REVIEW ARTICLE

The Darbendi-Bazian-Abandoned Alluvial Fan: An Indication for the Lateral Growth of Qara Dagh Anticline, SW Sulaimani, Kurdistan Region, NE Iraq

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Received: 18/01/2020 **Accepted:** 03/02/2020 **Available online:** 30/06/2020

ABSTRACT

Qara Dagh anticline is one of the main anticlines in the Iraqi Kurdistan Region with NW – SE trend. It is a double-plunging anticline, almost symmetrical, and consists of six minor anticlines, some of them exhibit en-echelon plunges. The anticline shows many indications of lateral growth that indicate Neotectonic activities. Among those indications is the Darbendi-Bazian-abandoned alluvial fan. In this study, the satellite images (Sentinel – 2) are used and interpreted visually to discuss the presence of the alluvial fan and it is supported by field data. The interpreted data are checked in the field, and it is found that the alluvial fan is a large fan showing typical symmetrical fan. It is a single stage fan covered by fine materials. The thickness of the fan ranges from (2.5 – 6) m, whereas its length and width are 4.18 km and 1.35 km, respectively. The fan originated from Tinal stream, which was draining the area behind the apex toward south and south west and nowadays flows in an opposite direction. The alluvial fan's geometry, constituents, genesis, and mode of deposition are discussed in this article.

Keywords: Abandoned alluvial fan; wind gap; water gap; Neotectonic

1. INTRODUCTION

Alluvial fans are formed by dropping of the solid materials carried by water either due to decrease of gradient of a stream or a drop in local base level (Bull, 1991). As this reduces the capacity of the channel, the feeder channel will change direction over time, gradually building up a slightly mounded or shallow fan shape. Therefore, the sediments of any alluvial fan are usually poorly sorted. "The fan shape can also be explained with a thermodynamic justification: the system of the sediment introduced at the apex of the fan will trend to a state, which minimizes the sum of the transport energy involved in moving the sediment and the gravitational potential of the material in the cone" (American Geological Institute, 1962). At the apex of the fan which represents the discharge point there will be iso-transport energy lines forming concentric arcs. Thus, the materials will tend to be deposited equally about these lines, forming the characteristic cone shape (Baker et al., 2015).

Different authors have discussed the role of the climate in the formation of alluvial fans (Dorn, 2009). Majority of authors believe that the

Access this article online

DOI: 10.25079/ukhjse.v4n1y2020.pp57-68 | E-ISSN: 2520-7792

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climatic changes influence the weathering, stream flow, mass movements, and sediment supply in the drainage basin above the fan, as well as the gullying and soil development on fan deposits, besides the base level of a closed basin. Therefore, the role of the climate in formation of alluvial fans is essential, and it is one of the main and major factors that play role in their formation.

1.1. Study Area

The study area is located in Sulaimani Governorate at Darbendi Bazian, near Takya town within the Iraqi Kurdistan Region (Fig. 1). The main road between Kirkuk and Sulaimani cities crosses the fan longitudinally from SW to NE. The coordinates of the studied 6 sections are shown in Table (1).

