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Alluvial terraces as a measure of vertical movements and neotectonics: evidences from Wadi Zazah, Al Jabal Al Akhdar, NE Libya

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ABSTRACT

Wadi Zazah as part of the Al Jabal Al Akhdar Mountain has suffered numerous tectonic events throughout the geologic time. Wadi Zazah is one of the longest observable wadis that cut the lower escarpment and 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 behaviour, 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 terraces of a tectonic control, and ascribed to the effects of one of those tectonic episodes. Wadi Zazah due the fluvial terraces in this investigation can be considered as one of those morphotectonic valleys in Al Jabal Al Akhdar Mountain.

The present work disagrees with the conclusion of previous work, which suggested that Wadi Zazah is a tectonically stable region.

1. Introduction

In most rivers and valleys, terrace fragments are found either flanking the valley sides, or alongside the present river channel on the floodplain. Sometimes they occur as single features, but on occasions, they are arranged in vertical successions forming a flight or a staircase. Terraces may be erosional, with bedrock being planated to form low-gradient strata, which is often covered by a thin veneer of gravel, or they may represent the upper level of aggradation before subsequent downcutting the surface of former floodplains. The gradient of river and valley is determined by the position of base-level, the lower limit of potential erosion by river incision (Selby, 1985). Ultimately, this is the sea-level. A change in base-level will automatically lead to a change in river bed gradient, as the altitudinal difference between river source and mouth has been altered. Thus, the gradients of abandoned floodplains (terraces) can be used to reconstruct former long profiles of rivers and valley, and to infer past changes in base level. However, other factors may also influence the evolution of river long profiles, for gradients can change between contemporaneous terrace surfaces due to the influence of local base-levels, as a result of local variation in sediment supply or water volumes, or through changes in run-off patterns (Selby, 1985).

River and valley terraces occur in all geomorphological and climatic environments and reflect of the operation of universal fluvial processes. They may be preserved as either paired or unpaired terraces. Where there have been significant and comparatively sudden changes in the rivers behaviour, due for example to aggradation because of an increase in sediment load, or incision by the river into the valley floor, then paired terraces may form on both sides of the valley. Where the river begins to meander, however, lateral migration of the stream channel leads to erosion of the floodplain gravels on the outer edge of the meander and a single or unpaired terrace develops. Terrace sequences, therefore, reflect both lateral migrations of the river channel and vertical displacements through sequence of downcutting and aggradational phases i.e., that is a process usually referred to as cut and fill (Selby, 1985).

Because river and valley terraces are most frequently developed in unconsolidated sediments, they are easily destroyed by subsequent fluvial action, and hence, a previous floodplain surface will usually the only preserved feature in the form of individual terrace fragments. Tectonic uplift leads to rejuvenation of rivers, and therefore, to increased gradient. Instrumental leveling of the terrace fragments and analysis of the data by means of height-distance diagrams will enable down valley gradients of particular terrace fragments to be reconstructed (Selby, 1985). Altitudinal data can aid in the interpretation of landform assemblages and may enable landforms of different ages to be identified. For example, only fragments of former river terraces may be preserved in a particular area, and it may be impossible to identify and correlate terrace fragments of similar age, and to develop a chronology of terrace development simply based on field mapping. The present work is done to achieve the following:

1) To reconstruct the Quaternary vertical movements at Wadi Zazah, Al Jabal Al Akhdar, NE Libya.
2) To develop a chronology of terrace development simply based on field mapping that help to determine any neotectonic movements.

2. Tectonic setting of the Al Jabal Al Akhdar

Al Jabal Al Akhdar promontory covers about 150,000 km^2 of northeastern Libya. Arms of the Sirt rift complex and its offshore extension of the Gulf of Sirt bound it to the west and south. To the east, it extends into the Marmarica Platform of the Western Desert of Egypt. Cyrenaica broadly consists of two distinct tectonic provinces separated by the Cyrenaican Fault System (El Hawat & Abdulasmad, 2004) (Fig. 1). These are the north Cyrenaica inverted basin, referred to as Al Jabal Al Akhdar; and Cyrenaica Platform to the south. Two elongate Tertiary depositional troughs occur south of the inversion axis; these are the Marmarica and

Soluq (Ash Sheliedima) Troughs located north of the platform. These troughs are dipping relative to their depocenters to the southeast and southwest, respectively, along the Cyrenaica Fault System and are separated by an elevated structural saddle that joins midway with Al Jabal Al Akhdar (El Hawat & Abdulasmad, 2004). To the south, Al Jaghbub High forms the southern extension of Cyrenaica Platform. It is separated from the eastern extension arm of Sirt Basin that is called Al Hameimat Trough by south Cyrenaica Fault System (Anketell, 1996).

