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Slim Aliouet
Department of Geography, CGMED Laboratory, Faculty of Arts and Human sciences of Sousse, Tunisia

Corresponding Author:
Slim Aliouet
Department of Geography, CGMED Laboratory, Faculty of Arts and Human sciences of Sousse, Tunisia

Geomorphological landscape of the southern foothill of Jbel Alima-Chouabine, Metlaoui chain (South-West of Tunisia): Diversity of pleistocene heritages and chrono-stratigraphic proposal

Slim Aliouet

Abstract
Five Quaternary units, dating from the Middle Pleistocene to the Historic period, are identified in the study area. They are the results of the activities of various morphodynamic agents. Diffuse waters were responsible for shaping two generations of glacis from Middle to Late Acheulean (Middle to Late Pleistocene). Torrential and diffluent waters, for their part, generated the interlocking of two generations of alluvial fans, attributed to the Mousterian and the Capsian (Upper Pleistocene to Holocene). In addition, the longitudinal water inputs from the mountain system are responsible for the establishment of a single generation of terrace attributed to the Capsian (Holocene to Historical) which fits into all of the quaternary forms described.
The study of the forms and deposits of quaternaries allowed us to draw a synthetic section. This shows the position as well as the chrono-stratigraphic succession of different units by representing the morphological evolution of the studied area.

Keywords: Quaternary, geomorphological landscape, forms, deposits, chrono-stratigraphy and morphological evolution

1. Introduction
The southern foothill of Jbel Alima-Chouabine, occupies the central part of the Metlaoui chain. It comes in an elongated oval shape. It is separated from jbel Zeref by the Thèlja lock on the eastern side. In its western part is separated from jbe Al Blijou by the valley of Doukhane Hamda. Jbel Alima-Chouabine differs from the rest of the Metlaoui range by its development (Jbel Alima 13.5km and Chouabine approximately 7km), which orient from West to East, culminating at 748m at the level of Alima and at 735m for Jbel Chouabine. It has a concave profile and strongly dissected by well-set rivers such as river Segdoud and river Mzinda. (Figure 1).

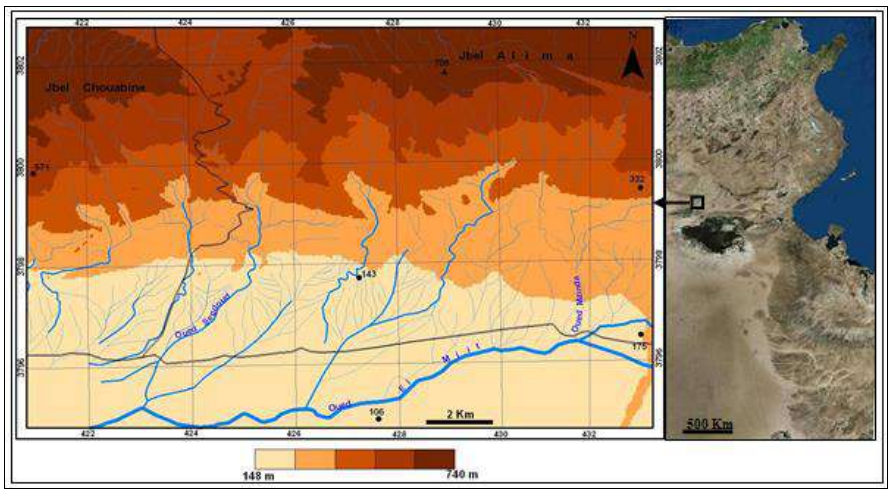

Fig 1: Digital elevation model showing the location of the study area.

The geomorphological landscape of our study, have been the subject of several studies and at different scales. Such us, the work of Roux, 1911 [17]; Vaufrey, 1932 [20]; Castany, 1953 [53]; Castany & Gobert, 1954 [54]; Coque, 1962 [12]; Coque & Jauzein, 1965 [13]; Zargouni 1984 [21]; Zargouni, 1986 [22]; Boukadi, 1989 [9]; Ballais & al. 1988 [3]; Ballais, 1991 [4]; Sghari, 1991; Ballais and Ben Ouezdou, 1992 [4]; Ballais & al. 1995 [5]; Dlala & Hfaeidh 1993; Ben Ouezdou & Zargouni 1988; Ben Ouezdou, 1994; Zouari, 1990; & 1995; Said, 2011; Gasmi, 2012; Aliouet, 2017 [1]. Aliouet, & all, 2020 [2].

