

GLACIAL ACTIVITY SIGNS DURING THE PLEISTOCENE EPOCH IN RAWANDUZ RIVER VALLEY, KURDISTAN REGION, NORTHEAST IRAQ

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ABSTRACT

The clastic sediments on both sides of the Rawanduz River Valley were investigated for glacial signs. The Rawanduz River, one of the major tributaries of the Greater Zab River, its source area is located in the high ridges of the mountains on the Iraqi – Iranian border. The topography map (1: 25 000) was utilized to determine the best locations for glacial landforms and features. Elevation data was retrieved from the electronic maps of the Maplog. The study was based on field observations, erosional landforms indication and sedimentological analysis, including field visual determination of roundness and sphericity of gravel. The occurrence of glacio-alluvial sediments (tills), terraces more than 10 meters above the present river level, and erosional features of glacial origin indicate that the drainage area of the Rawanduz River, from its source to its conjunction with the Greater Zab River near Bekhma Village, experienced variable rates of glacial activities during the Pleistocene Epoch.

دلائل النشاط الجليدي في العصر البلايستوسيني في وادي نهر رواندوز، إقليم كردستان، شمال شرق العراق

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المستخلص

تمت دراسة الرواسب الفتاتية على جانبي وادي نهر رواندوز بحثاً عن العلامات والدلائل الجليدية. يعتبر نهر رواندوز أحد الروافد الرئيسية لنهر الزاب الكبير، ويبدأ منبعه من منطقة الجبال العالية الواقعة على الحدود العراقية – الإيرانية. تم استخدام خريطة التضاريس بمقياس (1:25000) لتحديد أفضل المواقع للظواهر والدلائل الجليدية. وتم استرداد بيانات الارتفاع من الخرائط الإلكترونية لسجل الخرائط. استندت الدراسة إلى الملاحظات الحقلية وطبيعة أشكال التعرية الأرضية بالإضافة إلى تحليل شكل الرسوبيات بما في ذلك الاستدارة والكروية للحصى. ان وجود الرواسب الجليدية (tills) والشرفات النهرية التي يزيد ارتفاعها عن 10 أمتار فوق مستوى النهر الحالي والسمات التآكلية ذات الأصل الجليدي تشير إلى أن منطقة وادي نهر رواندوز (من منبعه إلى التقائه مع نهر الزاب الكبير بالقرب من قرية بيخمة) شهدت معدلات متباينة من الأنشطة الجليدية خلال عصر البلايستوسين.

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INTRODUCTION

The commencement of the Pleistocene Epoch is controversial. Estimates range between 300 thousand years and 3 million years, but the most acceptable estimate is that this epoch began 2.588 million years ago (International Commission on Stratigraphy, 2008). The end of this era (or, rather, the end of the last glacial phase or extensions) is about 11,000 years ago (Clark *et al.*, 2009). The first half of this period, which is called the Villefranche, extended for one third of a million year and was characterized by heavy rainfall with intermittent occurrence of ice. When the Villefranche came to its concluding stages the Earth gradually started to cool. Arctic ice crawled over neighbouring continents in the form of thick ice sheets (Coon, 1962).

Geological evidence indicates that several glacial phases have passed on Earth since its forming inception (Carlson, 2011). Numerous glacial phases in the pre-Cambrian and three glacial phases in the late Palaeozoic Era occurred. The first of these was in the early Carboniferous and the second was in the late Carboniferous to the beginning of the Permian, while the third phase was in the Middle Permian (Carlson, 2011). The Pleistocene glacial age is the last glacial event that covered parts of the Earth which began about 600,000 years ago (Wright, 1962). The last of it was about 20,000 years ago, when snow covered large areas of the Earth. The end of the glacial phase was different from place to another based on its location on the Earth. In the Kurdistan Region, the climate has improved to a large extent before 11,000 years ago and the cold climate ended completely before 9,000 years ago (Wright, 1962). The climate became warmer and; hence, humans started to appear in the caves in Kurdistan (Jozi, 1980). Table 1 shows the comparison between geological and archaeological times.

It was noticed during the study of glacier sediments in the European Alps that these sediments were not due to single ice age (Coon, 1962). These sediments came sequentially, separated by sediments that were not habitual during glacial ages. Consequently, four phases of glaciation were identified, where glaciers crawled and covered large areas of the Earth, identified as glaciations phases. Between each of these phases, the glaciers took a regression.

The sediment age was determined by radioactive carbon which showed differences in the age of these sediments (Coon, 1962; Ivy-Ochs *et al.*, 2008). Various names were assigned to the phases (Ivy-Ochs *et al.*, 2008; Clark *et al.*, 2009). The number of the phases varied depending on the areas studied and not proved that these phases were the same in all regions (Baqir, 1973). The most common name in Europe is the one that describes the glacial ages in the Alpine Mountain (Clark *et al.*, 2009), which remained their traces after the end of this age in the valleys confined between the Alpine Mountain chains (Table 2). The names of these valleys were used to name the glacial phases. The first glacial phase is known as Günz, the second as Mindel, the third as Riss, and the fourth as Würm (Coon, 1962). Between these glacial phases there was relatively warm non-glacial times (Coon, 1962), which were named according to the two preceding and subsequent glacial phases (Al-Dabagh, 1981).

