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# ALLUVIAL TERRACES AS A MEASURE OF VERTICAL MOVEMENTS AND NEOTECTONICS: EVIDENCES FROM WADI SIDI MOUSSA, CYRENAICA, NE LIBYA

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## Abstract:-

Al Jabal Akhdar Mountain suffered by numerous tectonic events throughout the geologic time, these events are most affected on the earth surface features. Wadi Sidi Moussa is one of the longest observable wadies that cut the lower escarpment, this wadi being having distributed fluvial terraces in different parts and locations. These terraces are shown with obvious variation in their elevations, some being higher, while others abruptly decreased in steps like behavior, where a series of steps and surfaces developed above and below the escarpment. Logically these terraces are explainable of odd and non-natural occurring, hence the fluvial terraces in the wadi attributed and interpreted as of a terraces of a tectonic control, and ascribed to the effects of one of those tectonic episodes. Wadi Sidi Moussa due the fluvial terraces in this investigation can be considered as one of those morphotectonic valleys in Al Jabal Al Akhdar Mountain.

**Keywords:-***Alluvial terraces; Wadi Sidi Moussa; Neotectonics; Morphotectonic; Al Jabal Al Akhdar*.

## 1. INTRODUCTION

In various streams and valleys, terrace remains can be found in bank sand valley sides, or at the side of the current river canal on the floodplain. Frequently, they are found as single terraces, but it is not uncommon to find in a succession of such terraces forming a socalled 'staircase'. Terraces might be erosional, forming in the bedrock with a low-gradient layer that is regularly covered by a thin layer of gravel, or that may perhaps characterize the upper altitude of aggradations previous to subsequent down-cutting of the plane of previous floodplains. The gradient of the associated stream and valley is defined by the underlying terrain, with, the lower edge of prospective erosion marked by waterway incision (Selby, 1985). Finally, this structure reaches sea-level. An alteration in base-level may result in the alteration of a river's single bed gradient, while the altitudinal variation between river supply and mouth will be changed. Accordingly, the gradients of cast-off floodplains (terraces) can be utilized to restructure the earlier long profiles of streams and wadies, and to deduce previous variations in base level. Nevertheless, other aspects may possibly also result in the development of stream long profiles, for gradients be able to amend between period terraces outside owing to the control of restricted base-levels, as a result of restricted difference in deposit deliver or water capacity, or through variation in the run-off basin-pattern (Selby, 1985).

Stream and wadi terraces are formed in all climatic and geomorphologic settings and reveal the function of worldwide fluvial processes. They might be conserved as either unpaired or paired terrace fragments. Where there been considerable and relatively abrupt alterations in the stream's flow, due for instance to aggradation as a consequence of an increase in sediment weight, or scoring by the waterway into the wadi floor, there is a possibility that paired terraces can form on both walls of the wadi. Where the stream begins to meander, sideways migration of the flow channel directs the attrition of the floodplain sediments towards the outside boundary of the bend and a single paired terrace will begin to builds up, resulting in a succession of terraces throughout the meandering section of the river. As a result, reveal together side transferring of the stream channel and erect displacements during succession of aggradational and downcutting stages i.e., that is a route frequently referred to the same as fill and cut (Selby, 1985).

Because stream and wadi alluvial terraces are for the most part built-up from loss sediments, they are easily damaged by later fluvial action, and thus, a preceding floodplain plane can frequently the just conserved characteristic in the form of terrace fragments. Tectonic uplift results in the rejuvenation of streams, resulting in an enlarged gradient. The instrumental altitude of the terrace fragments and examination of the data by means of elevation-distance illustration can enable down-wadi gradients of terrace fragments to be renovated (Selby, 1985). Altitudinal information may aid in the analysis of landform assemblies and might also enable landforms that can be associated with diverse eras to be determined. For instance, only fragments of previous stream terraces can be conserved in a exacting region, and it might be impossible to classify and correlate terrace fragments of analogous periods, and to determine a chronology of terrace expansion merely on the basis of field mapping.

The intention of this work is to address the following goals:

**1)** To restructure the Quaternary vertical movements in the Wadi Sidi Moussa region, Cyrenaica, NE Libya.

**2)** To determine the chronology of terrace expansion on the basis the field mapping to help determine neotectonic activities.