2. Materials and Methods

In this work we have tried to cross and develop the material provided by previous geomorphological research, Quaternary and prehistoric geology with those obtained by multiple cartographic supports at very high resolution, and geomorphological cartography at large-scale, to field observations carried out at the level of the various units on the southern footslope of Jbel Alima-Chouabine. In order to study their setting in the geomorphological landscape and to establish a chrono-stratigraphic diagram in correlation with the existing chronology for South West Tunisia.

The various cartographic, photographic and satellite data and the very high resolution images used for the study and the mapping of the geomorphological landscape of the southern foothill of jbel Alima-Chouabine are presented in Table 1.

To achieve our objectives, the data used were geo-referenced in the same coordinate system: UTM projection-Zone 32 – and WGS 84 ellipsoid reference under ENVI software (Exelis-Visual Information Solutions, USA). All these layers were held within a Geographical Information System (ArcGIS, ESRI, USA).

Table 1: Data used

Database	Date	Scale	Title
Topographic maps	1957 and 1993	1/100000 and 1/50000	Metlaoui
Geological map	1985	1/100000	Metlaoui
	1952	1/25000	
Aerial photographs	1963	1/25000	Chain of Metlaoui
	1990	1/60000	
ASTER satellite image	2000	15 m	Chain of Metlaoui
Landsat ETM+ image 2001	2001	30 m	Chain of Metlaoui
Very high resolution Google image	2009	15 m	
	2012	10 m	Chain of Metlaoui
	2015	5 m	

The general methodology adopted for the gemorphological mapping of these quaternary forms and deposits, is illustrated in Figure 2. Topographic and geological maps, are essential data for defining and describing the topographic, hydrographic and structural features of the study area. Their use allowed us to quantify the morphometric and hydrographic elements (altitudes, values and orientations of the slopes, organization of the hydrographic line, geological outcrops, etc.) and to specify the arrangement of the morpho-structural units. The interpretation of aerial photos, satellite images and images from google at very high resolution allowed us to identify the modeling units as well as their extent and arrangement. The results are verified by field visits.

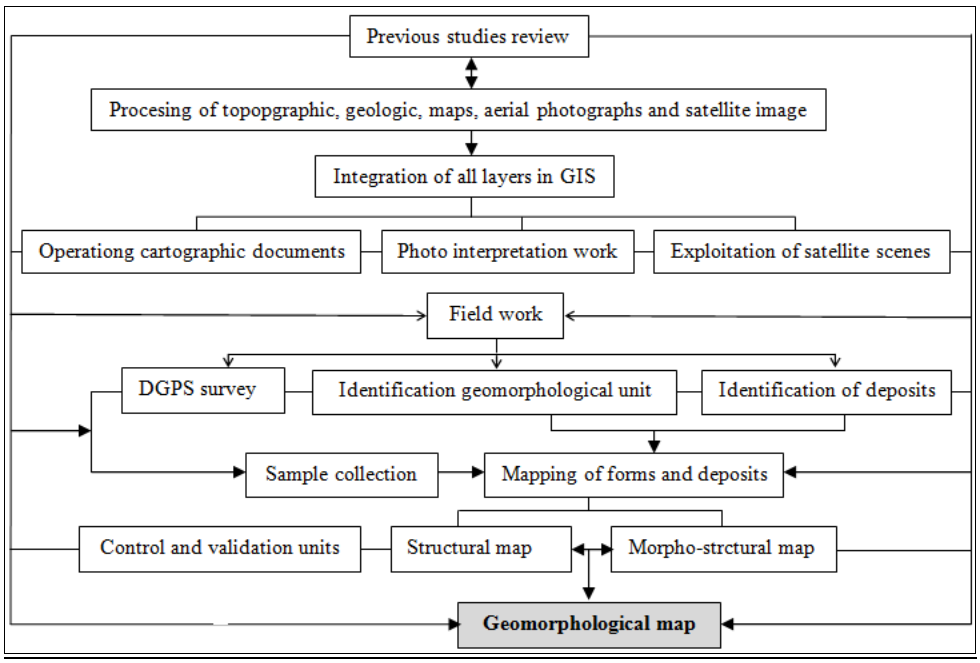

Fig 2: Data Processing Flowchart

3. Results

Five morphological units could be distinguished in the morphological landscape of Jbel Alima-Chouabine and its southern foothills. Going from the oldest to the most recent and from the highest to the lowest, there are two generations of glacis, two alluvial fans and a low terrace (Figure 3).