Other classification for glacial stages is the one used in the United States. There are four named major glaciation stages in North America (Table 3). The earliest is named the Nebraskan, found on the plains of the central United States. It followed by the Kansan which overlies it and extends slightly farther southwest into Kansas. The Illinoian, as the name implies, terminates primarily in Illinois, and the last one is the Wisconsin Glacial Stage, that was extensive in Wisconsin as well as in New York, and New England (Bowen, 1978). The Würm Glacial Stage is the major division of the Late Pleistocene sediments and time in the

Alpine Europe followed by the Riss-Würm interglacial period which is correlated with the Wisconsin Glacial Stage of North America. The Alpine glaciations of the Pleistocene were early recognized and formed the basis of modern Pleistocene glacial theory. The Würm Glacial Stage began about 70,000 years ago and is divided into early, middle, and late phases. The end of the Würm Stage and the retreat of the final glaciers was a complex of minor retreats and advances (Pallardy, 2019).

Table 1: Archaeological and geological time scales (International Commission on Stratigraphy, 2008; Baqir, 1973)

Era	Period	Epoch	Climate	Age	Archaeological Age			Year B.C.
Cenozoic	Quaternary	Holocene	Recent Climate	Recent	Mesolithic (Zarzian)			— 8000 — 15000
		Pleistocene	(Glacial and Pluvial)	Warm	Late (Bradostian)	Magdalenian		
						Solutean		
						Gravettian		
						Aurignacian		
						Périgordian-Châtelperronian		
				Middle	Mousterian			
					Levalloisian - Mousterian	— 120000		
				Early	Levalloisian	— 180000		
					Acheulian	— 240000		
						— 430000		
						Clactonian	— 480000	
					Abbevillian	— 540000		
					Palaeolithic		— 600000	
							— 1000000	
				Tertiary	Pliocene	Pliocene Climate	Gelasian	Eolithic

Table 2: Estimated time (in years) for the length of glacial phases and interglacial intervals (Coon, 1962)

Glacial Phase/Interglacial	Age	From	To
Phase 4	Würm	120,000	15,000 (or 10,000)
Interglacial 3	Riss-Würm	180,000	120,000
Phase 3	Riss	240,000	180,000
Interglacial 2	Mindel-Riss	280,000	240,000
Phase 2	Mindel	480,000	280,000
Interglacial 1	Günz-Mindel	540,000	480,000
Phase 1	Günz	600,000	540,000

Table 3: Chronology of major glaciations (ice ages) and inter-glaciations (wormer phases) in North America and Alpine Mountain in Europe (Bowen, 1978)

Thousand years ago	Mid US Classification		Alpine Classification	
	Glaciation	Interglaciation	Glaciation	Interglaciation
60 - 130	Wisconsin		Würm	
115 - 140		Sangamon		Riss-Würm
140 - 350-	Illinoian		Riss	
440 - 500		Yarmouth		Mindel-Riss
500 - 640	Kansan		Mindel	
640 - 700		Aftonian		Günz-Mindel
780 - 900	Nebraskan		Günz	
900 - 1300				Donau-Günz
1300 - 1500			Donau	

There are few studies and investigations on glaciers and glacial activities during the Pleistocene Epoch in the northeastern mountainous area and the lands nearby Rawanduz River Valley (e.g. Wright, 1962, Tali *et al.*, 2016 and Hughes, 2018). Evidences of cirques of ice cores in the eastern and northern parts of the Hasar-i-Sakran cirque and Hasar-i-Qandil cirque are found and the existence of the dunes inside the cirques resembles hummock dunes (Tali *et al.*, 2016). This work attempts to identify the glacial signs from the sediments and landforms in the areas around the Rawanduz River Valley.

STUDY AREA

The mountainous area located in the northeastern part of Iraq, on Iraqi – Iranian border, is a part of Taurus-Zagros mountain range, that extends from Turkey to northeastern Iraq, then passes to western and to southwestern Iran., The highest elevation in Iraq is 3,611 m a.s.l. at Cheekha Dar Peak, with rugged ridges nearby Hasar-i-Rost Mountain (elevation 3,000 – 3,500 m a.s.l.) (Worldatlas, 2018). From its source area at the Iraqi – Iranian border, the Rawanduz River flows downstream across Rayat, Choman, Rawanduz, and Galy Ali Beg Valley to its conjunction point with the Greater Zab River at the entrance of Bekhma Gorge. The Pleistocene glaciers formed on the northern slopes of ridges within elevation from 2,400 – 3,500 m, flowed through gaps southward down valleys tributary to the Greater Zab River to elevations as low as 1,100 m (Wright, 1962).