## 2. Tectonic setting of the Al Jabal Al Akhdar

The Al Jabal Al Akhdar peninsula covers area of around 150,000 $km^2$ in the northeastern part of Libya. It constitutes a branch of the Sirt rift complex and the offshore spread of the Sirt Gulf which bounds it to the west and south. Toward the east, it stretches into the Marmarica Platform in the West Egyptian Desert. Cyrenaica generally speaking, has two distinctive tectonic regions divided by the Cyrenaican Fault System (El Hawat & Abdulasmad, 2004) (Fig. 1). These are the north Cyrenaica reversed basin, known as Al Jabal Al Akhdar Mountain, and the Cyrenaica Platform towards the south. Two lengthy tertiary deposit depression are situated to the south of the inversion axis; known as the Marmarica and Soluq (Ash Sheliedima) Troughs which are situated at the southern part of the Platform. The troughs are plunging relative to their depocenters in the southeast and southwest directions, correspondingly, alongside the Cyrenaica Fault System and are divided by a high structural burden that connects in the middle with Al Jabal Al Akhdar (El Hawat & Abdulasmad, 2004). In the south, in the Al Jaghbub High region the southern part spread out in to the Cyrenaica Platform. It is divided from the eastern part of the arm of Sirt basin named the Al Hameimat Trough via the south Cyrenaica Fault System (Anketell, 1996).

The northern boundary of Cyrenaica inversion anticlinorium is downward faulted toward the coastal plain. It pulls out towards the north into the offshore region to shape a slender and steep continental edge. The Cyrenaican continental gradient is additionally faulted and folded and is divided as of the Ridge of Mediterranean by an draw out narrow and deep (El Hawat & Abdulasmad, 2004). This trough might indicate the start of a key fault system throughout the offshore region, matching the Cyrenaican coastline and is indicated as the north Cyrenaica fault system (Huguen & Mascle, 2001; El Hawat & Abdulasmad, 2004). The Cyrenaican peninsula embodies a topographical, geological region in addition to a geophysical abnormality on the north-eastern part of the African coastline. The geological map and cross sections of northern Cyrenaica prove which of the inversion structures of the earlier subsiding basin by the existence of Upper Cretaceous inliers at the axis of the inversion structures belong to the earlier subsiding basin of the anticlinorium (Fig. 2). These structural inliers match the highest topographic regions of Cyrenaica (El Hawat & Abdulasmad, 2004; Arsenikos et al., 2013; EL Oshebi et al., 2017).

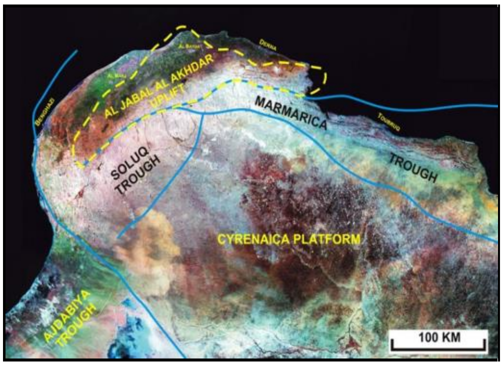



**Figure 1 Landsat photo of Cyrenaica viewing the most important tectonic regions (From: El Hawat & Abdulasmad, 2004).**

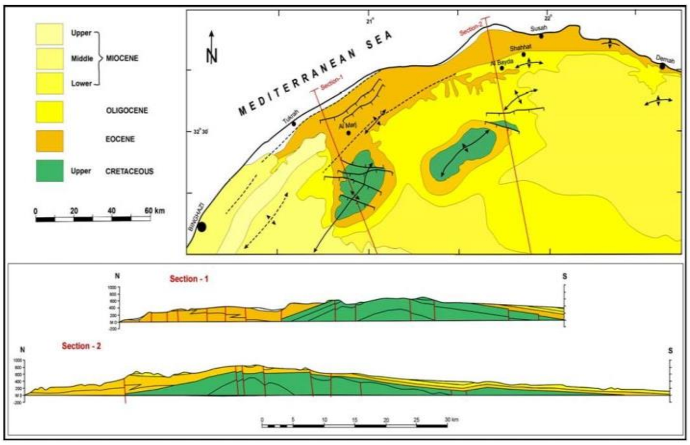



**Figure 2 Geological map and cross sections of the northern part of Al Jabal Al Akhdar (From: El Hawat & Shelmani, 1993).**

