculty of Science, Ibn Tofail University. BP 133, 14000. Kenitra. Morocco.

Said CHAKIRI

Natural Resources Geosciences Laboratory (LGRN), Department of Geology
Faculty of Science, Ibn Tofail University. BP 133, 14000. Kenitra. Morocco.

Jamal ABBACH

Faculty of Sciences and Techniques of Al Hociema, University of Abdelmalek Essaadi,
Morocco.

Zohra BEJJAJI, Fatima EL HMIDI

Department of Geology, Faculty of Science, Ibn Tofail University. Kenitra. Morocco.

* Corresponding Author E mail: labriki.allal@gmail.com

ABSTRACT

Large landslides are the regular natural hazards frequent in the mountainous areas. They often defined as the movement of a mass of rock sufficient to forms a landslide dam or barrier lake, which obstruct the river water flow. The “Tamda” lake, located 15 km to the north of the Jbel Bouyablane summit, is a natural dam formed by landslide blocked Tmorghot wadi and modified the water circulation and sedimentation. This landslide seem to be triggered by a superposition of several geological factors (predisposition and trigger). In fact, the predisposition inherent in the structural and tectonic setting (strike, dip and fault planes) of the Eastern Middle Atlas allow to determine the nature and the form of the mass movement. In addition, the dissolving and the undermining due to the water flow, and the seismic activity related to the central Middle Atlas great fault, are the main triggering causes of this ground instability phenomena. In addition, seismic activity related to the central

Middle Atlas fault, the dissolution and basal undermining by water flow are the main causes of Tamda landslide.

Keywords: landslide dam, morpho-dynamic, Tamda Lake, Middle Atlas, Morocco

Cite this Article: Allal Labriki, Mohamed Amine Zerdeb, Issam Majid, Said Chakiri, Jamal Abbach, Zohra Bejjaji and Fatima El Hmidi, Morphodynamic and Structural Analysis of Tamda Landslide Dam (Middle Atlas, Morocco), *International Journal of Civil Engineering and Technology*, 11(7), 2020, pp. 52-65.
<https://iaeme.com/Home/issue/IJCIET?Volume=11&Issue=7>

1. INTRODUCTION

Large landslides are defined as mass movements, often affecting unstable slopes in mountainous areas. They generate the movement of large volumes of rocky materials, which can cause considerable damage to infrastructure and human life, It is also sufficient to create obstacles opposing the flow of water (Costa and Schuster, 1988)[11]. The “Tamda” rockslide, located in the Eastern Middle Atlas, at 15 km to the north of the “Jbel Bouyablane” summit, is a large-scale movement affecting the southern slope of “J. Ich Nerkibat”, and which mobilized a large volume of rocky materials (fig.1). This volume of rocks was large enough to form a dam that prevents the water flow from the Oued valley “Çouf Igrane” in the upstream area of the “Tmorghot” wadi, and formed the natural lake “Guelta Tamda”(El Fellah, 1994 ; Obda et al., 2009)[15][28] (fig.1c), with a flood zone extending over almost 3 km and an area of approximately 45 ha (Obda et al., 2009)[28].

Figure 1 Geographical location of the study area: (a) the administrative situation in the south of the Taza province; (b) high resolution Google Earth image of the study area; (b) photographic view of the “Guelta Tamda” lake from the “landslide dam” body.

The study area, limited to the watershed of the "Çouf Igrane" wadi, presents a very particular geomorphological aspect generally oriented NE-SW. Towards the downstream, the hydrographic network shows a very deep encasement, generally favored by brecciated formations in the fault plans (Sabaoui, 1998)[30] ; to upstream, this network reveals several topographical anomalies probably associated with intensive karstification or tectonic activity. Hydrologically, the Tamda landslide changed the appearance of the basin to an endorheic basin(fig.1b), where the "Guelta Tamda" lake constitutes a reservoir of runoff water, which supplies the underground karst reservoirs during low water periods.