The Rawanduz River crosses Rayat and Choman towns. Near Naopurdan Village, it conjuncts with another main branch that stream down in between the high ridge of Sakran Mountain. The river continues streaming down passing near the Galala Gorge, the 3rd main branch that heads between ridges of Halgurd and Hassar-i-Roast near the intersect road of

Smilan with Hamilton Road. Then, crossing Barsarin Gorge to Jundian and then to Rawanduz Valley (Khara-Rash Valley; on the west of Rawanduz Town). After that conjuncts with Balakiyan Stream and Alana Stream, passing Galy Ali Beg to Khalan Valley to its conjunction with the Greater Zab River (Fig.1).

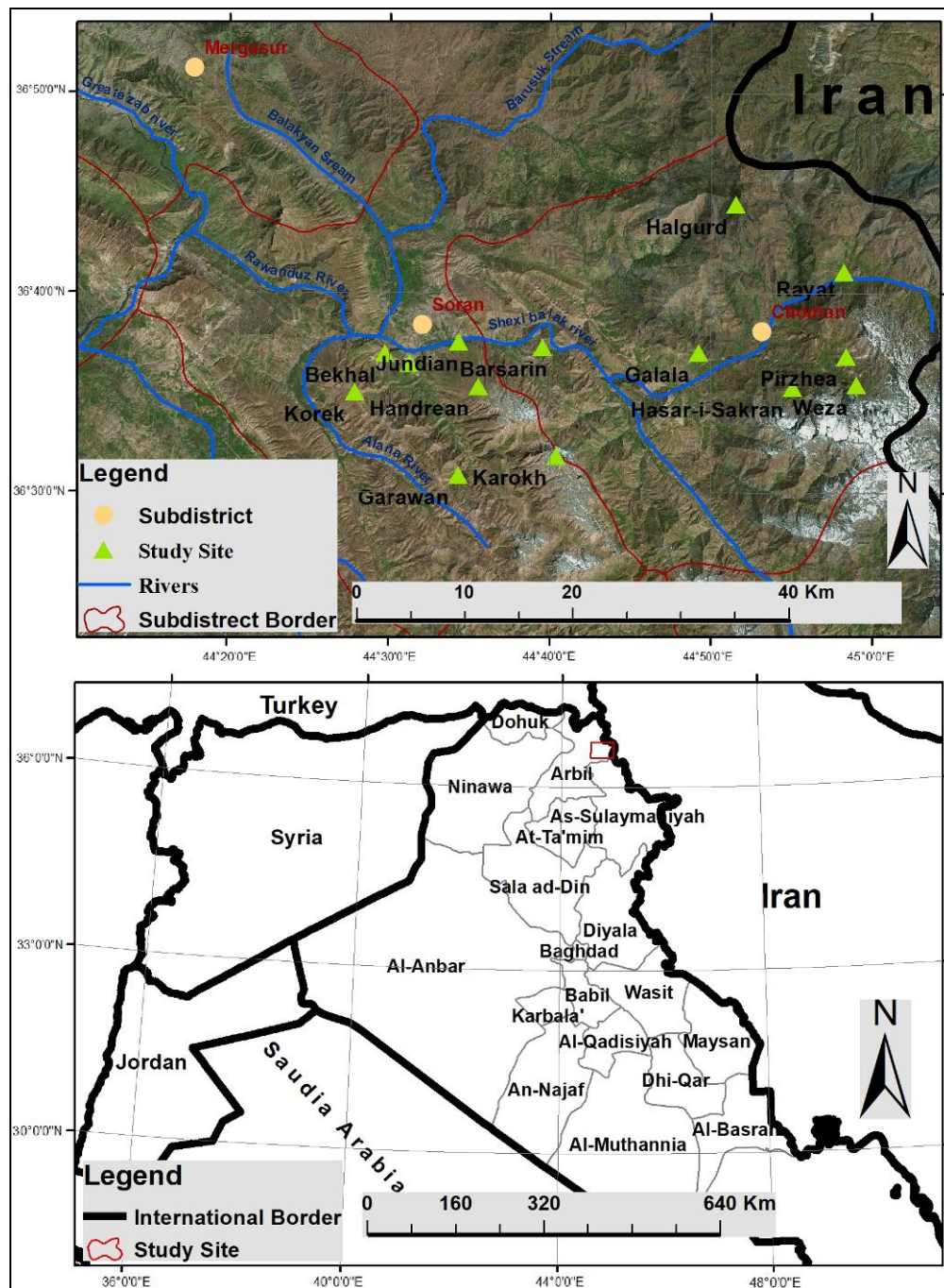


Fig.1: Location map shows the studied sites

The climate of the Kurdistan Region is marked by cold rainy winter and dry hot summer. The rains are brought in partly by cyclonic disturbances from the Mediterranean Sea and partly by circulation around an anticyclone centered in winter over the Arabian Peninsula (Hama *et al.*, 2014). The regional precipitation increases with elevation in the mountains and