The inversion of north Al Jabal Al Akhdar Mountain through the Upper Cretaceous was a direct outcome of the compressive forces resulting from the convergence of the Aegean and African–European plates (El Hawat & Abdulasmad, 2004). These are also revealed in the sedimentation record of northern Al Jabal Al Akhdar Mountain. Confirmation of repetitive syn-depositional accumulation movement of sediments, unconformities, and post-depositional deformation structures pulls out from the upper Cretaceous to the current representation of these persistent compressive events (El Hawat & Abdulasmad, 2004). Main slump structures, slides, debris flows constitute empirical evidence in terms of surface exposures of the Cretaceous, Eocene and the Oligocene period (El Hawat & Abdulasmad, 2004).
Since confirmation of the current tectonic seismic movement events in the Al Jabal Al Akhdar are (1) the continual chronological earthquake devastation of the earliest town of Cyrene (now Shahhat) around ~ 262 and ~ 365 A.D, (2) the fall of the whole harbour amenities of the ancient town of Apollonia that at this moment is no less than 2 meters below sea- level, (3) the further modern devastating earthquake that smashed the current-day city of Al Marj in 1963. The entirety of these effects are proof of the continuing tectonic movement of Cyrenaica from the Upper Cretaceous inversion to the present day (El Hawat & Abdulasmad, 2004; Arsenikos et al., 2013; El Oshebi et al., 2017).

## 3. Category of cyclical terraces

This form of cyclical river terrace build-up depends on the environment and origin of the earlier floodplain that it characterizes; that is, it depends on whether the terrace plane was shaped by river erosion, by deposition, or by a mixture of the two. Appropriate classification as to the type of cyclic river terrace is critical to the understanding of the series of leadings to the terrace. While may be seen in the debate of terrace kind that follows, each sort of terrace has a geomorphic history fairly diverse from all others and viewing kinds of terraces in (Fig. 3), (Easterbrook, 1993; El Oshebi et al., 2017).

### 3.1. Cut-in-bedrock terraces

Floodplains engraved by graded rivers across rocks of opposing resistance are bottomed with rock, and mantled with a slight layer of alluvium whose thickness does not go beyond the depth of the channel of the river. Accordingly, when the score of the river channel is changed, this keeps them as remains above the channel, and the terraces contains rock that is lightly veneered with alluvium (Fig. 3A). These terraces, recognized as cut–inbedrock terraces, have the straightforward geomorphic record of in the least of the terrace types.

### 3.2. Fill terraces

Fill terraces are the miscellanies of previous valley bottoms that have been assembled by aggradation. Gorges are first filled with alluvium during aggradation, followed by scoring of the stream waterway into the fill which leaves terraces filled totally with alluvium. The terrace plane in this case is depositional in nature, in contrast to the cut-in-bedrock form which is erosional. Fill terraces may perhaps have the similar surface form of cut terraces and may perhaps have analogous gradients, but they are otherwise different, most notably in their geomorphic record. A cut terrace involves an era of floodplain progress at a particular level, followed by scoring of the channel (Fig. 3B). Alternatively, a fill terrace involves down-cutting, followed by aggradation to fill the gorge, and lastly further down-cutting to leave a fill plane above the channel. In consequence, discriminating between these types of terraces is vital to an appropriate interpretation of their geomorphic record.

### 3.3. Cut-in fill terraces

Cut-in fill terraces are mixture of previous valley bases that have been scored with alluvium, followed by canal incision. They fluctuate from fill terraces in that their plane is erosional in nature, while fill terrace planes are depositional in nature. (Fig. 3C) characterizes the difference. A valley is first cut to level (a), followed by filling of the gorge to altitude (b). The gorge fill is followed by scoring to level (c), and the latest flood plain extends out, followed by converted scoring to level (d), finally exiting the floodplain, that had a cut-in fill, in a similar manner to a terrace. Hence, the terrace plane at (c) is erosional, and while it is fairly comparable to a cut-in-bedrock terrace, it is different in being cut in alluvium rather than rock. Note that the maximum terrace height, level (b), is a fill terrace as the basis of its plane was depositional.