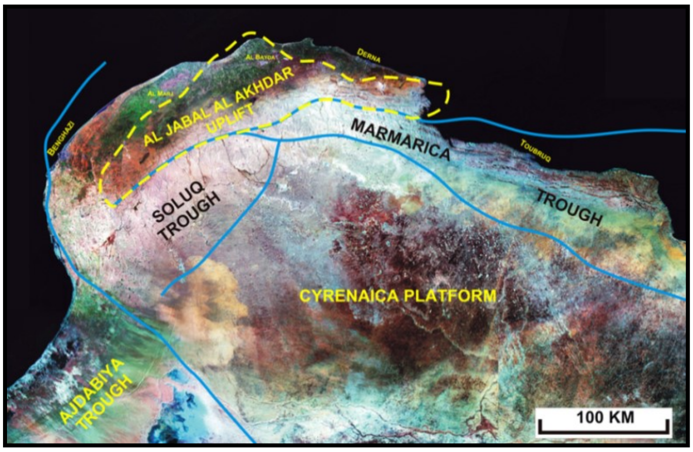

Fig. 1. Landsat image of Cyrenaica showing the main tectonic provinces (from: El Hawat & Abdulasmad, 2004).

The northern limit of Al Jabal Al Akhdar inversion anticlinorium is also down faulted to the north of the coastal plain. It extends northward into offshore to form a narrow and steep continental margin. Significantly, the Cyrenaican continental slope is also faulted and folded and is separated from the Mediterranean Ridge by an elongate narrow and deep (El Hawat & Abdulasmad, 2004). This furrow may represent a scare of a major Fault System running in the offshore parallel to the Cyrenaican coast and is referred to as north Cyrenaica fault system (Huguen & Mascle, 2001; El Hawat & Abdulasmad, 2004). The Cyrenaican promontory represents a topographic, geological as well as a geophysical anomaly in the northeast African coast. The geological map and cross sections of northern Al Jabal Al Akhdar confirms that the inversion structures of the formerly subsiding basin by the presence of Upper Cretaceous inliers at the axis of the inversion structures of the previously subsiding basin by the presence of Upper Cretaceous inliers at the axis of the inversion structures of the anticlinorium (Fig. 2). These structural inliers coincide with the highest topographic areas of Al Jabal Al Akhdar (El Hawat & Abdulasmad, 2004; Arsenikos *et al*., 2013). The inversion of north Cyrenaica Basin during the Upper Cretaceous was a direct result of the compressive forces induced by the convergence between the African – European and Aegean plates (El Hawat & Abdulasmad, 2004). These are also reflected on the stratigraphic record of northern Cyrenaica. Evidence of repeated syndepositional mass movement of sediments, unconformities, as well as post depositional deformation structures extends from the upper Cretaceous to the present demonstrating these recurring compressive events (El Hawat & Abdulasmad, 2004). Major slump structures, slides, debris flows and are commonly observed in surface outcrops of the Cretaceous, Eocene and the Oligocene (El Hawat & Abdulasmad, 2004).