ranges from about 300 mm per year in the outer foothills to more than 1,000 mm in the highest parts of the Halgurd and Sakran mountains. The precipitation reaches a maximum here not only because the mountains are high and massive, but also because the trend of the ranges shift from east to southeast. The storms which follow the outer flank of the range from the Mediterranean Sea eastward are forced to rise over the mountains or to be diverted sharply to the southeast (Wright, 1962; Hughes, 2018). Temperatures are high at the piedmonts, with daily maximum generally exceeding 35 °C from May to October. In areas above 1,000 m, summer heat is less intense and nights are cool. The great variation in mean temperature between July and January (about 25 °C) is a reflection of the basic continental climate (Wright, 1962). There are no climate stations in high mountains on the Iranian border from Iraq's side. The only temperature data available is by Tali *et al.* (2016) which is based on synoptic data of Piranshahr station east of Haji Omaran for the period between 1995 and 2012. The meteorological data show that the average annual temperature is 11.9 °C with a high temperature fluctuation in mountainous areas. They mentioned that the mean of minimum temperature is 4.1 °C and that the maximum is 14.4 °C. The maximum temperature is 39 °C and the minimum is -28.6 °C in the region (Tali *et al.*, 2016).

The climate during the glacial ages was different from now; the climatic zones that are now located south of the ice line have become much narrower than they are now (where the area of the ice and its associated climate has expanded) Thus, it is reasonable to assume that the glacial and post-glacial climatic changes that occurred in Europe during the Pleistocene Epoch to have its effect on these mountainous area as part of Taurus-Zagros mountain arc, including the lands around Rawanduz River from source area heading from Iraqi – Iranian border into its valley towards the conjunction point with Greater Zab River (Tali *et al.*, 2016). The Pleistocene glacial features were studied principally in high mountainous land on the Iraqi – Iranian border and the area around the Rawanduz River Valley to its conjunction with the Greater Zab River at Bekhma Village (Wright, 1962; Tali *et al.*, 2016).

METHODOLOGY

The topography map (1: 25 000) was utilized for determining the best locations for glacial landforms and features. Elevation data was retrieved from the electronic maps of the Maplog. The field trips were performed during the summer season from May 12 to May 21, 2018. The study was based on field observation, erosional landforms indication, and sediment analysis including roundness and sphericity of sediments. Studying and analysing the land forms and sediments were based on ice flow, glacial erosional effects, sediment deposition processes, and characteristics. Numerous glacial erosional landforms were identified such as cirques, glacial horns, arêtes, U-shape valleys, and hanging valleys. Analysing characteristics of depositional landforms also included glacier retreat effect and their freight of crushed rock and sand created glacial drift, glacial moraines and glacio-alluvial sediments. The photos were either taken directly from the field within this study or extracted from the NRT TV reporting video on 3rd of March 2019; Akoyi, 2019; Glacial landforms, 2019; and Aziz, 2019.

OBSERVATIONS AND DISCUSSION

An abundance of rock fragments (plucks) that are usually produced by the friction of the glacier with the bed rocks during the glacial movement causes the bottom of the glacier to melt, and then the melt water freezes in the joints of the rocks. When the glacier moves again the rock fragments are pulled away or 'plucked out' from the base of the glacier valley (Worldatlas, 2017). The observations of such erosional landforms indication and sediments roundness and sphericity were recorded at the following localities:

▪ *Rayat Village*

The Rayat Village is located about 100 Km northeast of Erbil City (coordinates: 36° 41' 06" N, 44° 58' 20" E). On the headwaters region of the Rawanduz River, at an elevation of about 1,100 m. It is surrounded by mountains where the close ridges elevation ranges between 2,100 – 3,000 m. The lithology of the area is marked by metamorphic rocks (slate and serpentinite) in many locations. The debris cover contains erratic stones and a thin soil layer. A terrace, located at the junction of two main tributaries opposite to the Rayat Village about 30 m high consists of poorly-sorted sediments which contains conglomerates composed of metamorphic rocks, such as slate and serpentinite as well as of limestone sedimentary rocks of large sizes. The section features several pieces of limonite (Fig.2). The small cirques on sheltered slopes at elevations as low as 1,400 – 1,500 m and the larger cirques at 2,100 – 3,000 m represent the last main glacial phase of the Pleistocene (Wright, 1962). He found fresh hummocky moraines confined to the area just below cirques, but found at less elevation at 1,200 m near Rayat Village. This glaciation event was correlated with the last glacial phase depending on basis of topographic expression and elevation range (Wright, 1962).

▪ *Galala Valley*

The Galala Valley is a river valley that passes between mountain ridges east and west of the Galala Village (36° 36' 50" N, 44° 49' 19" E, at elevation 1,060 m) to its conjunction with the Rawanduz River Valley. The mountain ridge at the head of Galala Valley elevates between 2,400 – 3,000 m. The terrace sediments found over 30 – 40 m above the river contains large size boulders up to 1 m in diameter. They consist of metamorphic rocks (slate and schist), sedimentary rocks (limestone boulders), as well as igneous rocks (basalt) with pieces of serpentine (green color). The boulders are angular and non-rounded in shape which indicates that they were moved from the nearby source (short transport distance). The thickness of these sediments reaches 12 m (Fig.3).