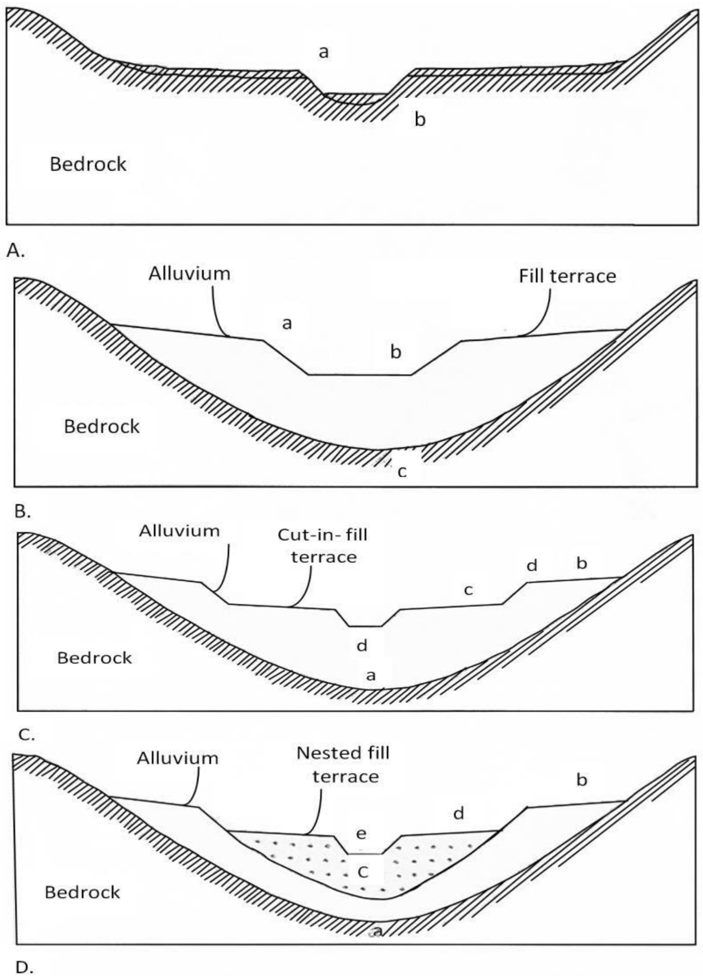


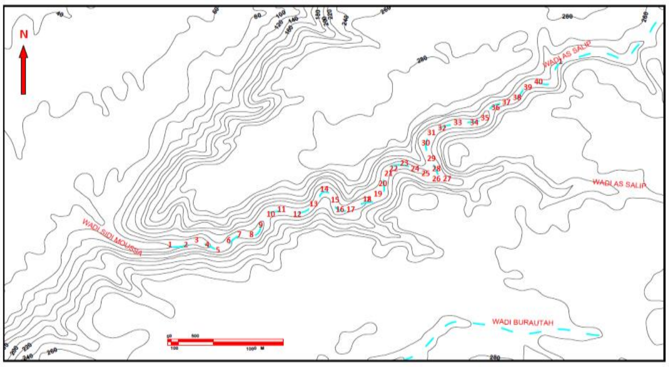

**Figure 3 Categories of stream terraces: (A) bedrock (cut) terrace, (B) fill terrace, (C) cut–in-fill terrace, (D) Nested fill terrace (from: El Oshebi et al., 2017).**

### 3.4. Nested fill terraces

Nested fill terraces contain consecutively inset fill terraces, each surrounding one another (Fig. 3D). They are depositional in basis, although are divided by eras of channel score. For instance, in (Fig. 3D), the stream is first cut down to level (a), and subsequently filled to level (b), followed by further down-cutting to level (c), and filling back up to level (d). Additional down cutting to level (e) is followed by weighty back up to level (d). The succession of terraces hence might look like the cut-in-fill terraces (Fig. 3C), although in this case, the entirety of the plane is depositional, rather than erosional in basis, and the geomorphic record is noticeably more complicated.