2. MATERIALS AND METHODS

In order to determine the process of triggering this large landslide. We used two different approaches. On the one hand, it is a morpho-dynamic analysis, based on the interpretation of topographic data and the analysis of a high resolution Google Earth image, which aims to determine the type, speed and age of the slide, so as to draw up a detailed morpho-dynamic map of the slide area ; on the other hand, a morpho-structural analysis of the predisposing factors has been devoted to defining a geometric triggering model. For this, it is first necessary to determine the lithostratigraphic and tectonic predisposition in this area of the pleated middle atlas. By adopting a mapping strategy, based on the processing of a "Sentinel-2A" satellite image acquired on 25-12-2017, and visual photo-interpretation for manual digitization of all tectonic and structural anomalies.

3. THE GEOLOGICAL AND SEISMOTECTONIC CONTEXT

The Middle Atlas chain is subdivided into two structural units separated by the North Middle Atlas great fault (Choubert 1956; Martin 1973, 1981; Hollard et al. 1985)[9][24][20] (fig. 2a): the Middle Atlas Causse is structured in tiered trays which reflect an organization in tilted blocks ; and the pleated Middle Atlas arranged in anticline wrinkles and separated from large synclinal depressions (Soufiani & Fedan, 2002)[31]. The sector studied is part of the pleated Middle Atlas north of Bouyablane. It is bounded by the wadi watershed "Çouf Igrane" which stretches structurally over the Tamatroucht syncline (fig. 2b).

Figure 2 The geological and tectonic context : (a) simplified geological map of the Middle Atlas and the Upper Moulouya (from Fedan et al., 1989)[19] ; simplified geological map between the "J. Ich Nerkibat" ride and the "J. Bouyablane" ride (from Sabaoui, 1998)[30] with the location of the study area.

The structure of the Tamatroucht syncline responds adequately to the tectonic setting, organized in wrinkles and depocentres (Fedan 1989; Sabaoui, 1998)[19][30], responsible for the individualization of the middle Atlas basin. The sedimentary succession in this syncline is relatively similar to that of the El Mers syncline, and combined with the development of the carbonate platform during the lower and middle Lias (Dresnay, 1963, Choubert & Faure-Muret 1967, Fedan 1989)[10][14][19]. Indeed, the wrinkles bordering this region are made up above all of calcario-dolomitic series of the lower Lias, but the more than we move towards the center of the syncline one marks the appearance of a depocenter series constituted essentially by the marl-limestones of the Middle and upper Lias, surmounted by a marly Dogger formation (Sabaoui, 1998)[30]. On the north side, this sector is marked by the central Middle Atlas great fault which played a major role in the fracturing of rock massifs, and which controls seismic activity in this region(fig. 2b).

4. MORPHO-DYNAMIC ANALYSIS OF THE TAMDA LANDSLIDE

The landslide started at an altitude of 2020 m on the South-Eastern slope of the monoclinic wrinkle of “J. Ich Nerkibat”(Fig. 3). A difference in altitude of 680 m provided enormous kinematic energy to the sliding body, of a considerable volume of calcario-dolomitic formations, suddenly detached from the upper envelope and which ended with the creation of a rocky barrier in the bottom of the “Çouf Igrane” valley(Fig. 3b). The blockage of water flow by this dam created the natural lake “Guelta Tamda” with 3 km in length and about 300 m in width. The observation and analysis of a high resolution Google Earth image shows that the sliding zone is affected by a single displacement of the material which reflects a simple translational morphology according to the classification of Varnes (1978)[33] and (Dikau et al., 1996)[13], and can be roughly divided into three different zones which undoubtedly correspond to the zones defined by Millies-Lacroix in 1981[25] (Fig. 3a) :

- The upstream sector : detachment zone or sliding head (Main scarp) ;
- The intermediate zone : surface of the slide or transport zone (Hu et al., 2018)[21] ;
- The downstream sector: accumulation zone occupied by the body of the slide (Hu et al., 2018)[21].