Fig.2: Thick layer of conglomerates composed of large boulders of metamorphic rocks and limestones, Rayat Gorge (coordinates 36° 40' 47" N and 44° 58' 21" E)



Fig.3: Sediments of large size angular boulders up to 1 m in diameter. They consist of metamorphic rocks (slate and schist), sedimentary rocks (limestone boulders up to 1 m in diameter), as well as igneous rocks (basalt) with a pieces of serpentine (green color), Galala Valley (latitude 36° 36' 46" N and longitude 44° 49' 13" E)

▪ ***Barsarin Village***

The Barsarin Village is located about 12 Km northeast of Rawanduz Town (coordinates 36° 37' 20" N 44° 39' 38" E). Several formations outcrop on both sides of the river (Barsarin, Sargelu, and Naokelekan) as well as conglomeratic sediments are found over the Sargelu and Barsarin formations forming angular unconformity. Several gravel terraces are found in different localities on the elevation ranging between 35 – 60 m above the river level and contain rounded pebbles, cobbles, and rare boulders of metamorphic and igneous rocks derived from higher mountain ridges as well as limestone boulders from nearby ridges, inter-fingering with rounded river gravel sediments. Within Rawanduz River Valley, from the Barsarin Gorge and upstream, terraces and intercalated colluvial sediments are found generally at 30 – 50 m above the river level. Wright (1962) believed that these terraces are outwash sediments that should be associated with an earlier Pleistocene glacial phase before the last phase.

▪ ***Hawara Kon Area***

The Hawara Kon Valley is located on the eastern side of the Rawanduz River at the piedmont of a ridge about 1,000 m a.s.l. and located between the Barsarin and Hawara Kon villages, about 10 Km northeast of the Rawanduz Town. The main rocks in the area belong to the Shiranish and Bekhme formations and the Quaternary sediments consist of river flood plain sediments of variable grain size and thick soil of mud and silt overlain by light green fine sandstone layer. A thin layer of clay with a short curvature form shape pinch out and is believed to have been deposited in a small depression consisting of a small pool during the melting of the ice. There are layers of large and coarse size sediments located over the river sediments (Fig.4).



Fig.4: A layer of mud and silt overlain by >15 m thick light green fine sandstone layer. A thin layer of clay with a short curvature is believed to have been deposited in a small depression consisting of a small pool during the melting of the ice. Layers of unsorted and unstratified coarse size sediments are located above the river sediments with palaeo-soil layer sandwiched between them, Hawara Kon area, Erbil, Iraq (coordinates 36° 38' 16" N, 44° 38' 34" E)

▪ *Valleys around Rawanduz Town*

The Rawanduz Town is located 107 Km northeast of Erbil City (coordinates 36° 36' 31" N 44° 31' 47" E), 850 m a.s.l., surrounded by huge mountains of different elevations; Handrean about 2,450 m a.s.l. on the east, Korek 2,127 m a.s.l. on the southwest, Zozik about 1,750 m a.s.l. northeast, and Gorraz 1,400 m a.s.l. in the West. The town is located between two big valleys; Kharand on the east and Khara-Rash on the west. The maximum depth of Khara-Rash Valley is about 300 m and Kharand Valley about 250 m. The banks of the valleys consist of limestone and dolostone rocks with some thin marl beds mostly of the Bekhme and Qamchuqa formations. Both valleys contain terraces and other features of possible glacial origin. Although, the valley is not clearly U-shaped at least with respect to the cross section of the slopes, but it has been considered a U-shaped valley that is not well developed enough (Figs.5 and 6).

Glacial melting sediments are comprised mainly of crashed and well consolidated angular boulders, cobbles and gravels composed of limestone and dolomitic limestone (Fig.7). The terraces of the lower part of the Rawanduz River near the junction with the Greater Zab River are probably Middle or Early Pleistocene in age, but they may be of tectonic rather than glacial climatic origin (Wright, 1962).

The upper portions of broad valleys were plugged with glacial debris without distinct morainic loops due to washout, but with lakes and other small depressions and found small cirques with floors as low as 1,500 m on north-facing slopes of subsidiary ridges (Wright, 1962). The best exposed and most accessible Pleistocene terraces and associated with colluvial sediments of any area in the mountains of northeastern Iraq were found within gorges and valleys of the Rawanduz River. The small benches of limestone breccia sediments

were found on the flanks of some limestone ridges that represent old slopes and valley floors. They formed when the drainage level was as much as 400 m above the present level that represents the oldest Pleistocene sediments in the area (Fig.7).