## 4. Methods and materials

The key rationale of this study is to seek to reconstruct the Quaternary vertical events at Wadi Sidi Moussa region by comparing the altitudinal and directional information describing the different alluvial terraces. The method of geomorphogical mapping (Waters, 1958 & Savigeor, 1965) is concerned with the identification of individual gradient basics in the landscape and the nature of the intersections among them (Crofts, 1981). Tool levelling, for instance, with clinometers, Abney levels or altimeters and more recently Global Positioning System (G.P.S), is essential to establishing an accurate altitude (elevation) map, and in determining the variation in elevation of exacting landforms. Field work was carried out mainly to collect the directional and altitudinal information for the entity terrace fragments found in the Wadi Sidi Moussa region (elevations were measured using GPS built into an iPhone). Terrace fragments were documented at 40 locations (measuring stations) along the length of the wadi from the down-stream to the upper-stream region (Fig. 4). By taking precise elevation measurements on apiece terrace fragment, previously constant features can be restructured, gradients can be determined and the chronological relations between terraces can, ultimately, be recognized (Lowe & Walker, 1984). Additionally, 150 reading joints were measured within the exposed rock unit (Apollonian and Darnah formations) using a Brunton compass in the Wadi Sidi Moussa region (Fig. 8).




1-40 Measuring stations

**Figure 4. Topographic map of the Wadi Sidi Moussa region viewing the locality of stations for measuring the altitude and direction of the documented terrace fragments.**

The Wadi Sidi Moussa region characterizes one of the largest valleys in the Tukrah area, Al Jabal Al Akhdar, NE Libya (Fig. 5). The study area extends ~ 7 km in an E-W direction and ~ 4 Km in an N-S direction, which in total represents ~ 28 km². It is about 6 km southeast of the Tukrah area, and about 66 km east of Benghazi city. After nearly 15 km arrives at the first escarpment of Al Jabal Al Akhdar, of which the study area itself represents only a small part of this escarpment passing through the Benghazi plain to the west into the Barsses check point.

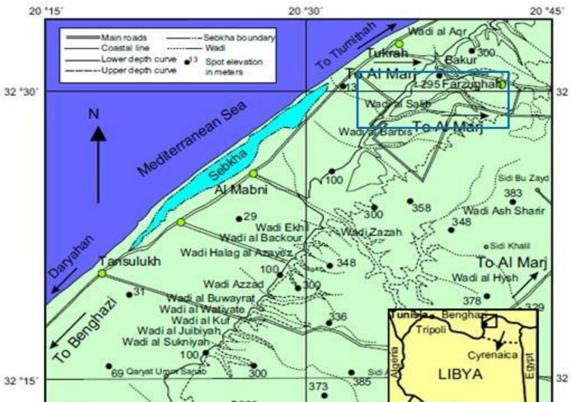



**Figure 5 Topographic map of the NW part of Cyrenaica viewing the studied area highlighted in blue (Modified from: Abdulsamad et al., 2009).**

**6. Interpretation of results**

The relationship between each of the terrace fragments studied in the Wadi Sidi Moussa region remains speculative; it has to be acknowledged that there is no sufficient morphostratigraphic verification in this regard with the exception of the directional and altitudinal information. Nevertheless, the constructed height distance diagram (Fig. 6) may give some clues about the Quaternary and more recent tectonic movements in the area.

At the end of Wadi Sidi Moussa's downstream region, the lowest terrace fragment lies 90 m above the present-day sea level. Conversely, the highest terrace fragment is found 115 m above sea level. This implies a standard slope gradient of 1:38.51. Furthermore, in numerous regions all along the wadi's long-profile, terrace fragments can be seen at much higher altitudes, and these are anomalous to the average grade gradient (areas 1-10, Figs. 4 and 6). Based on the data that could be obtained, a reasonable interpretation of this situation is that the land, and therefore, the alluvial terraces were uplifted later than they were formed. Tectonic uplift of the area through the Quaternary and the Pleistocene marine terraces was also established, as recognized at several localities of Al Jabal Al Akhdar (Desio, 1935; Hey, 1956; El Oshebi et al., 2017).