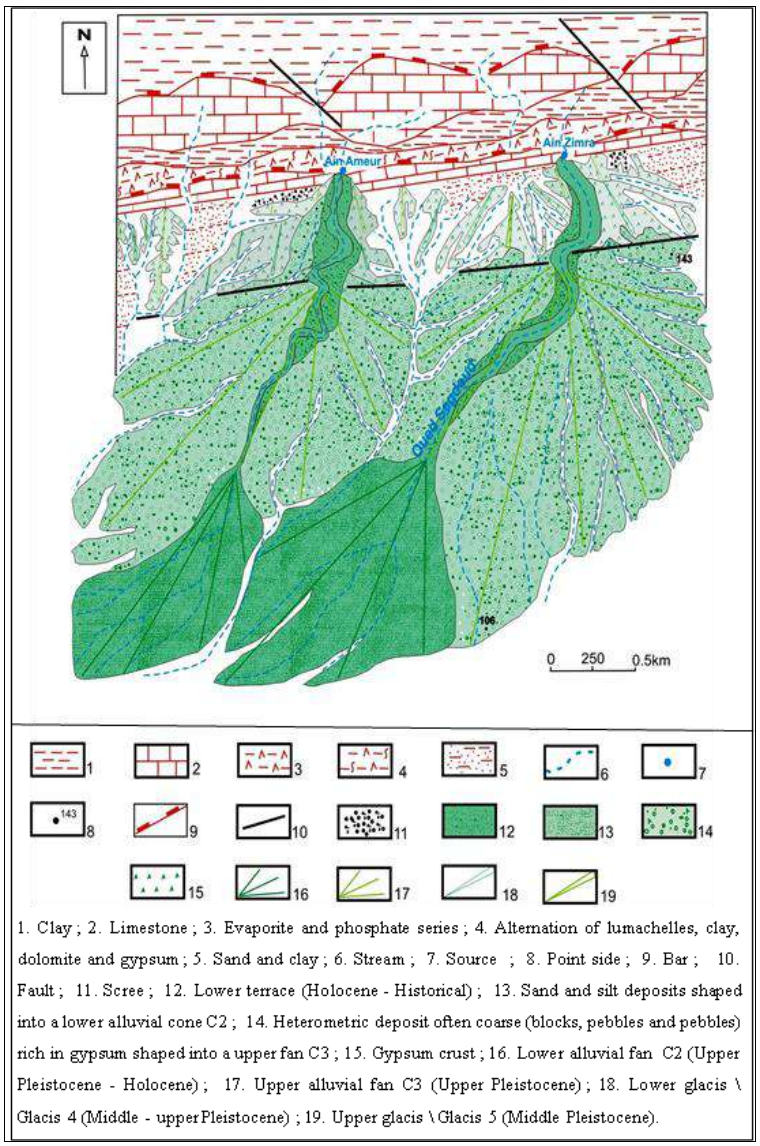

Fig 3: Geomorphological map of the southern foothills of Jbel Alima-Chouabine

3.1 An upper glacis [5]

It is the highest and the most extensive dominating the current thalweg of about 15 to 30m. It is preserved in the form of elongated an North-South strips, mounds and hills parallel to the slope of Jbel Alima-Chouabine (Photo 1). The cover of the upper glacis presents various characters. These are heterometric colluvial-alluvial deposits that lie in gully contact on clays and sands of the Neogene. These deposits consist of pebbles, gravel, coarse sand lenses covered by a crust and a whitish-colored gypsum crust.

3.2 A lower glacis [4]

It is the most developed. It is cut at the expense of the upper glacis with about 5m difference of level. It is well preserved upstream of cataclinical wadis and takes the configuration of strips and mounds. The coverage of the middle glacis shows a fairly significant extension and is characterized by a significant thickness. It is a detrital material with a lenticular structure made up of pebbles, gravels and coarse sands topped by a white gypsum crust with a sandy matrix at the top resting in gullying on the clays and sands of the Neogene.