Fig.5: The U-shaped (but not well developed) Kharand Valley. The hanging valley, on the right side was created by a smaller and less powerful valley glacier meeting the main glacial. Ruwanduz (coordinates 36° 36' 31" N 44° 31' 47" E)



Fig.6: The semi U-shaped Galy Ali Beg Valley, showing a higher valley level in the past, Rawanduz area (coordinates 36° 37' 27" N 44° 29' 58" E)



Fig.7: Glacial melting sediments containing large size angular boulders of sedimentary rocks (limestone) up to 1 m in diameter in unsorted sediments of smaller size sub angular to sub rounded and some flattened boulders, Lawan Road, Rawanduz Town (coordinates 36° 36' 19" N 44° 30' 24" E)

▪ *Halgurd Mountain*

The Halgurd is the second highest mountain peak (3,607 m a.s.l.) in the Zagros Range. The Halgurd Mountain is located northwest of Haji Omran Town, approximately 1.25 Km south of the Iraqi – Iranian border (coordinates 36° 44' 5" N and 44° 51' 28" E), 11 Km northwest Rayat Village, and 34 Km northeast of Rawanduz Town (Fig.1). Wright (1962) mentioned that the ridges near the Halgurd Mountain reach 3,000 – 3,500 m a.s.l. in elevation. They are located in a way respecting the drainage passage which he suggested that extensive Pleistocene glaciers formed on the northern slopes and flowed through gaps southward down valleys tributaries to the Greater Zab River to elevations as low as 1,100 m.

The upper portions of broad valleys were plugged with glacial debris without distinct morainic loops, but with lakes and other small depressions. Small cirques with floors as low as 1,500 m a.s.l. were found on north-facing slopes of subsidiary ridges (Fig.8), (Wright, 1962). The boulders are composed of basic igneous rocks, radiolarian chert, siliceous and calcareous shales, metamorphic schists, and limestones of unknown age. The soil is composed of serpentine fragments, sandy clay, and clay (Fig.9).

▪ *Jundiyan Tourist Resort*

This is a small tourist resort located 3 Km northeast of Rawanduz Town (36° 37' 36" N and 44° 34' 25" E), at an elevation of about 600 m a.s.l. It is situated on limestone rock beds of the Bekhme Formation at the northeast corner of the base of the Handrean Mountain, about 80 m above Rawanduz River located on the right bank of the river (Fig.10).



Fig.8: Lakes and other small depressions made by glacial movement, Halgurd Mountain (coordinates 36° 45' 34" N 44° 49' 56" E)

Fig.9: Frost shuttered back wall. Abrasion is when rock is frozen to the base and the back of the glacier scrapes the bed rock, Halgurd Mountain (coordinates 36° 45' 9" N 44° 50' 54" E)

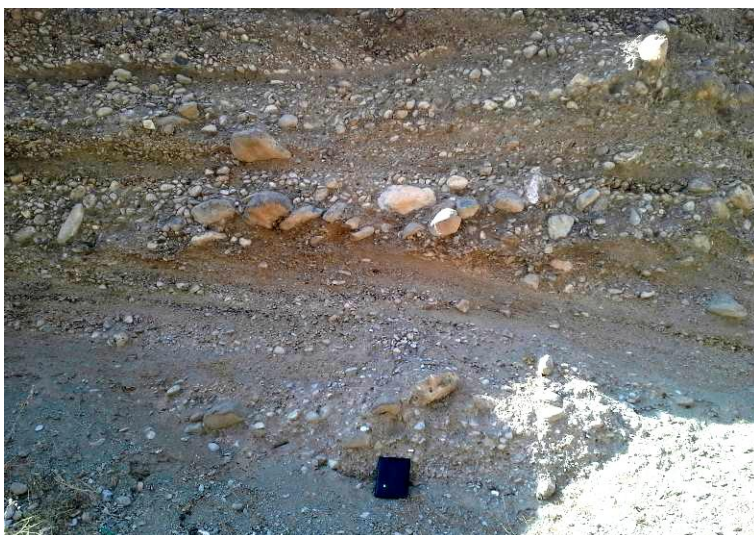


Fig.10: Sediments of coarse sand overlain irregularly by boulders and gravel of metamorphic origin. Location is near Jundiyan Bridge (coordinates 36° 37' 39" N and 44° 34' 19" E)

▪ ***Bekhal Village***

The Bekhal Village is located 1 Km west of Rawanduz Town at the piedmont of Korak Mountain at about 650 m a.s.l. The main formations covering the area are Tanjero, Shiranish, Bekhme, and Qamchuqa. The village itself is located about 600 m on the southwest side of the Ruwanduz River. Unsorted glacial sediments are found over the Tanjero Formation. Large sizes of boulders up to 1 m in diameter, angular to sub-angular to sub-rounded in shape

indicates that they are moved from the nearby source (short transport distance). The thickness of these sediments reaches 3 m. The direction of their movement cannot be determined from these sediments, (Fig.11).

▪ *Pirzhea Valley*

The Pirzhea Valley (coordinates 36° 34' 30" N 44° 59' 53" E) is located between the high ridges of Hasar-i-Sakran Mountain on close distance to the south east of Wize Village (coordinates 36° 35' 23" N, 44° 59' 04" E) west of Hasar-i-Sakran Mountain on the Iraq – Iranian border. Different glacial features are found including cirques, moraine loops, glacial valley, and glacial sediments (Figs.12 and 13).