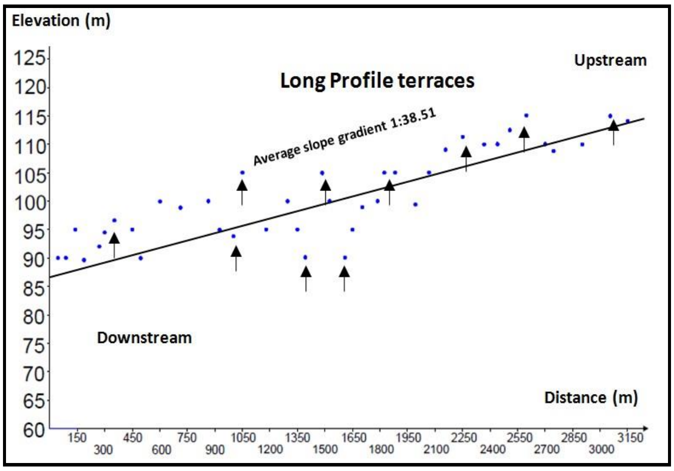



**Figure 6 Reconstructed long valley profile of the terrace fragments measured in the Wadi Sidi Moussa region.**

Another obstacle inherent to Wadi Sidi Moussa is that it has altered its course abruptly in all the regions studied, and thus, the terrace fragments additionally face in different directions (Fig. 7) (Tab. 1). Additionally, the directional data found for the terrace fragments demonstrates a major trend at N30°W corresponding to the major trend of joints measured (nearly N70ºW-SE) in the different exposed rock units within the Wadi Sidi Moussa region (Fig. 8) (Tab. 2).

**Table (1): The Frequency and Frequency % distribution of the direction of terrace fragments in the Wadi Sidi Moussa region.**

| Class Interval | NE-SW | | NW-SE | |
|---|---|---|---|---|
| | FREQUENCY | FREQUENCY % | FREQUENCY | FREQUENCY % |
| **0o-10o** | 1 | **2.5** | 2 | **5** |
| **11º-20º** | 6 | **15** | 3 | **7.5** |
| **21º-30º** | 2 | **5** | 7 | **17.5** |
| **31º-40º** | 3 | **7.5** | 5 | **12.5** |
| **41º-50º** | 3 | **7.5** | 2 | **5** |
| **51º-60º** | 1 | **2.5** | 0 | **0** |
| **61º-70º** | 0 | **0** | 3 | **7.5** |
| **71º-80º** | 0 | **0** | 1 | **2.5** |
| **81º-90º** | 1 | **2.5** | 0 | **0** |

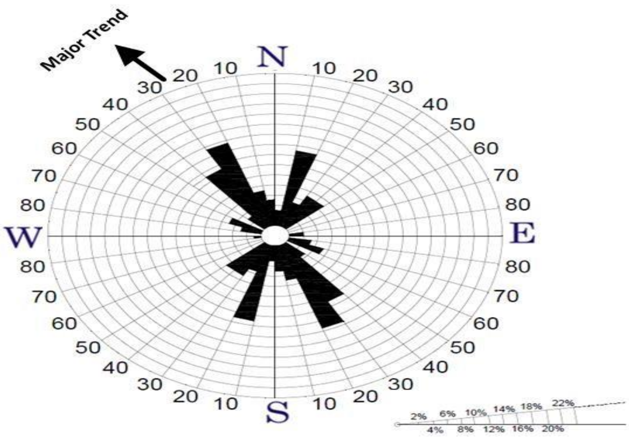



**Figure 7 Rose diagram representing the direction of (40) terrace fragments in the Wadi Sidi Moussa region.**

This mutual uniformity in the direction of the joints and terrace fragments may perhaps be attributed to the same tectonic periods. Furthermore, it support the suggestion of tectonic uplifts in the Wadi Sidi Moussa region in recent times.