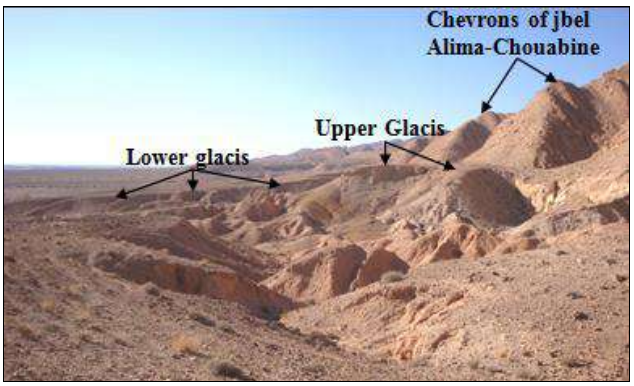

Photo 1: The layering of two levels of erosion glacis at the foot of jbel Alima – Chouabine

3.3 An upper alluvial fan [3]

They develop at the exit of the wadis of the dominant

mountain. They occupy various topographical positions. Sometimes they are connected to the mountain. Their domed and encrusted surfaces with a convex slope are quite extensive. The value of its slope weakens as one approaches the flow channel of the wadis. On average slopes are in the range of 1.6% to about 6%. The slope calculation was carried out based on the technique adopted by Ben Ouezdou (1994) which is called "*slope calculation in steps of ten*[1]". The results obtained by this technique are shown in Tables 2 and 3.

Table 2: Values of the slopes of the longitudinal profile of C3 and C2 fan of the Segdoud wadi

Drop (m)	Distance (m)	Slope (%)	Cumulative Drop	Cumulative Distance	Slope (%)
10	150	6.6	10	150	6.6
10	100	10	20	250	8
10	100	10	30	350	8.57
10	200	5	40	550	7.27
10	200	5	50	750	6.66
10	350	2.8	60	1100	5.45
10	450	2.2	70	1550	6.08
10	650	1.53	80	2200	3.63

Table 3: Values of the slopes of the longitudinal profile of C3 and C2 fan of the Aj-Jmal wadi

Drop (m)	Distance (m)	Slope (%)	Cumulative Drop	Cumulative Distance	Slope (%)
10	200	5	10	200	5
10	250	4	20	450	4.4
10	300	3.3	30	750	4
10	300	3.3	40	1050	3.8
10	350	2.85	50	1400	3.57
10	400	2.5	60	1800	3.3
10	450	2.2	70	2250	3.1
10	550	1.8	80	2800	2.8
10	650	1.53	90	3450	2.6

These alluvial fans are built by the wadis of Segdoud, Zimra, Mzinda, Ain Hamda, Ain El Hanèche, Aj-Jmal. Their sizes vary according to those of the receiving basins responsible for their water and sediment supply. They extend for approximately 1.5 to 2.5 km. From upstream to downstream, the upper fans generally dominate the current flow section of the rivers of about 8 to 15 m.

The deposits of these alluvial fan are heterometric, friable and characterized by a high proportion of coarse elements. These are large blocks, often angular, of sub-blunt pebbles, then the material becomes less coarser in the downstream direction. The thickness of deposits is quite significant upstream (about 8 to 15 m). On the contrary, it decreases rapidly downstream where fine sediments dominate. These contain few lenses of coarse elements. This level has a gypsum crust of whitish color at the top. These deposits are laying on sands and clays of the Neogene.

[1] *The technique consists of measuring the slope every ten meters of vertical drop. This is the value between two successive contour lines given that the equidistance of the contour lines is 10 m (Ben Ouezdou, 1994). This technique is possible thanks to the significant extension of the terrace fan in relation to the glacis, which are small shreds in our field of study. The slope calculations were carried out using the topographic map of Metlaoui at 1: 50,000. This map has contour lines equidistant by 10m. The measurements are taken along the same profile between contour lines.*

3.4 A lower alluvial fan [2]

The lower alluvial fans occupy a lower altitudinal position and interlock with the preceding fans (upper alluvial fan C3). The value of the interlocking reaches approximately 6 to 8 m (Figure 4). They extend more downstream in the streams. They have a convex profile. Their altitudes are less than 100m. The development of these lower alluvial fans is clearly visible at the level of the Hamda (2.01 km²) and Segdoud (1.85 km²) rivers. There are forms of fan-shaped accumulation with sub-horizontal surfaces before reaching the axial course of the el Miit river. These alluvial fans generally dominate the current flow bed of rivers of about 4 to 6 m.

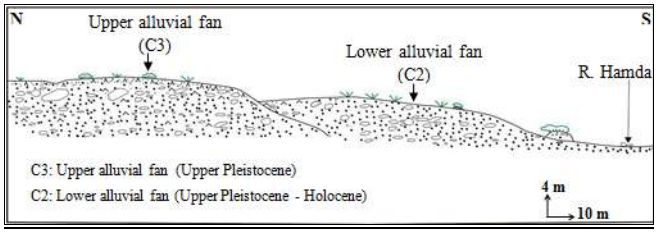

Fig 4: Interlocking of the lower alluvial fan in the upper fan at Hamda river

This lower fan is made up of coarse deposits upstream, with a thickness that can reach about 6 m in places. These are often gravel, relatively dull cobbles, pebbles and coarse sands rich in gypsum. On the other hand, the deposit is finer downstream. This level bears no crusting.