Fig.11: Unsorted glacial sediments overlying the Tanjero Formation. Banazewk, Rawanduz, main road to Bekhal (coordinates 36° 36' 29" N 44° 30' 46" E)

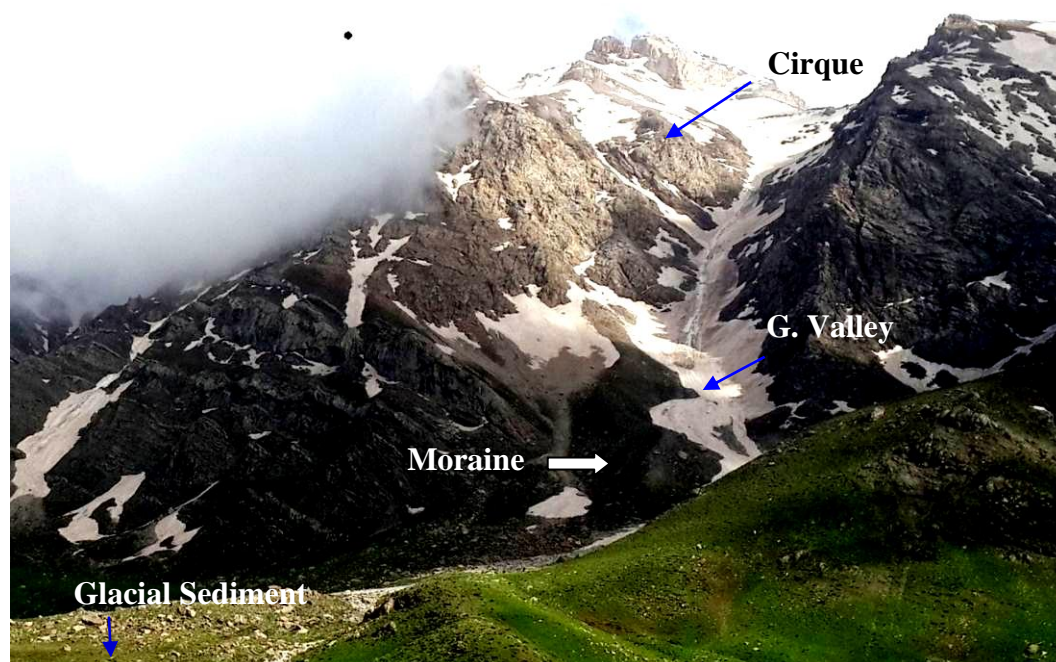


Fig.12: Pirzhea Valley at the Iraqi – Iranian border, showing cirques, moraine loops, glacial valleys, and glacial sediments (coordinates 36° 34' 30" N 44° 59' 53" E)



Fig.13: Pirzhea Valley at the Iraqi – Iranian border, showing glacier sediments (coordinates 36° 34' 30" N 44° 59' 53" E)

▪ ***Hasar-i-Sakran Mountain***

The Hasar-i-Sakran Mountain is located at the Iraqi – Iranian border (coordinates: 36° 32' 31" N 44° 58' 09" E) about 11 Km southeast of Choman Town with several ridges separated by valleys. The elevation of the highest ridge is about 3,400 m a.s.l.. Several glacial cirques (Worldatlas, 2018) are located on the top of the ridges and between them. Bekodian Cirque and the lake (tarn) are located on one ridge at an elevation of about 3,150 m a.s.l. and Fellow Lake at an elevation of 1,750 m a.s.l. Sediments produced from abrasion process of rock pieces loaded in glaciers with bed rocks during glacial movement downstream can be seen (Figs.14 and 15).

Cirques are identified between and near the high ridges of mountains. Some of them are well developed creating a small lake, while the others are less developed without lake. These cirques look like armchair-shaped hollow in the mountain side formed by glacial erosion and freeze-thaw weathering, forming the beginning of valley glacier, when the glacier melts. It can leave a small circular lake which is called a tarn. The cirques at 3,000 m a.s.l. on the high ridge south of Marana Valley can be assigned to recent glacial erosion (Wright, 1962).

▪ ***Garawani Saroo***

The Garawani Saroo is a small village located in a narrow valley on a high elevation within the Garawan Mountain between several ridges on East, South, and West of the village. Cirque and U-shaped valley or glacial troughs are formed as a glacier moves through a river valley. The glacier smoothes off the sides and removes the interlocking spurs leaving behind a U-shaped valley with steep sides and a wide flat floor (Fig.16).

▪ *Karokh Mountain*

The Karokh Mountain is located to the east of Rawanduz Town at the east side of the Handrean Mountain having an elevation of about 2,400 m a.s.l.. Cirques are recognized between and near the high ridges of the mountain. Some of them are developed and created a small lake (Fig.17).