Figure 3 The morpho-dynamic map of the landslide dam “Tamda” (a), with a synthetic section along the landslide areas (b).

4.1. The Upstream Sector

The "starting" zone is characterized by a main detachment slope which extends over 2300 m, with a steeper section on the West side visible by a height exceeding 220 m in the upper part (Fig. 4b). On the north side this crown takes a less abrupt shape marked by the presence of an escarpment linked to the sagging of the sliding body. However, a fissure network fragments the crown and the back of the main landslide escarpment, testifying to the recent action of the traction forces affecting the slope (Fig. 4b). The image analysis, from photographs taken in the field, Shows that this sector evolves mainly by the collapse of blocks or the collapse of cliffs (Fig. 4c). Vertical cracks and the topographic amplification effect on seismic waves (Bouchon & Barker, 1996)[4] facilitate the detachment of large rock sections "co-seismic mass movements". These movements are localized mainly along the western section and presents an ablation zone with an almost vertical escarpment, formed in the massive calcario-dolomitic formations of the lower Lias.

Figure 4 The upstream sector : (a) morpho-dynamic map with the location of the main escarpment ; (b) photographic view of the main escarpment showing very intense fracturing and shear planes subparallel to the surface slope ($\alpha = 42^\circ$) ; (c) the main faults directing the sliding movement.

4.2. The Intermediate Zone

This area constitutes a flat surface of more than 306159 m² on which the body slide has moved, roughly oriented E-W with an average slope of 48.56% directed towards the South and strictly follows the dip of the dolomitic formations of the lower Lias. The observation of

certain shear planes in the main detachment slope, affirms that the rupture also occurred by the development of a shear surface in the stratification joints. In addition, this intermediate zone is covered, along the foot of the main escarpment which borders the slide on the west side, by accumulation cones filled with gravity debris resulting from a permanent fragmentation at the top of the slide (Fig. 5a). At the granulometric level, these gravity deposits are heterogeneous with a generally coarse particle size, centimetric to decimetric, as well as grading is decreasing from bottom to top. On the other hand, the trees show many signs of previous damage from falling stones and the stems of Holm oak are generally short and twisted (Fig. 5b). These field data confirm that the slide activity is still continuing with a regression phase of the main crown by rock collapses and falling boulders.

Figure 5 The intermediate sector : (a) debris cones and deposits of recent rockfall activity toward the foot of the talus slope ; (b) the green oak trees at the foot of the talus slope show ample evidence of past rockfall damage, their stems are typically short and twisted with multiple scars and callus pads are seen on the stem surface.

4.3. The downstream Sector

The accumulation zone appears as a chaotic body occupying a relatively narrow zone of the "Çouf Igrane" valley. It measures approximately 785 m long and 670 m wide, and covers an area of 415870 m² with an estimated volume of 20278485 m³. The plan view of this deposit area shows the shape of a dam filling the entire bottom of the valley, and goes up the opposite slope to around 150 m in height. According to the classification of Costa and Schuster (1988)[11], these characteristics refer to a "Type II" landslide dam. In view of its morphometric characteristics, the deposits of this body of the dam slide are very heterogeneous with a wide range of element sizes (Fig. 6) ; it seems that the middle and lower layers have not strongly disintegrated and consist of almost intact rock masses resulting from a direct translation from the source zone towards the bottom of the valley (fig. 6a) ; the external cover is mainly composed of debris and fragments of variable sizes (Fig. 6 b, c), mixed with metric blocks strongly disintegrated by a burst due to shock in a very high speed movement (Fig. 6d). Consequently, we note that such a structure can only occur in a deep rocky slide, which will lead us to specify the type of dam slide in "Sub-type III" according to the classification of Fan et al. (2017)[18].

Figure 6 The downstream sector : (a) the body slide still has intact layers due to translational movement ; (b) the materials mobilized exhibit very intense fracturing ; (c) the body slide is covered by chaotic deposits of different sizes ; (d) exploding figures at the rock structure indicating a very fast speed of movement.