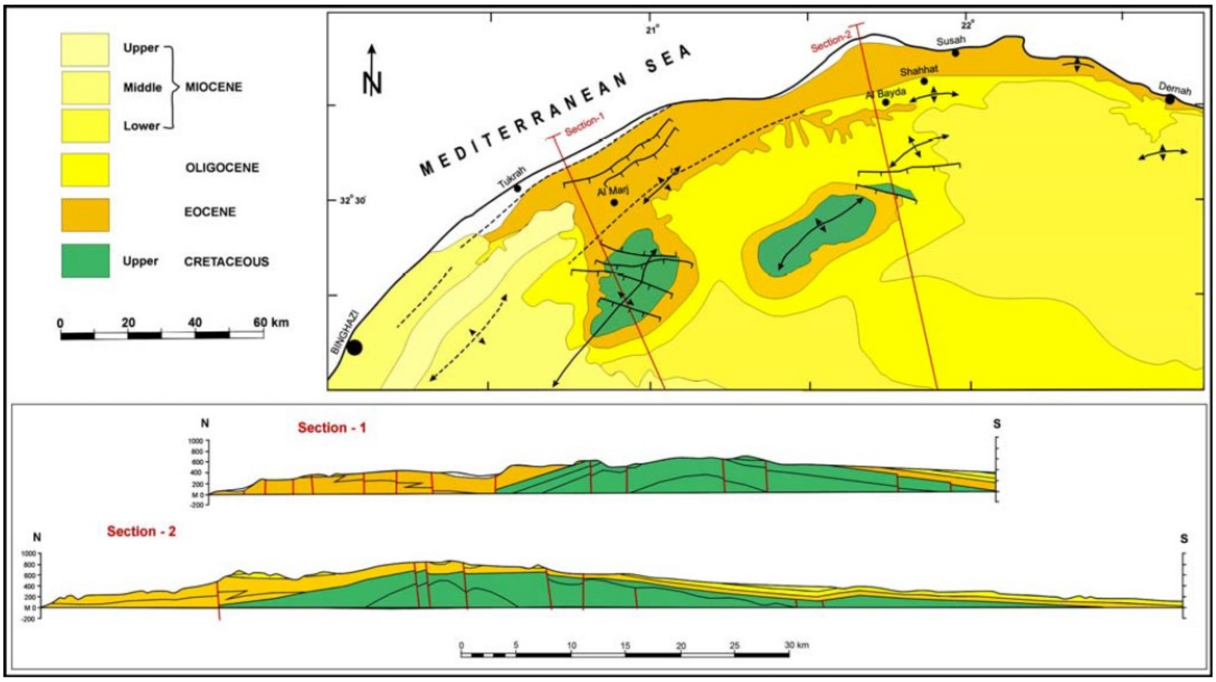

Fig. 2. Geological map and cross sections of northern Cyrenaica (from: El Hawat & Shelmani, 1993).

As an evidence of the recent tectonic seismic activity events in the Cyrenaica are (1) the repeated historical earthquake destruction of the ancient city of Cyrene (now called Shahhat) during the 262 and 365 A.D, (2) the sinking of the entire harbor facilities of the old city of Apollonia that is now at least 2 meters below sea-level, (3) the more recent devastating earthquake destroyed the present-day city of Al Marj in 1963. All of these events and signatures are testament of the ongoing tectonic activity of Cyrenaica since the Upper Cretaceous inversion to the present day (El Hawat & Abdulasmad, 2004; Arsenikos *et al.*, 2013; El Oshebi, 2017).

3. Types of cyclic terraces

The type of cyclic stream terrace developed depends on the nature and origin of the former floodplain that it represents; that is, it depends on whether the terrace surface was created by stream erosion, by deposition, or by a combination of the two. Proper identification of the type of a particular cyclic stream terrace is essential to the interpretation of the sequence of events leading to the terrace. As will be seen in the discussion of terrace type that follows, each type of terrace owns a geomorphic history quite different from all others and showing types of terraces in (Fig. 3), (Easterbrook, 1993).

3.1. Cut-in-bedrock terraces

Floodplains carved by graded streams across rocks of differing resistance are floored with rock, mantled with a thin veneer of alluvium whose thickness does not exceed the depth of scour of the stream. Thus, when renewed incision of the stream channel leaves them as remnant above the active channel, the terraces consist of rock thinly veneered with alluvium (Fig. 3A). These terraces, known as cut–in–bedrock terraces, have the simplest geomorphic history of any of the terrace types.

3.2. Fill terraces

Fill terraces are remnants of former valley floors that have been constructed by aggradation. Valleys are first filled with alluvium during aggradation; then incision of the stream channel into the fill follows, leaving terraces composed entirely of alluvium. The terrace surface in this instance is depositional in origin, in contrast to the cut-in-bedrock which is erosional in origin. Fill terraces may have the same surface form as cut terraces and may have similar gradients, but they differ significantly in their geomorphic history. A cut terrace implies a period of floodplain development at a particular level, followed by incision of the channel (Fig. 3B). On the other hand, a fill terrace implies down cutting, then aggradation to fill the valley, and finally renewed downcutting to leave fill surface above the active channel. Thus, distinguishing between these types of terraces is essential to proper interpretation of their geomorphic history.

