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Research Article
Glacial Landforms in Border Mountainous Areas Between Iran and Iraq

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Abstract

Background: Iran and Iraq political border in the West of Azrbaijangharbi province in Iran and Arbil and Soleymanieh provinces in Iraq coincide with a mountain region with North to South ridge that is named Ghandil mountain. Border area, insecurity and hard to access to mountain get landforms of this area in the unknown condition. Based on Pedrami research only one part of Gandil mountain that is contain Abkhoreh, Bikos and koper next to Zab-e-kouchak river is accessible and had a research. **Materials and Methods:** In this study topography map (1:25000), elevation data of Aster sensor, field study and sediment sampling were the main material of research. For determining of snow-line in the past period based on Wright method, 60% of cirques defend by field, elevation data and satellite image processing determined. Roundness and sphericity analysis used sediment samples of 40 cm depth. About 50 coarse grains of each sample have been prepared for roundness and sphericity analysis and also100 g of each sample based on sieve shaker until 0.63 microns analyzed for granolometry. **Results:** Snowline elevation in the study area found in the elevation of 3162.8 m a.s.l., based on differential equation of cirques elevation delta in combine with isoline that is merged with location of 60% of cirques quantity. Also, part of Gandil mountain that is located in Iran boundary we face lots of big glacier valleys. The biggest glacier valley named Seikh Aysh with West-east ridge. In the location of this valley that is conjunction location of West-east valleys, Chorrin and Drosepi valley found lots of signs that are related to glacier sediments in the elevation of 1740-220 m. In the lowest part of Badinawe, Pradanan and Abkhordeh rivers found 4 alluvial terrace that describe last period climate changes. **Conclusion:** The signs of glacier erosion and accumulation are the main cause for determining the area of glacier coverage areas. Meanwhile, the study in Iran glaciers barrier line are showed that elevation of 3162.8 m a.s.l., is the barrier elevation for determining glacier and pre glacier areas, while the result of this study that achieved based on sedimentology analyses of samples, surveying of cirques and other glacier signs in the field observation in combine with result of regression analyses between temperature and elevating showed that barrier line for determining glacier barrier line is different.

Key words: Glacial landforms, ghandil, glacial cirques and valleys, Ghandil mountain, snow-line

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

In Pleistocene epoch, Iran experienced activities of mountain glaciers. The findings of investigations on glaciers in mountainous areas of Iran indicated that Alamkuh is the most obvious example of mountain glaciers in Northern Iran. It is now moving about 230 cm year^{-1} [1]. Seif and Ebrahimi[3] studied glacier cirques that is located above 3200 m a.s.l., in Shirkooh based on 1:25000 topography map with 10 m accuracy[2]. They found that speed of vertical development is so faster than width and length development. Also base elevation of cirques doesn't have any relation with snow-line in the past period of ice age. While, this is not suitable model for determining equality snow-line in the arid area's glaciers. Also, Seif and Abtahi[2] studied climate evolution of Salt lake that is located in the central part of Iran. He mentioned that exist cirques in elevation of 2500 m a.s.l. In the catchment of Salt lake they found signs of a cold era[3]. In 2015, Seif[4] used several method contemporary for determining snow-line in Oshtoran Kohh in the central part of Iran and found that based on the last location of moraines, snow-line located at the 3121 m a.s.l., while in the high development of glaciers based on exist snow-line is located in the 4500 m a.s.l., in result snow-line in Oshtoran Kooh located 1380 m lower than now location[4]. Yamani *et al.*[1] found that elevation of the cirques base of Karkas mountain is located at 3000 m a.s.l. and based on a temperature of 0° was determined by the last ice age[1]. Although, Mojtaba *et al.*[5] had a research for determining cirques, middle and base moraine that was founded as signs in the elevation[5] of 2000 m a.s.l. Ghahroudi Tali and Gharnaie[6] in the catchment of Dallakhani in the center on Iran estimated elevation of snow-line in the last period of ice age that research was based on the regression method between temperature and elevation, elevation of quantity of 60% of existing cirques and also sediment sampling. In result, they found that average of temperature in the Dallakhani catchment was 5.38° colder than now[7]. Ghahroudi[8] determined snow-line in Haraz catchment in the North of Iran in 1800 m a.s.l.[8,9]. Ghahroudi Tali and Gharnaie[6] founded an elevation of the snow-line in the 1550 m a.s.l., in the Ghandil mountain that is located in the border of Iran and Iraq[6]. Ghahroudi *et al.*[10] in the Zab-e-kouchak catchment reached to an elevation of 1650 m a.s.l., for the snow-line[10].

Above mentioned it is significant that local conditions of glaciers in the cold period reign in Iran. That based on Iranian research focus on field study is the best way in the study of glaciers in Iran. Some traces of glacial erosion were also identified in internal arid areas; for example, in Shirkuh, Yazd[11], Jupar, Kerman[12] and glaciers of North Isfahan[13]. The studies of Bobek[14] indicated that the permanent snowline was lowered at 3400 m a.s.l., on Alborz mountain Ranges[14]. Preu[15] also estimated maximum development of the glacier discharged by avalanches at 3200 m a.s.l.[15].

The earliest studies on the glaciers of North-east Iran were conducted by Mahmoudi. He found the quaternary glaciers in mountain areas higher than 3600 m a.s.l., Sabalan and Sahand mountains[16]. Many years of studies by Khayam in Azerbaijan, North-west Iran, indicated the elevation of the glaciers in 2500 m a.s.l.[17]. Pedrami[18] made studies the glaciers on the mountains in the border areas between Iran and Iraq and observed some glacial deposits in Southwest part of Piranshahr at 1350 m a.s.l.[18]. He also referred to the cirques of Abkhordeh, Bikos and kawpar in the areas, about 15-21 km from Piranshahr. He stated that the Bikos glacier has fluvial drainage from 2750 m a.s.l. and shows obviously the moraines of early Würm glaciation. Furthermore, in Iraq, Halgurd mountain in Birkim Valley and southeastern hills of Turkey, the traces of glacial deposits can be observed in 1500 m a.s.l., in river terraces. Wright[19] found the permanent snowline at 1500 m a.s.l., in ice age. The result was obtained by 0.68° decrease in temperature with 100 m increase in elevation. Thus, decline in snow elevation was due to snow fall by Mediterranean storms[19].