4.4. The Stability of the Dam

Lakes dammed by landslides can last several minutes or several thousand years (Costa and Schuster, 1988)[11]. The duration of a landslide dam is likely to be short when a small landslide blocks a stream with a fairly large watershed (Swanson et al., 1985)[32]. Many factors, including the volume and the dam shape, the geotechnical characteristics of the dam materials, and the infiltration rate through these materials and the water flow into the newly formed lake (Costa and Schuster, 1988)[11]. Regarding the stability and durability of these lakes, landslide dams of “subtype III” tend to be more consolidated than those of “subtypes I and II”(Fan et al. 2017)[18], which are therefore less likely to undergo a complete rupture. The Tamda dam is mainly formed by a deep rocky slide which runs aground as a largely intact mass and flows into the narrow valley of "Çouf Igrane". The filling level, indicated by the twigs and plant debris deposited by the water (fig. 7), never exceeded the level of the dam, which shows that the annual water inflows are generally lower than infiltration and evaporation (filling speed < emptying speed). So nowhere can the dam fill up to overtopping so that its materials can never be eroded due to overflowing. Consequently, and in view of the geotechnical characteristics of the deposits, it can be seen that the “Guelta Tamda” dam is durable and very stable.

Figure 7 Dam stability indices: (a) An extract from the Google Earth image with the location of the photographic views “b and c” ; (b) and (c) the maximum water level indicated by the twigs and plant debris does not show any overshoot.

5. MORPHO-STRUCTURAL ANALYSIS OF PREDISPOSING FACTORS

In rock massifs, the state of degradation over time will be linked to the action of several factors (Antoine & Giraud, 1992; Azimi & Desvarreux, 1996; Couture et al. 1997)[2][3][12]. First of all, it is necessary to understand the natural evolution of a massif or a slope to know the type of ground movement that could happen. In the structural overview of our study area, there is a structure that does not show much variation. We essentially have a succession of anticline or faulty monocline folds, which are narrow, and broad synclinal folds with a flat bottom (Sabaoui, 1998)[30]. The lithological map obtained from the analysis of the "Sentinel-2A" multi-spectral image shows these two structures (Fig. 8 a, b). The first type is designated by the anticlinal forms, which limit the study area by the monoclinical wrinkle of "J. Nerkibat" on the North side, and the wrinkle "d'Ich N'Tchoumt" and "J. Tikchar" on the South side (Fig. 8b) ; the second type is designated by the Tamatroucht syncline separating the two wrinkles previously described. It corresponds to a fairly wide synform area with an N70 direction.

For the fracturing analysis, we adopted a mapping strategy based on visual photo-interpretation, and only the lineaments qualified as tectonic anomalies (faults, fracturing) were digitized (Fig. 8b). At the kilometer scale, the satellite image shows the existence of two families of regional extension faults, with a well pronounced aspect marked by the installation of the hydrographic network (fig. 8b). The first family is generally oriented NNE-SSW and cuts the Tamatroucht syncline transversely by a sinistral strike-slip fault, to guide the

installation of the Oued "Çouf Igrane" and "Oued El Bard" valleys ; the second family shows a clearly visible cartographic expression on the surface, with a regional extension smaller than that of the first type.

Figure 8 The morpho-structural analysis and the photo-interpretation of the "Sentinel-2A" satellite image acquired on 25-12-2017 (a) ; (b) the lithological and fracturing map obtained from the "Sentinel" image; (c) the rose diagram obtained from the fracturing analysis.

These faults are expressed by a network tectonic discontinuities oriented NNW-SSE, which this time indicate a dextral strike-slip. On the decametric scale, we have produced a fracturing map which includes approximately 4256 fractures of varying sizes (fig. 8b), the rose diagram of this fracturing also exposes the two main directions of the two fault families (fig. 8c). Consequently, the observation and analysis of the strike-slip faults

previously described, shows that these faults are presented by deformation corridors comprising many conjugate secondary faults. In addition, the spatial organization of this fracturing network shows an eventual division of the carbonate materials into a rhombic block system giving the segmented appearance of the structures, which show the geometric arrangement into several blocks of rupture polyhedra.