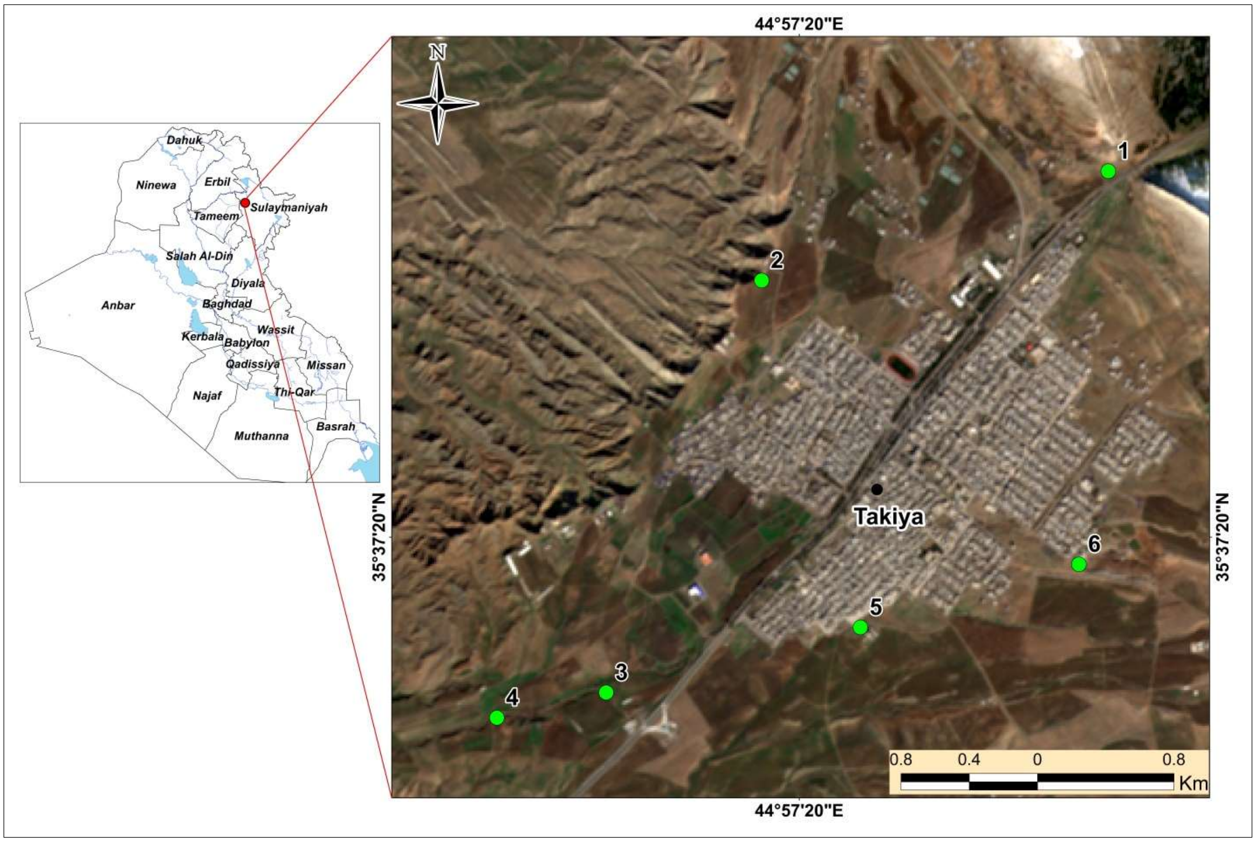

Figure 1: Satellite image showing the location of Darbendi Bazian alluvial fan and the studied six stations

Table 1: Coordinates of the six studied sections

Section No	Easting	Northing	Section No.	Easting	Northing
1	44°58'19.068"	35°38'16.761"	4	44°56'22.437"	35°36'52.25 9"
2	44°57'12.468"	35°37'59.863"	5	44°57'31.311"	35°37'5.992"
3	44°56'43.229"	35°36'55.692"	6	44°58'12.895"	35°37'15.76 4"

1.2. Aim

This study aims to prove the existence of an abandoned alluvial fan called the Darbendi Bazian alluvial fan in this study. Moreover, to prove that the fan was abandoned owing to Neotectonic activity, which indicates the lateral growth of Qara Dagh anticline and that Tinal stream was the feeder channel of the fan and nowadays it is flowing in a reverse direction and crosses Qara Dagh anticline at Bassara gorge.

1.3. Previous Works

The following studies were carried out near the study area:

Sissakian (2010) studied the Neotectonic evidences at Darbendi Bazian vicinity and along Qara Dagh anticline. Sissakian and Abdul Jab'bar (2010) studied many transversal gorges in Iraqi Kurdistan Region; among them is Darbendi Bazian gorge, they mentioned it is a wind gap. Al-Kubaisi and Abdul Jab'bar (2015) studied the lateral growth of Qara Dagh anticline from which Darbendi Bazian alluvial fan is originated and concluded that Qara Dagh anticline consists of six segments. Sissakian et al. (2018) studied Qara Dagh anticline and proved it consists of six segments that are growing and are conjugated together.

1.4 Materials and Methods

To fulfill the aims of this study, the following materials were used:

- Geological maps at a scale of 1:100000 and 1:250000,
- Topographic map at a scale of 1:100000,
- Sentinel-2 Satellite images of 80 m resolution,
- Reviewing published articles that deal with study area and near surrounding,
- Reviewing relevant published articles and books that deal with the development of alluvial fans.