3.3. Cut-in fill terraces

Cut-in fill terraces are remnants of former valley floors that have been cut in alluvium, followed by channel incision. They differ from fill terraces in that their surface is erosional in origin, where as fill terrace surface are depositional in origin. (Fig. 3C) illustrates the difference. A valley is first cut to level (a), followed by filling of the valley to level (b). The valley fill is then incised to level (c), and a new flood plain is widened out, followed by renewed incision to level (d), leaving the floodplain, which had been cut in fill, as a terrace. Thus, the terrace surface at (c) is erosional, and although it is somewhat analogous to a cut-in-bedrock terrace, it differs in being cut in alluvium rather than rock. Note that the highest terrace, level (b), is a fill terrace because the origin of it is surface was depositional.

3.4. Nested fill terraces

Nested fill terraces consist of fill terraces successively inset within one another (Fig. 3D). They are depositional in origin, but are separated by periods of channel incision. For example, in (Fig. 3D), the valley is first cut down to level (a), then filled to level (b), followed by downcutting to level (c), and filling back up to level (d). Further, down cutting to level (e) is followed by filling back up to level (d). The sequence of terraces thus may resemble the cut-in-fill terraces (Fig. 3C), but in this instance, all of the surface are depositional, rather than erosional, in origin, and the geomorphic history is considerably more complex.

4. Methods and materials

The main purpose of this study is to attempt to reconstruct the Quaternary vertical movements at Wadi Zazah, Al Jabal Al Akhdar, NE Libya by correlating the altitudinal and directional data of the different alluvial terrace fragments. The technique of geo-morphological mapping (Waters, 1958 & Savigeor, 1965) is concerned with the recognition of individual slope elements in the landscape and the nature of the junction between them (Crofts, 1981). Instrumental leveling, such as Abney level, clinometer or altimeter and more recently Global Positioning System (G.P.S) is necessary to determine the precise altitude (elevation), and difference in altitude between particular landforms. Field work was conducted primarily to collect the altitudinal and directional data for the individual terrace fragments recorded at Wadi Zazah, Al Jabal Al Akhdar, NE Libya (altitudes were measured by device of Global Positioning System 'etrex device'). Terrace fragments were recognized at 37 points (measuring stations) along the wadi from the downstream to the upperstream (Fig. 4). By obtaining precise altitudinal measurement on each terrace fragment, however formerly continuous features can be reconstructed, gradients can be deduced and the temporal relationships between individual terraces can be established (Lowe & Walker, 1984). Moreover, 295 readings joints were measured within exposed rock unit (Darnah Formation) by using Brunton compass at Wadi Zazah (Fig. 8).

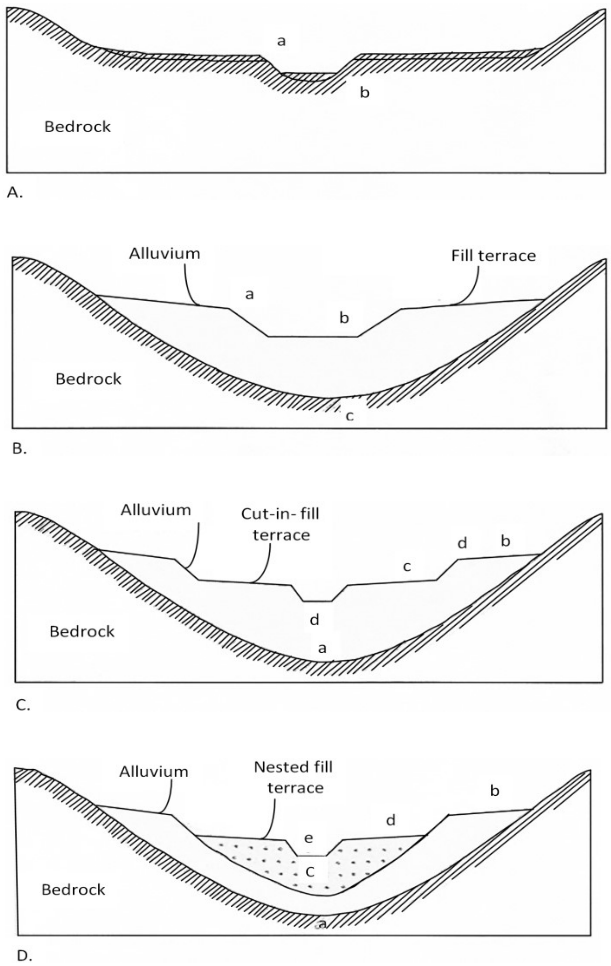

Fig. 3. Types of stream terraces: (A) bedrock (cut) terrace, (B) fill terrace, (C) cut–in–fill terrace, (D) nested fill terrace.