6. THE TRIGGERING FACTORS

On the scale of a mountain range, earthquakes are able to generate several landslides (Keefer, 1994; Marc et al., 2016b; Hu et al., 2018)[26][22][21], with an amplitude that increases more than the magnitude of the earthquake considered is high (Keefer, 1984)[22]. In Morocco, many authors have already reported that the action of historical seismicity (tab. 1) would have been the cause of several topographical upheavals (El Mrabet, 1991; Chaouki, 1991)[17][5] and many large-scale landslides (El Fellah et al. 1996, Labriki et al. 2019)[16][23]. The Fez earthquake on 11-05-1624 (tab. 1) was considered, with the Lisbon earthquake in 1755, as the strongest historical seismic event that affected Fez and its surroundings (Cherkaoui et al., 2017)[8]. So, due to the proximity of the Tamda landslide to the epicentral region of the Fez earthquake, and its position on the southern limit of the central Middle Atlas great fault, we can consider this dam landslide as a contemporary seismic event.

Table 1 The main destructive historic earthquakes in Morocco of intensity greater than VIII (Cherkaoui, 1991)[7].

Date	Epicentral region	Intensity	Affected regions in Morocco
1079	?	?	Considerable damage and several deaths in Morocco
1276	Larache	?	Would have caused the destruction of the city and causing several deaths
22-09-1522	Almeria	IX	Destruction of Fez and Peñón de la Gomera; damage in Tetouan
11-05-1624	Fez	IX	Would have completely destroyed Fez, Meknes and Taza; The port of Peñón de la Gomera was damaged.
1719	?	?	Would have destroyed a part of Marrakech and was felt in Fez
27-12-1722	Atlantic	X	Great damage on the West Moroccan coast
1731	Atlantic?	VIII	Destruction a part of Agadir
01-11-1755	Atlantic	X	Thousands of deaths and considerable damage throughout the northern half of Morocco
12-04-1777	Atlantic	VIII	Would have completely destroyed Tangier
31-08-1792	Melilla	VIII	Destruction of several buildings in the city

On the climatic level, the region studied is part of a climatic domain, Mediterranean mountain, humid to sub-humid in cold winter (Zeryouhi, 1970; Obda et al., 2009)[34][28], with an average rainfall of 678.4 mm/year registered in Tamtroucht (tab. 2). The snowfall is high on the mountains from 1400 m, and can remain on the summits for several weeks. On the Bou Iblane summit (3190 m), the snow cover period can extend from mid-November to the beginning of June. As for temperatures, they are not very high, with annual averages that do not exceed 18°C (tab. 2), and can drop less than 0°C during the period October-April.

Storing this precipitation water in the snow form can increase the mass overload on the slopes and trigger landslides. Furthermore, the structural state of the carbonate formations promotes infiltration and intensification of the dissolution processes resulting in the development of different karst forms such as dolines, avens and poljés. The high resolution Google Earth image analysis shows that these forms of dissolution are widespread in the southwest of the study area (fig. 8b), which indicates that this region has undergone a very advanced phase of karst evolution.

Table 2 Average annual rainfall and temperature between 1980 and 2019 (Data From National Forestry Research Center (NFRC))

Station	Latitude (N)	Longitude (W)	Altitude (m)	Rain (mm /an)	Temperature (°C)
Tazekka	34°11'	4°12'	1380	851.4	18
Bou Iblane	34°14'	4°02'	2500	678.6	18
Tamtroucht	34°14'	4°01'	2450	678.4	17

7. DISCUSSION

There is no longer any doubt, after morpho-dynamic analysis, that the geometric shape of the Tamda landslide reveals a process of translational collapse, which develops exclusively in rock formations with major discontinuities (stratigraphic joints, subvertical fractures). It also appears, from the sliding body shape and the bursting figures in the structure of this body, that the speed of movement was extremely fast.