The geological and topographical maps with the satellite images were used to study, measure, and interpret visually the dimensions, shape, and characters of Darbendi Bazian alluvial fan. Filed work was carried out to check the interpreted data, describe the sediments of the fan from the existing exposures along the limits of the fan and some hand dug water wells. The size, shape, and roundness of the pebbles are measured and/or indicated. Moreover, to make relevant documentary photos for features that prove the existence of the fan.

2. GEOLOGICAL SETTING

The geological setting of the study area is briefed hereinafter depending on the best available geological data. The geomorphology, tectonics and structural geology, and stratigraphy of the study area are mentioned depending on Sissakian et al. (2014), Fouad (2012) and Sissakian and Al-Jiburi (2014).

2.1. Geomorphology

The study area is located physiographically between the High Mountain Province and Low Mountains Province (Sissakian and Fouad, 2012). The main geomorphological units are:

- **Structural Unit:** The main forms are the anticlinal ridges along the southwestern limb of Qara Dagh anticline (Fig. 2).
- **Alluvial Unit:** The main forms are the alluvial fans (Fig. 1) that are well developed along the southwestern limb of Qara Dagh anticline (Fig. 2).
- **Structural Denudational Unit:** The main form is the flat irons that are well developed along the southwestern limb of Qara Dagh anticline within the Pila Spi and Fatha formations (Fig.3).

2.2. Tectonics and Structural Geology

Darbendi Bazian alluvial fan is located mainly in the Low Folded Zone; whereas, the apex of the fan is located in the High Folded Zone (Sissakian and Fouad, 2012). Both zones are located within the Outer Platform (Unstable Shelf) of the Arabian Plate (Fouad, 2012). Moreover, both zones belong to the Zagros Fold – Thrust Belt (Berberian, 1995; Alavi, 2004 and Fouad, 2012). The alluvial fan had originated from a large water gap that was developed within the southwestern limb of Qara Dagh anticline, which is a long and narrow NW – SE trending anticline consisting of six segments of double-plunging anticlines (Sissakian et al., 2018).

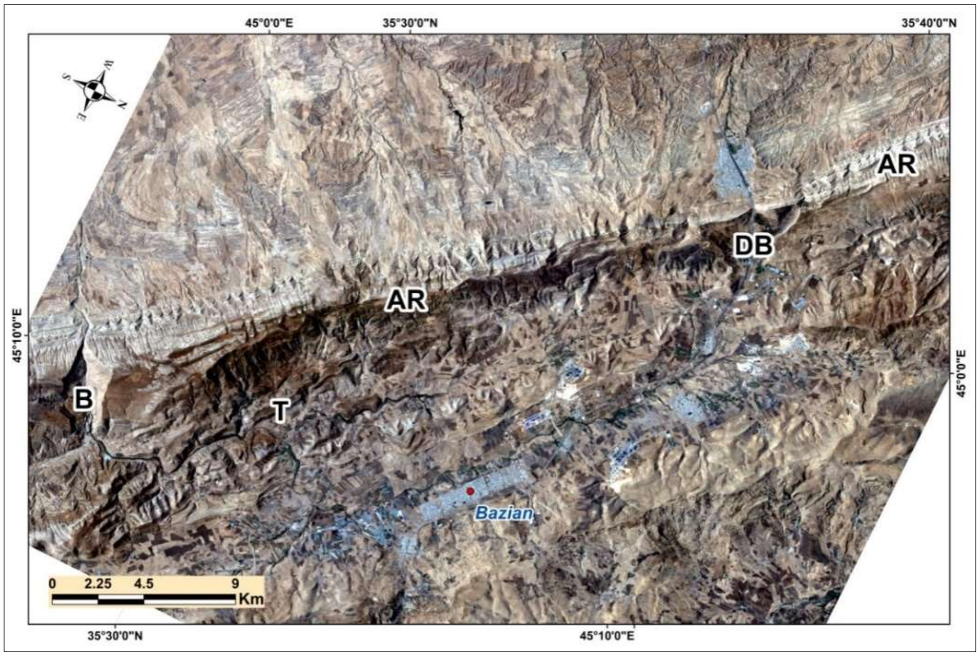

Figure 2: Satellite image showing anticlinal ridges (AR), Darbendi Bazian gorge (DB), Bassara gorge (B), and Tinal stream (T)

Figure 3: Satellite image showing well developed flat irons (FI) along the southwestern limb of Qara Dagh anticline and Darbendi Bazian alluvial fan (DBAF).