3.5 A low terrace [1]

It fits into the whole. It is preserved in the convex lobes of the meanders and on both sides of the axes of the flow of the Segdoud, Mzinda, Ain Hamda, Ain Ameur, Aj Jmal wadis and in other wadis that come from Jbel Alima-Chouabine, with a relatively developed extension to the Plain of Miit River. The visible thickness of the deposits of this terrace does not exceed 2 m and its width increases along the banks of the wadis from upstream to downstream. It is made up of coarse materials in the upstream part of the rivers. These are boulders, cobbles, gravel and coarse sands. Downstream, the material becomes finer and finer with dominance of sandy and silty elements.

4. Discussion

We have drawn up a synthetic section (Figure 5) which shows the position of the different levels of quaternary forms and deposits as well as their chronostratigraphic succession. The latter begins with the oldest level which corresponds to the highest level (the upper glacis) and ends with the most recent level which coincides with the lowest level (the lower terrace). The positioning of the different levels in the Quaternary chronology was argued taking into account the geomorphological position (interlocking and layering), the lithological constitution, the altitudinal and/or altimetric criterion between the different units, the nature of the shapes and formations. and correlations with existing chrono-stratigraphies, in particular those of Coque, 1962 [12]; Ben Ouezdou, 1994; Said, 2011 and Gasmi, 2012. The units described are all posterior to the Lower Pleistocene (Ben Ouezdou, 1994). Five quaternary levels could be distinguished on the southern foothill of jbel Alima - Chouabine. From the oldest to the most recent, we observe

the following device:

4.1 Level 5\Glacis 5

It corresponds to the upper glacis (Glacis 5) with a crust and gypsum crust. The oldest level dominates the other levels. It would be the equivalent of glacis 4 defined by Coque, 1962 [12] and attributed by this same author to the average Acheulean. It would also be the equivalent of Glacis 5 identified by Ben Ouezdou, 1994 and Gasmi, 2012. This level would date from the Middle Pleistocene (Ben Ouezdou, 1994).

4.2 Level 4 \ Glacis 4

It is represented by the medium glacis (Glacis 4) with a gypsum crust. It would be the equivalent of Glacis 3 defined and attributed by Coque, 1962 [12] to the evolved Acheulean and also the equivalent of Glacis 4 identified by Ben Ouezdou, 1994 and Gasmi, 2012. This level would date from the middle to upper Pleistocene (Ben Ouezdou. 1994).

4.3 Level 3 \ fan 3

It corresponds to the upper alluvial fan (fan 3) with a gypsum crust. This level would be the equivalent of glacis 2 defined and attributed by Coque, 1962 [12] to the Mousterian. It would also be the equivalent of the terrace, glacis and fan 3 identified by Ben Ouezdou, 1988 and 1994 and the equivalent of the terrace and cone-terrace 3 identified by Gasmi (2012). These units are believed to be from the Upper Pleistocene (Ben Ouezdou, 1994).

4.4 Level 2 \ fan 2

It corresponds to the lower alluvial fan (fan 2), and does not bear any crusting. This level presents several fragments of flint cut on the surface (Photo 2): cortical flakes, full debitage flakes, core maintenance flakes, strike plan maintenance flakes, cores and nucleoidal flakes, notched flakes and denticulate. The volume of the tools and the importance of the flakes and blades with back down as well as that of the chisels attach this series to a typical Capsian type "*Bortal Fakher*". These morphological and prehistoric elements allow the establishment of these C2 fan deposits to be attributed to the end of the Upper Pleistocene and the beginning of the Holocene. As a result, the C2 fan is slightly earlier than the Glacis I dated Capsian (Coque, 1962) [12] and Tersasse 2 and cone 2 identified by Ben Ouezdou, 1994 and Gasmi, 2012 that delivered a Capsian industry. This level would date from the Upper Pleistocene-Holocene (Ben Ouezdou, 1994).