5. Location of the study area

The area of Wadi Zazah represents one of the largest valleys at Al Mabni area, Al Jabal Al Akhdar, NE Libya (Fig. 5). The study area extends ~ 10 Km in E-W directions and ~ 10 Km in N-S direction, which totally represent ~ 100 km^2. It is about 6 Km south Al Mabni village, and about 66 km east of Benghazi city. After nearly 22 Km be arrived to the first escarpment of Al Jabal Al Akhdar, in which the study area represents a small part of this escarpment, which passing through Benghazi plain to the west into Tansalukh check point.

6. Interpretation of results

The correlation between the individual terrace fragments measured at Wadi Zazah remains speculative. This is because there is no enough morphostratigraphic evidences except the altitudinal and directional data. However, the constructed height distance diagram (Fig. 6) may give some clues about the Quaternary and more recent tectonic movements of the area.

At the downstream end of Wadi Zazah, the lowest terrace fragment is recorded at 110 m above the present sea level. However, the heights terrace fragment is recorded at 210 m above the present sea level. This gives rise to an average slope gradient of 1: 39.21. Moreover, in many parts along the wadi's long profile, the terrace fragments are recorded at much higher elevations, which are anomalous to the average slope gradient (areas 1-8, Figs. 4 & 6). Based on the available data, the acceptable interpretation of this setting is that the land, and consequently, the terrace fragments were uplifted after they were formed. Tectonic uplift of the area during the Quaternary was also recorded and the Pleistocene marine terraces, which documented at many localities of Al Jabal Al Akhdar (Desio, 1935 & Hey, 1956).

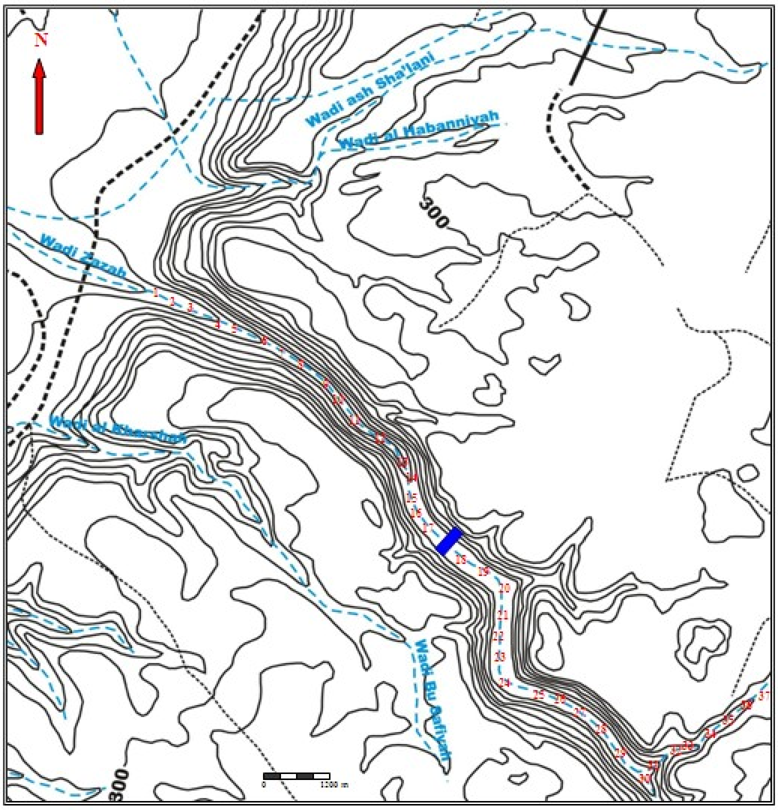

Fig. 4. Topographic map of Wadi Zazah showing the location of stations for measuring the altitude and direction of the recognized terrace fragments.
1-37 measuring stations; Wadi Zazah Dam.