2.3. Stratigraphy

Darbendi Bazian alluvial fan is originated from the Pila Spi Formation and lay on many other formations. All those formations are mentioned very briefly depending on Sissakian and Al-Jibury (2014) and Sissakian and Fouad (2012 and 2014).

- **Pila Spi Formation** (Upper Eocene): Consists of well-bedded dolostone and limestone with rare marl intercalations. The thickness of the formations is about **120** m.

- **Fatha Formation** (Middle Miocene): Consists of a reddish-brown claystone with few beds of hard light-gray limestone and hard gray and white gypsum. The thickness is 100 m.

- Injana Formation (Upper Miocene): Consists of cyclic alternations of reddish-brown well-bedded hard sandstone and reddish-brown fairly hard claystone (Fig. 4). The thickness is 120 m.

- **Mukdadiya Formation** (Upper Miocene – Pliocene): Consists of cyclic alternations of gray well-bedded fairly hard and friable sandstone and gray fairly hard claystone; some of the sandstone beds are pebbly. The thickness is 400 m.

- **Bai Hassan** Formation (Pliocene – Pleistocene): Consists of conglomerate, reddish-brown sandstone, siltstone, and claystone, in cyclic nature, the thickness is about 500 m.

- **Alluvial Fans** (Pleistocene): Besides Darbendi Bazian alluvial fan, many small fans are developed on both sides of the main fan (Figs. 1 and 3). The constituents of the fans are mainly pebbles and fragments of dolostone and limestone derived from the Pila Spi Formation, well cemented by reddish-brown clayey materials (Fig. 5). The thickness of the fan sediments as seen from the investigated exposures ranges from (2.5 – 6) m.

Figure 4: Exposure of the Injana Formation, note the reworked carbonate fragments and pebbles derived from Darbendi Bazian alluvial fan

Figure 5: Constituents of Darbendi Bazian alluvial fan

3. DARBENDI BAZIAN ALLUVIAL FAN

3.1. Characteristics

Darbendi Bazian alluvial fan is an abandoned fan derived from Darbendi Bazian gorge located at Qara Dagh Mountain. According to alluvial fans classification of Sissakian and Abdul Jab'bar (2014) in Iraq, the Darbendi Bazian alluvial fan is single stage, medium sized, and top covered by soil. No stages were recognized neither from visual interpretation of the satellite images nor during the field investigation. The length and maximum width of the alluvial fan are 4.18 km and 1.35 km, respectively. The height of the apex is 934 m (a.s.l.); whereas, the toe area is 835 m (a.s.l.). Accordingly, the gradient of the fan will be 2.34%, which is about 3°. This gradient is within the usual gradients and/or slopes that are usually less than 10° (Bull, 1991). The fan's concave shape is lost because of farming activities and because it is a residential area occupied by Takya town (Figs. 1 and 3).

To indicate the changes in the constituents of Darbendi Bazian alluvial fan including pebble size, roundness, and type, 6 stations were investigated (Fig. 1), the results are presented in Table (2). No filed data were recognized about the "bar and swale" micro-topography, within the alluvial fan. The authors believe the range is around (0.5 – 3) m.

In the study area, Qashlagh and Hanjira Mountains that are parts of Qara Dagh main Chain (Range) and are located on the west and east of Darbendi Bazian gorge are the source area for formation of the alluvial fan; they form elongated mountain chains with a maximum height of 1440 m (a.s.l.), almost with rare vegetation cover, forming the range topography. Whereas, Takya Plain is the depositional basin in which the alluvial fans are formed. Therefore, the "basin-and-range topography" is typically formed in the study area.

Table 2: The description of the studied stations in Darbendi Bazian alluvial fan

Station No.	Location	Thickness of the fan deposits (m)	Pebble			Comments
			Size (cm)	Shape	Type	
1	Apex	6	4 – 25	SR., SA		Partly cemented by reddish-brown clayey material.
2	Upper western part	2	4 – 16	R, SR	Limestone	Partly cemented by reddish-brown clayey material, pebbles coarsening upwards.
3	Distal part	3		R, SA		Fairly cemented by reddish-brown clayey materials.
4		3	2 – 10	R		Few pebbles almost loose in a clayey soil.
5	Lower eastern part	2.5	3 – 25	SR, SA	Limestone with gypsum	Pebbles are cemented by clayey and gypsiferous materials.
6	Upper eastern part	3	1 – 10	SA	Limestone	Top soil cover with loose rock fragments and pebbles.