On a local scale, the morpho-structural analysis of the predisposition to movements shows : On the one hand, that the rupture of the Tamda landslide inherent to the southern slope of "J. Nerkibat ", strictly meets the litho-stratigraphic arrangement in inclined layers in the anticline folds. On the other hand, the fieldwork shows at least two types of fault planes played a major role in the rupture, the first type is that of a normal fault oriented NNW-SSE with dextral strike-slip, drawing the line from a spectacular main escarpment ; the second type is clearly visible at the sliding foot, and associated with a fracturing network oriented NNE-SSW. At the regional level, the analysis of fracturing shows that this fault system observed at the local scale, is reproduced widely along the corridor limited by the two major faults (Central and South Middle Atlas great faults). This confirms that the surface traces of this large-scale fault system in this region are compatible with brittle deformation, in accordance with formation of classical Riedel shears (Chemenda et al., 2016)[6], including the faults NNE-SSW and NNW- SSE which develop in echelon, respectively designate R and R' Riedel's fracture networks in an area affected by a sinistral shear (Riedel, 1929)[29].

To explain the failure mode of the Tamda landslide as well as in all places of the same structural conditioning on a regional scale. We have proposed a geometric model based on the appearance of fracture polyhedra, limited by the intersection of the structural planes of the synthetic (R) and antithetic (R') conjugate faults on the one hand, and by inclined planes of the stratigraphy in the monoclinical folds on the other hand. In addition, it also seems that in this kind of rupture linked to the appearance of rupture polyhedra as is the case for The Eaux-Bonnes landslide (Western Pyrenees, France), where the undermining caused by erosion due to the formation of a deep canyon at the bottom of the slope is considered to be an essential predisposition factor for failure (Martins-Campina et al., 2008)[27]. Which gives that the location of several landslides on the left bank of the "Çouf Igrane" valley, is signified by the action of the basal undermining of this valley.

In certain geomorphological contexts, landslides can generate gigantic natural lakes when they block the flow of water, as was the case with the Usoi dam in Tajikistan during the Sarez earthquake of 18-02-1911 (Alford et al., 2000)[1]. The Moroccan historical seismicity analysis shows that the earthquake of 11-05-1624 which completely destroyed Fez and its surroundings (Meknès and Taza) (Cherkaoui, 1991; Cherkaoui et al., 2017)[7][8], would have been sufficient to trigger the Tamda dam slide . So that, this type of earthquakes intervene either, by the reduction of the resistance to the friction of the substrate by breaking the rock mass, or by episodic changes of the short-term stresses lead by the seismic acceleration (Fan et al., 2017)[18]. However, heavy precipitation also seems to have played a major role, as it could have been responsible for the accumulation of water in the snow form which induces a

loading effect on the slopes, as well as their cumulative effect of the hydrostatic pressure and dissolution phenomena.

8. CONCLUSION

Although we consider here that Lake Tamda is one of the rarest persistent landslide dams in the world, most of these lakes suddenly empty by rupture or overflow (Costa and Schuster, 1988)[11], causing devastating debris flows and devastating floods. Knowledge of the control factors, which led to the collapse of the Tamda landslide, and the development of a model explaining the conjunction between all of these factors, may be the first step in establishing a hazard map that will specify the distribution of potentially unstable sites under similar conditions on a regional scale. In addition, this study will also contribute to enriching the basic data on these natural phenomena, for scientific research on the functioning of landslide dams on a global scale.