**Table (2.) Frequency and frequency % distribution of the direction of joints in the Wadi Sidi Moussa region.**

| Class Interval | NE-SW | | NW-SE | |
|---|---|---|---|---|
| | FREQUENCY | FREQUENCY % | FREQUENCY | FREQUENCY % |
| **0o-10o** | 9 | **6** | 3 | **2** |
| **11º-20º** | 9 | **6** | 0 | **0** |
| **21º-30º** | 6 | **4** | 12 | **10** |
| **31º-40º** | 15 | **10** | 9 | **6** |
| **41º-50º** | 18 | **12** | 6 | **4** |
| **51º-60º** | 15 | **10** | 9 | **6** |
| **61º-70º** | 8 | **5.33** | 27 | **18** |
| **71º-80º** | 0 | **0** | 3 | **2** |
| **81º-90º** | 0 | **0** | 0 | **0** |

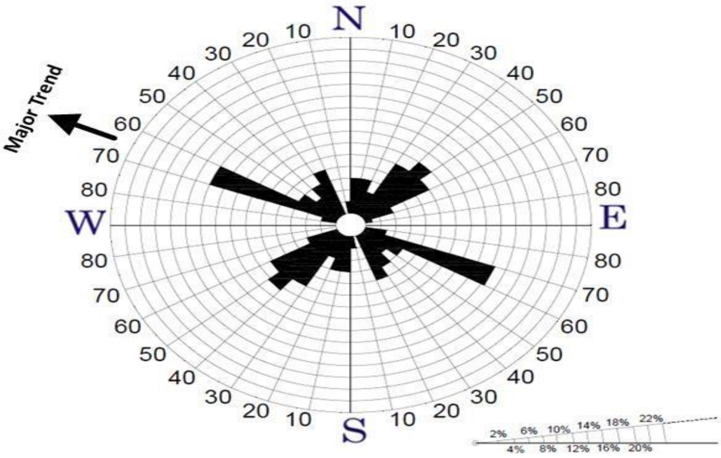



**Figure 8 Rose diagram representing the direction of 150 joints measured in the Wadi Sidi Moussa region.**

## 7. Discussion

This study was undertaken to consider the various aspects that play a considerable role in the construction and development of the Wadi Sidi Moussa terraces. The procedure was to traced or pursue terraces along the valley determining terrace altitude and thickness in order to indicate the associated variations and to gain an in-depth understanding of the focus area and its terraces. As a consequence, it was found that the downstream terraces began at an elevation of 90 m m.a.s.l and the upstream about at 115 m. They fluctuated several regions, even though we were heading up stream. Therefore, as it was clear that these formations were highly unusual in nature, the value and significance of this study becomes clear.

In the long profile illustration, the altitudes of the terraces in Wadi Sidi Moussa are plotted against distance to illustrate the relationship between the two factors. On the crosssectional diagram, the entire set of corresponding points show the variability from the lowest to the highest point of the wadi, where the terraces elevations take the form of meandering stripe. Occasionally, terraces heading for up and being in elevation, whereas in others dropped down, the multi differences in the distance and elevation in the section (Fig. 6), possibly it may be divided into ten loops, going to the upstream, these loops or cycles represent stepping or gradational difference, the differences themselves are revealed more in the middle of the line, the average of these measurements ranged from 90 to 115 m.a.s.l. (*see* Fig. 6).

As per the data presented in this study, it is clear that the Wadi Sidi Moussa region is tectonically still active due to the fluctuation in terrace elevations downstream to upstream, and the terraces deposited through the Quaternary era. For this reason, any changes in terrace elevation reflects more recent tectonic movements rather than ancient ones. El Hawat & Abdulasmad (2004) and El Oshebi et al. (2017) stated that the northern part of the Cyrenaica coastal margin demonstrates successive wave-cut erosional terraces far above the ground with residual Pleistocene calcarenite beach dunes that can be seen in areas up to 150 m in height above the present day sea level. These terraces were not elevated, and are purely due to the relative Pleistocene eustatic sea level changes.

## 8. Conclusion

To summarise, both the altitudinal and directional data of the terrace fragments measured in the Wadi Sidi Moussa region, we can conclude the following: the Wadi Sidi Moussa region characterizes a morphotectonic valley produced by combination of geomorphic and tectonic (structural) processes. Wadi Sidi Moussa is a mobile region and has been subjected to both recent tectonic (neotectonic) and Quaternary uplift. The whole area of Al Jabal Al Akhdar is tectonically active and behaves as a mobile region.

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