SR = Sub-rounded, SA = Sub-angular, and R = Rounded

Figure 6: Left) The apex of Darbendi Bazian alluvial fan, **Right)** The sediments at the apex area

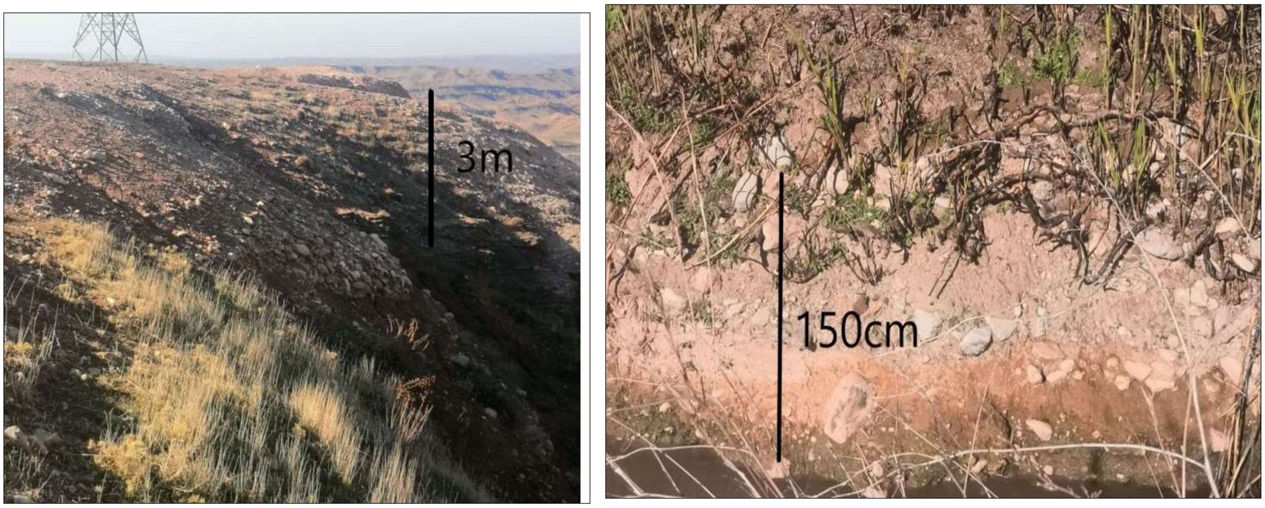

Figure 7: Darbendi Bazian alluvial fan sediments, Left) Station 2, Right) Station 3

3.2. Genesis

As the genesis of Darbendi Bazian alluvial fan is concerned, fans are classified according to the genetic sense by Blair and McPherson (1994) in Ritter et al. (2002) into two types: Type **I** and **II**. The classification depends mainly on grain size: their shape and sorting, feeder channel length, drainage basin size, bed rock lithology, and average slope. Following these parameters, the alluvial fan is classified as Type **I**

Figure 8: Darbendi Bazian alluvial fan sediments, **Left)** Station 4, **Right)** Station 5

Figure 9: Darbendi Bazian alluvial fan sediments at Station 6

3.3. Mode of Deposition

To delineate the mode of deposition of Darbendi Bazian alluvial fan, the concept of Ritter et al. (2002) is followed besides the available data about the characteristics of the alluvial fan (Table 2). Accordingly, the depositional model of the alluvial fan is constructed (Fig. 10). It could be seen that the deposition starts with Transitional flow and continues in Debris flow, then flows again by Transitional flow, changes to stream flow, and terminates in erosion process, the debris flow being the dominant mode. The last mode of deposition (stream flow) in the alluvial fan is indicated by the supply of the fine materials nowadays, as indicated from the top soil cover (Figs. 6 and 9), where the valleys have no more load-carrying ability to transform boulders, because of decrease in amount of rain water precipitation, and then the role of the erosion; accordingly, almost lost its shape because of cultivation activities and urbanization (Fig.1). It is worth mentioning that the fan was deposited by Tinal stream, which has changed its direction and flows out of Qara Dagh Mountain through Bassara gorge (Fig. 2