REFERENCES

- [1] Alford, D., and Schuster, R. L., 2000. Introduction and summary. In Alford, D., and Schuster, R. L.(eds.), *Usoi Landslide Dam and Lake Sarez. An Assessment of Hazard and Risk in the Pamir Mountains, Tajikistan*. ISDR Prevention Series, No 1. New York/Geneva: UN, pp. 1–18.
- [2] Antoine, P., Giraud, A., 1992. Typologie des mouvements de versant dans un contexte opérationnel. *Bulletin de l'Association Internationale de Géologie de l'Ingénieur*, 51 : 57-62
- [3] Azimi C. & Desvarreux P. 1996. -Quelques aspects de la prévision des mouvements de terrain. - *Revue Française de Géotechnique* n°76, 3ème trimestre, 63 – 74 pp.
- [4] Bouchon, M., and J. S. Barker (1996). Seismic response of a hill: The example of Tarzana, California. *Bulletin of the Seismological Society of America* 86, 66-72.
- [5] Chaouki A., 1991; Les mouvements de terrain et les risques associés dans la région de Bab Taza (Rif occidental). Thèse de l'université, Strasbourg , 211p.
- [6] Chemenda AI, Cavalié O, Vergnolle M, Bouissou S, Delouis B. Numerical model of formation of a 3-D strike-slip fault system. *C R Geosci* 2016;348:61–9.
- [7] Cherkaoui T.E., 1991. Contribution à l'étude de l'aléa sismique au Maroc. Thèse Doctorat, Univ. Grenoble, France, 246 p.
- [8] Cherkaoui, T.E., Medina, F., & Mridekh, A. (2017). Reevaluación de los parámetros del sismo mayor de Fez del 11 de mayo de 1624. *Física De La Tierra*, 29, 135-157. <https://doi.org/10.5209/FITE.57469>
- [9] Choubert G. 1956. Carte géologique du Maroc au 1/500.000, feuille Rabat. Notes et Mém. Serv.géol. Maroc, 70.
- [10] Choubert G. & Faure-Muret A. 1967. Le Jurassique de la région d'El Mers-Skoura (Moyen Atlas). Notes et Mém. Serv. géol. Maroc, 200, 9-32.
- [11] Costa, JE., Schuster, RL. (1988) The formation and failure of natural dams. *GeolSoc Am Bull* 100:1054–1068
- [12] Couture R., Antoine P., Locat J., Hadgigeorgiou J., Evans S.G. & Brugnot G., 1997. – Quatre cas d'avalanches rocheuses dans les Alpes françaises. – *Canadian Geotechnical Journal*, 34, 102-119
- [13] Dikau, R., Brunsden, D., Schrott, L., Ibsen, M.-L., 1996. *Landslides Recognition, Identification, Movement and Causes*. John Wiley & Sons, New York, 251 p.