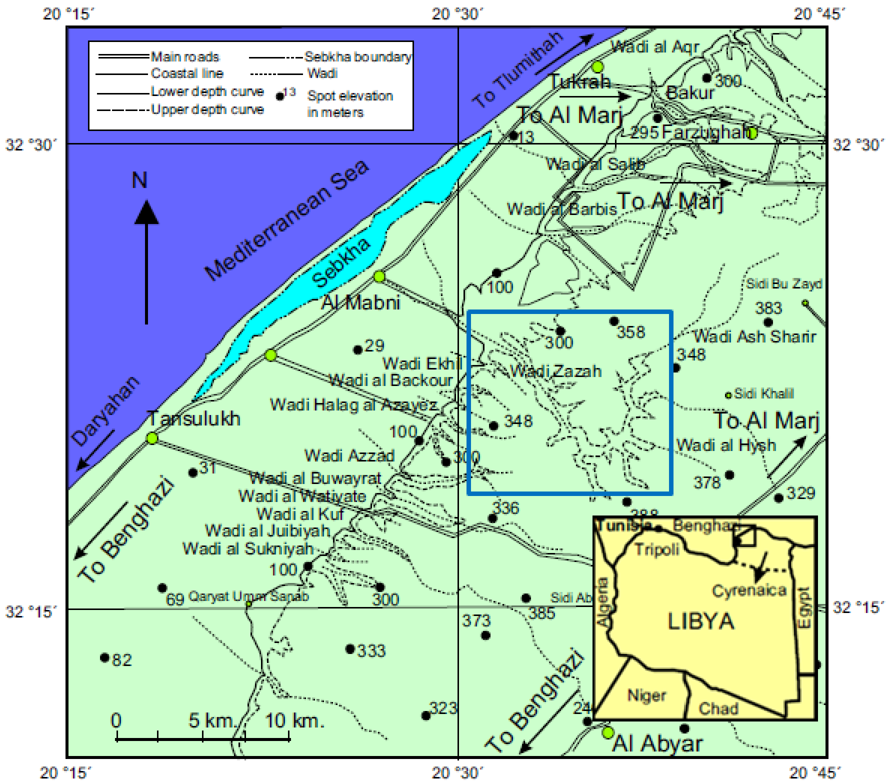

Fig. 5. Topographic map of NW part of the Al Jabal Al Akhdar showing the studied area highlighted in blue (modified from: Abdulsamad *et al.*, 2009).