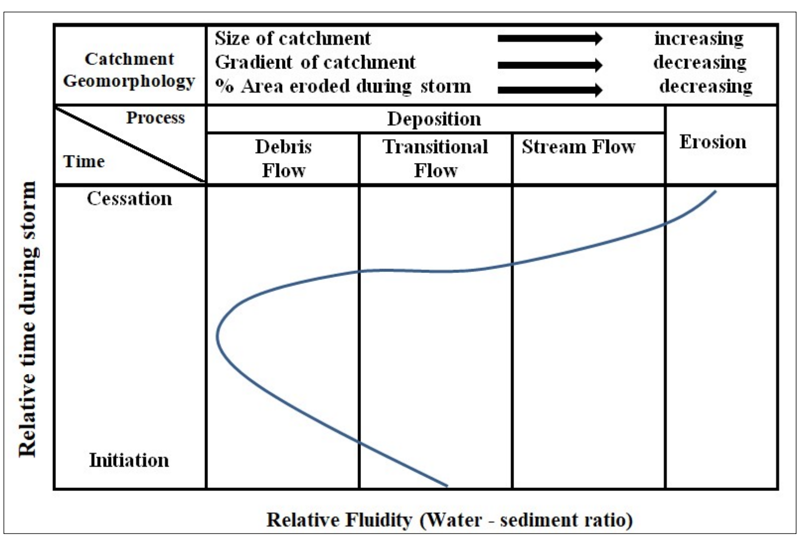

Figure 10: Conceptual model showing the change in the water/sediments ratio, the sequence of depositional and erosional events and associated flow conditions in Darbendi Bazian alluvial fans (modified after Ritter et al., 2002)

3.4. Abandonment of Darbendi Bazian Alluvial Fan

Alluvial fan is an old and abandoned fan; the indications are: **1)** no feeder channel exists in the fan, it is covered by recent sediments (Fig. 11), **2)** the fan lost the typical fan shape, **3)** at the toe area, active erosion started by active streams (Fig. 11), and **4)** the pebbles of the fan at the toe area are already loosening and accumulated as loose pebbles on the slopes of the underlying folded rocks (Fig. 12).

3.5. Age Dating

Absolute dating techniques are not available to the authors, but they believe that the age of Darbendi Bazian alluvial fan is most probably of Late Pleistocene. This assumption is based mainly on the climatic changes during Pleistocene and the existence of the Bai Hassan Formation (Pliocene – Pleistocene) below the sediments of the alluvial fan.

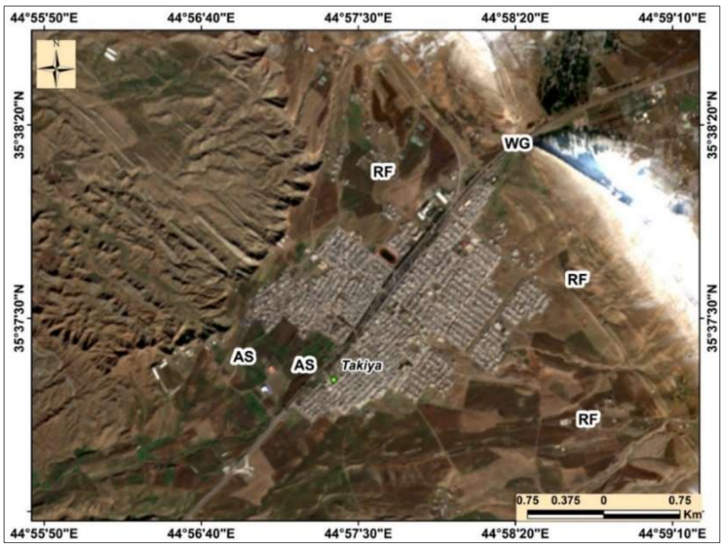

Figure 11: Satellite image of Darbendi Bazian alluvial fan. Note the absence of the feeder channel, the recent valleys (R F) that supply sediments that cover the whole map by soil, and the active streams (A S) at the toe area that started eroding the fan.