- [14] Dresnay R. du 1963. Données stratigraphiques complémentaires sur le Jurassique moyen des synclinaux d'El Mers et de Skoura (Moyen Atlas, Maroc). Bull. Soc. géol. France, 7, 6, 883-900.
- [15] El Fellah B., 1994. Guelta Tamda (Moyen Atlas Plissé. Maroc) : un exemple de lac de barrage naturel. RGM. 16. pp. 115-125.
- [16] El Fellah B., Azzouz O. & Asebriy L. 1996. Sikha d'Asfalou; exemple de glissement littoral sur la côte méditerranéenne de Bokoya entre Torrès et Bades (Rif, Maroc). ORSTOM, réseau érosion, Bulletin 16, 222-230.
- [17] El Mrabet A., T., 1991 - Histoire sismologique du Maroc. Doc. 3ème cycle, Fac. des Lettres, Univ. Mohammed V, Rabat, 375p.
- [18] Fan, X., Xu, Q., van Westen, C.J. et al. Characteristics and classification of landslide dams associated with the 2008 Wenchuan earthquake. *Geoenviron Disasters* 4, 12 (2017). <https://doi.org/10.1186/s40677-017-0079-8>
- [19] Fedan, B. (1988) Evolution géodynamique d'un bassin intraplaque sur décrochements : le Moyen Atlas (Maroc) durant le MésoCénozoïque. Thèse d'Etat, Univ. Mohammed V, Fac. Sci. Rabat, 337.
- [20] Hollard H., Bronner G., Marchand J. & Sougy J. 1985. Carte géologique du Maroc au 1/1.000.000. Notes et Mém. Serv. géol. Maroc, 260.
- [21] Kaiheng Hu, Wu Chaohua, Jinbo Tang, Alessandro Pasuto, Yanji Li, Shuaixing Yan (2018) New understandings of the June 24th 2017 Xinmo. Landslide, Maoxian, Sichuan, China. *Landslides* 15: 2465. <https://doi.org/10.1007/s10346-018-1073-2>
- [22] Keefer D.K. (1984). Landslides caused by earthquakes. *Bulletin of the seismological society of America*, 95, p. 406-421.
- [23] Labriki, A. ; Chakiri, S. ; Razoki, B. ; Bejjaji, Z. ; El Hmidi, F. & Kaid Rassou, K. – Study of the geo-mechanical evolution of the Paleozoic massif of Al Hoceima's tectonic klippe, by analyzing the instability structures and the interpretation of geotechnical data (Rif, Morocco), *Bulletin de l'Institut Scientifique, Rabat, Section Sciences de la Terre*, 2019, n° 41, 13 - 23
- [24] Martin, J. (1981) Le Moyen Atlas Central, étude géomorphologique. Notes Mem. Serv. Geol. Maroc 258, 445.
- [25] Millies-Lacroix A., 1981 – Classification des talus et versants instables. Bull. Liaison Labo. P. et Ch., Numéro spécial X, p.55-62.
- [26] Marc, O., Hovius, N., Meunier, P., Gorum, T., and Uchida, T.: A seismologically consistent expression for the total area and volume of earthquake-triggered landsliding, *J. Geophys. Res.-Earth*, 121, 640–663, <https://doi.org/10.1002/2015JF003732>
- [27] Martins-Campina B., Huneau F., Fabre, R., 2008 : The Eaux-Bonnes landslide (Western Pyrenees, France): overview of the possible triggering factors with emphasis on the role of groundwater. *Environmental Geology*, 55, 397-404.
- [28] Obda k, Taous A, Sabaoui A, A. M. (2009). Hydrologie du Haut Mouloulou(Moyen Atlas Nord Oriental). *GéoMaghreb*, 5, 89–102.
- [29] Riedel, W., 1929. Zur Mechanik Geologischer Brucherscheinungen. *Zentralbl. Mineral. Geol. Palaeontol. B.* 354–368.
- [30] Sabaoui A. (1998). Rôles des inversions dans l'évolution méso-cénozoïque du Moyen Atlas Septentrional (Maroc). exemple de la transversale El menzel-Ribat El Khir- Bou Iblane.

- [31] Soufiani, N. & Fedan, B. – Les dépôts bathoniens du synclinal d'El Mers (Moyen Atlas, Maroc) : unités formationnelles, analyse et cadre géodynamique, Bulletin de l'Institut scientifique, Rabat, section Sciences de la Terre, 200 2, n° 24, 1-14.
- [32] Swanson, F. J., Graham, R. L., and Grant, G. E., 1985, Some effects of slope movements on river channels, in International Symposium on Erosion, Debris Flow, and Disaster Prevention, Proceedings: Tsukuba, Japan, Erosion Control Engineering Society of Japan, p. 273-278.
- [33] Varnes D.J., 1978. Slope Movement Types and Processes. In Special Report 176: Landslides: Analysis and Control. In: Schuster, R.L., Krizek, R.J., (Eds), Transport Research Board, National Research, 11–33.
- [34] Zeryouhi I. (1970) : Etude géologique et hydrogéologique de la partie nord-est du Moyen-Atlas plissé et de la Moulouya inférieure. Thèse de spécialité. Univers, de Montpellier et rapp. inéd. MTPC/DH/DRE, 179 pp