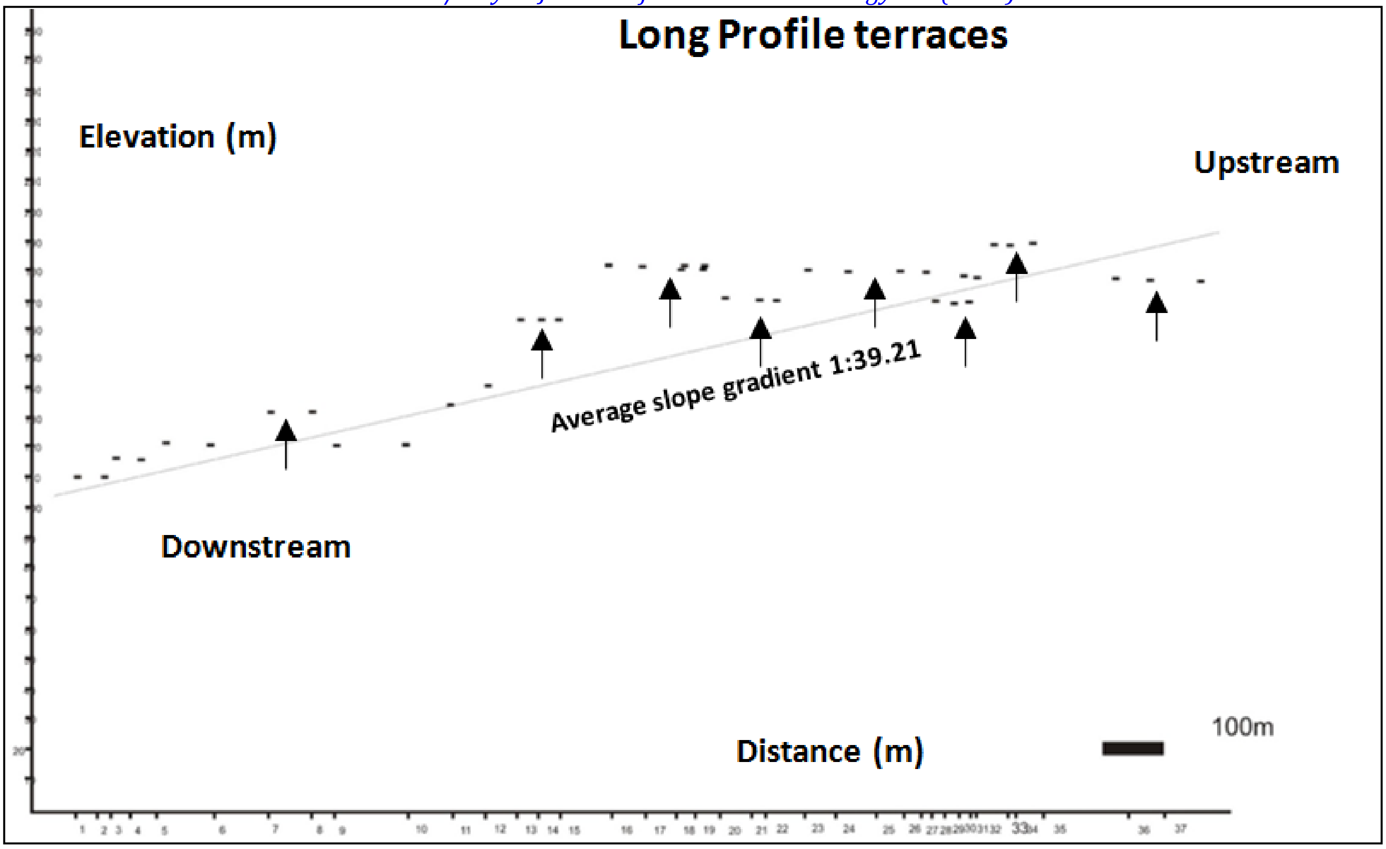

Fig. 6. Reconstructed long valley profile of the terrace fragments measured at Wadi Zazah, Al Jabal Al Akdar, NE Libya.

Another particular problem of Wadi Zazah is that it has changed its course suddenly in many areas, and as a result, the terrace fragments are of different directions (Fig. 7) (Table 1).

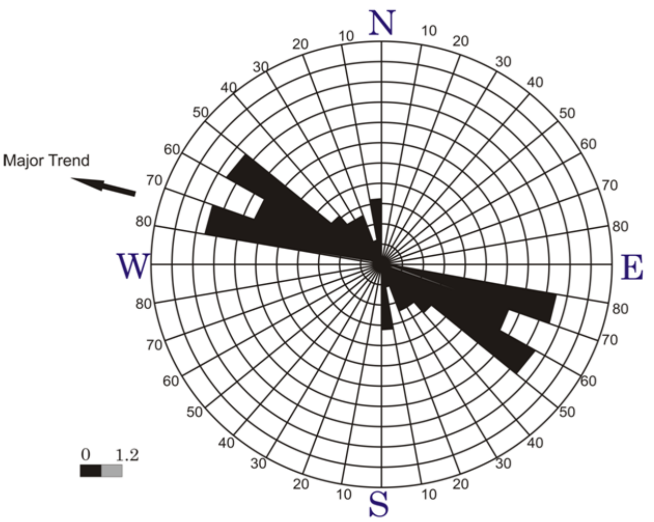

Fig. 7. Rose diagram representing the direction of (37) terrace fragments at Wadi Zazah, Al Jabal Al Akhdar, NE Libya.

Moreover, the directional data of the terrace fragments show a major trend at N80°W generally coinciding with the major trend of joints measured (nearly NW-SE) in the different rock units exposed at Wadi Zazah (Fig. 8) (Table 2).

This similarity in direction of both the joints and terrace fragments can be attributed to similar tectonic episodes. Furthermore, it supports the idea of tectonic uplifts of the area of Wadi Zazah during recent times.

Table 1
The Frequency and Frequency % distribution of the direction of terraces fragment at Wadi Zazah, Al Jabal Al Akhdar, NE Libya.

Class Interval	NW-SE FREQUENCY	NW-SE FREQUENCY %
0°-10°	4	10.8
11°-20°	1	2.7
21°-30°	3	8.1
31°-40°	3	8.1
41°-50°	11	10.8
51°-60°	8	18.9
61°-70°	6	13.5
71°-80°	8	27
81°-90°	0	0

Table 2
Frequency and frequency % distribution of the direction of joints at Wadi Zazah, Al Jabal Al Akhdar, NE Libya.