Photo 2: Flint fragments collected from the surface of the C2 alluvial fan of Hamda wadi

4.5 Level 1 \ low terrace

This is the lowest and most recent. It forms a low terrace which fits into all the quaternary forms. The findings of fragments of ancient ceramic dating back to Roman period (photo 3 A and B) on the surface of the deposit of the low terrace in the area also which extends between the wadi Bou Sayeb and the wadi Ad Dghima to Medjez el Hachana and Hir El Blida (UTM coordinate X 410497 Y3795206). They are brought back to the Roman period (4th - 5th centuries) [2]. These elements could be materials reworked by the Segdoud, Mzinda, Aj Jmal, Bou Sayeb and Ad Dghima wadis or their tributaries. They attribute the placement of these Lower Terrace deposits to the late Holocene and early history. As a result, the lower terrace is slightly earlier than Tersasse 1 identified by Ben Ouezdou, 1994 [8] and Gasmi, 2012. This level would date from the Holocene - Historical (Ben Ouezdou, 1994) [8].

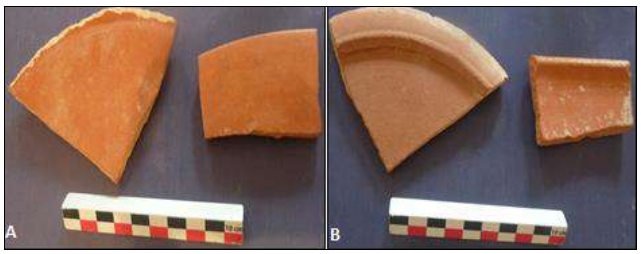

Photo 3: A- Ceramic fragments from a flat bottom collected from the surface of the terrace. B- Distal fragment of a bowl bearing part of the lip collected from the surface of the Bou Sayeb river terrace (UTM coordinate X 410497 - Y 3795206)

[2] *The interpretation and determination of the ceramic fragments are kindly carried out by Mr. Yamen Sghayer, and Soufien Ben Moussa teacher-researchers in Prehistory at the Faculty of Letters and Human Sciences of Sousse. Tunisia.*

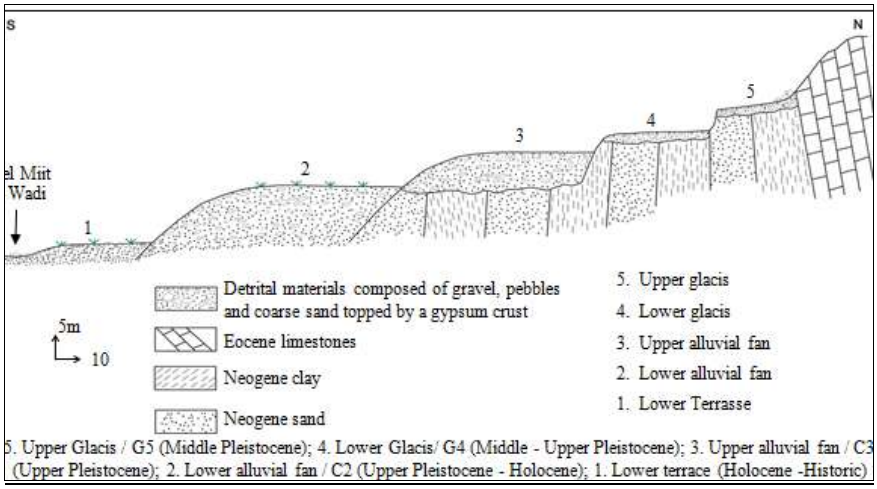

Fig 5: Synthetic section of the quaternary units identified on the southern foothill of Jbel Alima-Chouabine

5. Conclusion

The geomorphological study and cartography of the southern foothill of Jbel Alima-Chouabine allowed us to identify the different quaternary forms and deposits and to understand the conditions of their arrangement. Five quaternary morphological units linked to running water have been identified: two generations of glacis, two generations of alluvial fans and a low terrace. A relative dating test was developed taking into account the geomorphological and sedimentological characteristics and correlated with the chrono-stratigraphic scales existing in previous work on South-West Tunisia (Coque, 1962 [12]; Ben Ouezdou, 1994 [8] & Gasmi, 2012). The upper glacis (glacis 5) would be from the Middle Pleistocene, the lower glacis (glacis 4) from the Middle to Upper Pleistocene, the lower glacis (glacis 3) from the Upper Pleistocene. The upper alluvial fan would be from the Upper Pleistocene. The lower alluvial fan would be from the Upper Pleistocene to Holocene and the lower terrace of the Holocene to Historic.

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