Figure 12: Toe area of Darbendi Bazian alluvial fan, note the eroded part of the fan and accumulation of loose gravels on the slopes of the underlying folded rocks

4. LATERAL GROWTH INDICATIONS

Different authors have studied geomorphological and structural indications that confirm the lateral growth of fold; among them are: Oberlander (1985); Keller and Pinter (2002); Bennett et al. (2005); Ramsey et al. (2008); Mumipour and Najad (2011); Grasemann and Schmalholz (2012); Mousavi and Arian (2015); Whitney and Hengesh (2015); Collignon et al. (2016). In the study area of Darbendi Bazian alluvial fan the following indications were recognized.

4.1. Wind Gap

When a stream abandons crossing a fold owing to natural reason(s), the empty gap that is left is called the Wind Gap (Ramsey et al., 2008). Darbendi Bazian is a typical wind gap developed within the southwestern limb of Qara Dagh anticline (Sissakian and Fouad, 2012 and 2014a and b, and Sissakian et al., 2018). The stream that was crossing the anticline through Darbendi Bazian is called Tinal, which flows nowadays in an opposite direction and parallel to the southwestern limb (anticlinal ridge) of Qara Dagh anticline and flows out of the ridge through a gap called Bassara gorge (Fig. 2). Before changing the flow direction of Tinal stream, it was flowing out of the anticlinal ridge through Darbendi Bazian gorge. The indication for that is developed Darbendi Bazian alluvial fan (Figs. 1, 2, and 11). The presence of a wind gap at a fold is a solid indication that the fold is exhibiting lateral growth (Ramsey et al., 2008) and accordingly witnessing Neotectonic activity (Skilodimou et al., 2014), they revealed the importance of lateral growth and uplifts of folds as indications of active tectonics.

4.2. Abandoned Alluvial Fan

As we have aforementioned and indicated that Darbendi Bazian is an abandoned fan; therefore, this is another indication for a Neotectonic activity and accordingly confirms the lateral growth of Qara Dagh anticline. Many authors have confirmed that one of the indications is the presence of abandoned alluvial fans; among them are: Oberlander (1985); Keller and Pinter (2002); Bennett et al. (2005); Ramsey et al. (2008); Dorn (2009); Grasemann and Schmalholz (2012); Baker et al. (2015); Collingnon et al. (2016).

5. DISCUSSION

In a tectonically active area like the Iraqi Kurdistan Region which form the extreme northeastern part of the Arabian Plate and which is in collision with the Iranian Plate, the lateral and vertical growths of the folds is a common fact (Berberian, 1995; Keller and Pinter, 2002; Alavi, 2004; Ramsey et al., 2008; Grasemann and Schmalholz, 2012; Collignon et al., 2016). Accordingly, Qara Dagh anticline is one of those folds that exhibit lateral growth; as indicated by the presence of wind gap that was a water gap and through which a large alluvial fan was deposited by Tinal stream. Owing to the lateral growth of Qara Dagh anticline, the Tinal stream changed its flow direction and no water was flowing in the water gap; accordingly, it was changed to a wind gap. Therefore, the existing Darbendi Bazian alluvial fan was abandoned because no sediments were laid down. However, recently, fine sediments are deposited from small valleys located east and west of Darbendi Bazian gorge (Fig. 11) and accordingly, the abandoned alluvial fan is covered by top soil.

6. CONCLUSION

From the current study, we can conclude that Qara Dagh anticline is exhibiting lateral growth as indicated by the presence of one wind gap, which is present in Darbendi Bazian gorge, and the presence of abandoned alluvial fan, which is present as Darbendi-Bazian-Abandoned alluvial fan. For both cases, we have presented many indications that confirm the presence of a wind gap and an abandoned alluvial fan, including the pebbles that are totally derived from the Pila Spi Formation. The shapes and roundness's of the pebbles indicate that they are sediments of alluvial fans. The limits of the Darbendi-Bazian-abandoned alluvial fans are hindered below the sediments of recent alluvial fans, which are under development east and west of the abandoned Darbendi Bazian alluvial fan. Besides, the slope sediments which are derived from the slopes of the south western limb of Qara Dagh anticline, which have contributed in hindering the concave fan shape.

7. ACKNOWLEDGMENT

The authors express their thanks to the esteemed reviewers for their comments, which were considered to amend the article in its current version.

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