Class Interval	NE-SW		NW-SE	
	FREQUENCY	FREQUENCY %	FREQUENCY	FREQUENCY %
0°-10°	11	3.75	10	3.41
11°-20°	17	5.8	13	4.44
21°-30°	8	2.73	23	7.87
31°-40°	11	5.5	17	5.80
41°-50°	15	5.11	12	4.09
51°-60°	20	6.8	25	8.53
61°-70°	14	4.77	25	8.53
71°-80°	12	4.09	20	6.82
81°-90°	20	6.8	15	5.12

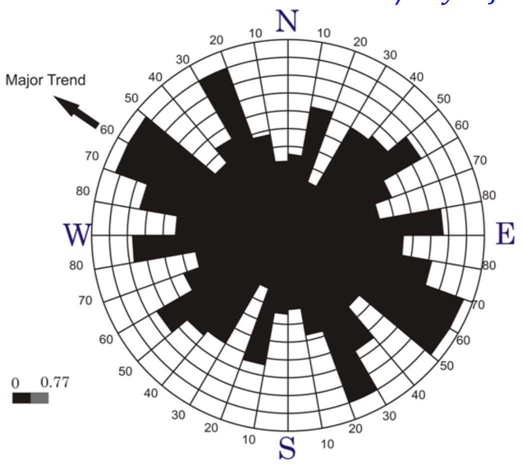

Fig. 8. Rose diagram representing the direction of 295 joints measured at Wadi Zazah, Al Jabal Al Akhdar, NE Libya.

7. Discussion

This study was essentially done to tackle factors that are playing a great role in the formation and development of Wadi Zazah terraces. The procedure of work terraces were followed or traced along the wadi measuring terrace thickness and elevation to denote the changes and to set an appreciation and a deep understanding of the study area and its terraces, as result at the downstream terraces started at an elevation of 110 m.a.s.l and was at upstream about 210 m. They were fluctuating at some parts even we are heading up stream. So that thing or manner is obviously not an ordinary thing that has given the present study its importance and valuable position.

In the long profile diagram, the elevations of the terraces in the Wadi Zazah were plotted against the distance to show the relation between the two parameters. On the diagram of cross section, the all corresponded points show the variability from the lowest elevation to the highest point of the wadi, where the terraces elevations remarked as having a curve of meandered line. Sometimes, terraces heading for up and being in increasingly relation, while in others changed down, the multi variations in the elevation and distance in the section, might it could be divided into eight loops, going to the upstream, these loops or cycles represent stepping or gradational variation, the variations themselves are shown more in the middle of the line, the average of these measurements ranged from 110 to 210 m.a.s.l.

Al Daghastani and Ben Amer (2008) studied analysis of Wadi Zazah by using aerial photographs in order to evaluate and trace faults. They suggested that Wadi Zazah is not affected by any neotectonic movements throughout the Quaternary Era. They also concluded that all joints and faults run parallel to the pattern of wadi. We strongly believe that the conclusions of Al Daghastani and Ben Amer (2008) is not valid and need to be reevaluated and compared with the surrounding valleys to make a comprehension interpretation of tectonic movements of the area.

Based on the new collocated data, this study revealed that Wadi Zazah tectonically active because of fluctuation of terraces elevation from downstream to upstream, the terraces deposited during Quaternary period. Therefore, any changes in terraces elevation reflect more recent tectonic movements rather than ancient tectonic possibility. Furthermore, El Hawat & Abdulasmad (2004) mentioned that the northern coastal margin of Cyrenaica exhibits successive elevated wave cut erosional terraces with residual Pleistocene beach-dune calcarenite that are observed in places up to 150 m elevation above the present day sea level. These terraces were not elevated only as result of the relative Pleistocene eustatic sea-level change.

8. Conclusion

On the basis of both the altitudinal and directional data of the terrace fragments measured at Wadi Zazah, we can conclude the following: Wadi Zazah represents a morphotectonic (consequent) valley formed by the combination of both tectonic (structural) and geomorphic processes. Wadi Zazah is a mobile area and has subjected to both Quaternary and recent tectonic uplift (neotectonic). The entire area of Al Jabal Al Akhdar is tectonically active and acting as a mobile region. Based on this discussion, the present work disagrees with the conclusion of Al Daghastani & Ben Amer (2008) that the basin of Wadi Zazah is not affected by appreciable deformation (neotectonic movements) and all faults and joints directions in the wadi are similar to the main fault that cut the wadi.

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