▪ *Korak Mountain*

Korak Mountain is about 2,035 m a.s.l. high and located southwest of Rawanduz Town. The main rocks are limestone, dolomite, shale, sandstone and marl of the Tanjero, Shiranish, Bekhme, and Qamchuqa formations. Cirque is formed as a glacier moves through a valley smoothing off the sides and removing the interlocking spurs (Fig.18).



Fig.14: Bekodian cirque and glacial lake (tarn), Hasar-i-Sakran Mountain (coordinates 36° 32' 45" N 44° 58' 51" E) with an elevation of 3,150 m a.s.l., (photo by Akoyi, 2019)

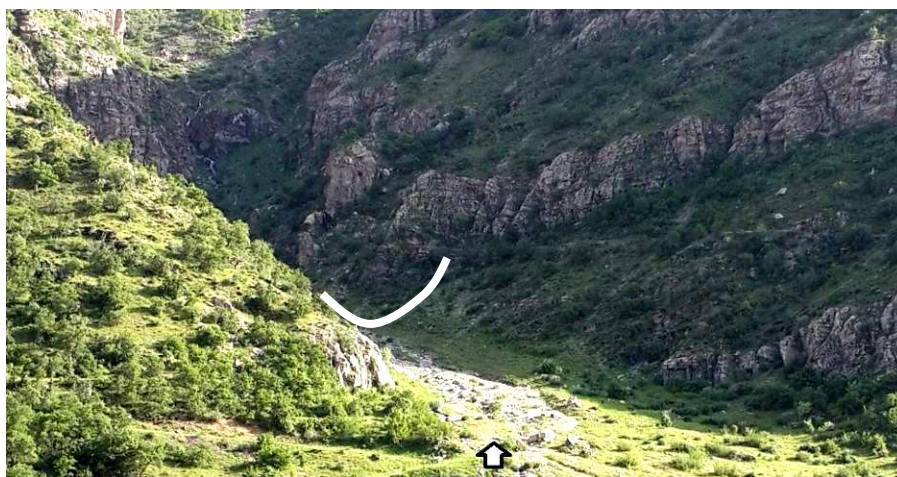


Fig.15: Sediments produced from abrasion process of rock bits which are embedded in the ice from plucking and freeze-thaw weathering scrape and grind against the rocks at the base and sides of the glacier valley, wearing it away and accumulating it with glacial melting sediments, Hasar-i-Sakran, (coordinates 36° 37' 19" N and 44° 55' 58" E) (Glacial landforms, 2019)



Fig.16: Cirque or glacial troughs are formed at Garawani Saroo, Qalay Gadar Mountain, Rawanduz (coordinates 36° 30' 02" N and 44° 34' 16" E)



Fig.17: Karokh Mountain Cirque (coordinates 36° 31' 49" N 44° 40' 27" E)
(photo by [Aziz, 2019](#))



Fig.18: Cirque, Korak Mountain, Rawanduz (coordinates 36° 34' 26" N and 44° 28' 42" E)

▪ Handrean Mountain

The Handrean Mountain is about 2,450 m a.s.l. high, located East of Rawanduz Town. It is mainly comprised of limestone, dolomite, shale, sandstone and claystone rocks of the Tanjero, Shiranish, Bekhme, and Qamchuqa formations. Glacial movements were observed near Mawilian Village (Fig.19). It is worth noting that on the 3rd of March 2019 a glacial sliding took place in the northern part of the Handrean Mountain near Mawillian Village. The sliding caused movement of noticeable glacier sediments down to the river.



Fig.19: Recent glacial movement, Handrean Mountain (photo extracted from NRT TV reporting video on 3rd of March 2019)

CONCLUSIONS

- The occurrence of glacio-alluvial sediments (tills) and terraces, more than 10 meters above the present level of the Rawanduz River, and erosional features of glacial origin indicate that the Rawanduz River from its source to its conjunction with the Greater Zab River experienced variable rates of glacial activities during the Pleistocene Epoch.
- The intensity of the last glacial phase in the Rawanduz Gorge is shown in the occurrence of compact limestone and dolomitic breccias, overlain by moraine and washout sediments over the beds of the Tanjero and Shiranish formations.
- The existence of Kharand U-shaped and hanging valleys represents the difference between glaciers in size and their power action on the rocks.
- Occurrence of Cirque and glacial lake over the Hassar-i-Sakran and Halgurd mountains indicates the intensity of the last glacial phase in the area.
- Occurrence of Moraine sediments at Pirzhea Valley signifies the glacial impact.

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For collecting evidence, we needed on site information on the features supporting glacial activities which were only available at high and rugged mountainous rugged ridges. It was difficult to reach these sites without the assistance and information provided by local people in the villages located there. We acknowledge their assistance and role. We thank our colleague Kakarash Muhammad from General Directorate of Water Resource and Dams, Erbil, Kurdistan Region, who provided insight and useful electronic links for previous studies and resources that greatly assisted the research.

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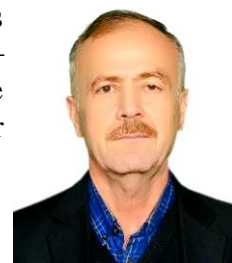
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