Wright[19] mentioned 13 cirques in Sakran mountain in Kurdestan, Iraq and near the political boundary of Iran. It is also recognized their glacial moraines downstream the valleys in Navperdan village. It is also referred to some glacial moraines on the banks of one of the tributaries of Zab-e-bozorg river in Rayat, downstream of the small town of Haj Omaran. Recently, grading activities for road building exposed the moraines. It seems that Wright[19] was not entered the area in his field works and just surmised that there were cirques also beyond the borders of Iran*. Given the moraine traces remained on the Halgurd valley (Berkim) in Kurdestan, Iraq and west part of Rust as well as the location of cirques, Wright believed that Pleistocene permanent snowline dropped to 1800 m a.s.l. Now in the Southern slopes of Halgurd the evacuated moraines from a great glacial cirque can be observed at 1450 m a.s.l., downstream Navanda village in Northwest part of Chuman city, Kurdestan, Iraq. According to Wright[19], the Halgurd was influenced by mountainous glaciers in Pleistocene. The Southern slopes of the area along the Havarajo, Siahkuh and Kilashin highlands have also many cirques. There are evidence of glacial deposits in entire the

*This is because he did not mention anything about the mountains of Ashnavieh, Piranshahr and Sardasht.

area from the sites of the cirques to the villages of Bola, Bani and Birkim. The altitude of permanent snowline was dropped at 2000 m and even 1800 m a.s.l. The existence of till was confirmed to be at 1100 m a.s.l., in the vicinity of Birte Village and three km of Sidake Village. Now the glacial deposits have been incised by river about 10 cm deep[19]. There are many different views about snowline. For example, Bobek[20] believed that it is by 0.6° decrease in normal temperature with 100 m increase in elevation and that the 4° temperature was the snow limit in Kurdestan Mountains, Iran[20]. Moreover, Wright[19] believed that the decrease of normal temperature was 0.67° per 100 m of increase in elevation and that 12° temperature decreased to 1800 m a.s.l., in Kurdistan, Iraq. However, detached ice pieces were observed about 1000 m lower than the snowline in the area. They may be reached the areas due to slope collapses or avalanches. However, there is the possibility that they are independent of the climatic conditions prevailing on the area[21,22] as quoted by Brooks). Furthermore, the permanent snowline in the late wurm in the area from Sardasht to Urmia was 1600 m a.s.l., along the Ghandil to Halgurd and in the north to Kurdestan, Iraq[18]. The satellite image interpretations of the areas in the vicinity of the borders of Iran and Iraq in Turkey represent the permanent snowline at 3400 m a.s.l., though there are now glaciers in Sat and Silo mountains[23]. The reports of Pedrami[18] refer to the cirques of Abkhureh, Bikus and Kawpar that carried the moraines down near Zab-e-kouchak river[18]. There is also the cirque of Seri Gumi on the slopes of Pire Luk mountain at 2500 m a.s.l. The moraines of the cirque were transported down to 1700 m a.s.l., next to river banks.

Despite the many studies in the area, there are even unknown glaciers. The border area between Iran and Iraq in West Azerbaijan and Ardabil in Iran to Solimanieh in Iraq is mountainous region of North-south direction. The region is less investigated in terms of glacial geomorphology because of border situation, security issues and inhospitable and difficult access.

Ghandil mountain area is located in Southwest Piranshahr, in southeast part of West Azerbaijan province, Iran. The region is positioned from 36°24′-36°40′ Northern latitude and from 45°-45°30′ Eastern longitude. The mountains of Ghandil are continued as a bow with tens of peaks, more than 3000 m high, from Sakran mountains. There are three important peaks of small Ghandil, big Ghandil and Ghochy Karan. The ridge of the mountain is determined as the border between Iran and Iraq. It is distant from Turkey border. As Northern section of Zagros mountain Range, Ghandil is inside Sanandaj-Sirjan morpho-tectonic zone. This is fractured by the pressures of Arabian Tectonic plate on western areas of Iran. Active fault of Piranshahr in a Northwest-Southeast direction moved it up as thrust. The rocks are mainly from transformed cretaceous limestone with green schist rock facies. The alternative chale, limestone and sandstone are ubiquitous all over the mountain. The structure of the lands in some areas of the mountain is altered by igneous masses. The glaciers are begun from 3300 m a.s.l. and its components are continued to 2500 m a.s.l. The great typic cirques of the region known as barrier have long walls, 500 m high. They are considered as the most important cirque walls of Iran following that of Alamkuh. There are tens of small and big cirques and many glacial valleys in the vicinity of Ghandil. In the study, we have investigated the glacial landforms of Ghandil and surrounding mountains. The position of Ghandil mountain is illustrated in Iran and Iraq border (Fig. 1). Based on synoptic data of Piranshahr station in the period 1995-2012, annual rainfall in the region is 680 mm. About 68% of the total precipitation is in cold period. The snow on the mountain can remain until the late September. In 1455 m a.s.l., the average temperature is 11.9°. The temperature fluctuation is high in mountainous areas. The mean of minimum temperature is 4.1°C and that of maximum 14.4°C. The maximum absolute temperature is 39°C and the minimum absolute -28.6°C in the region. The study area is mainly under the influence of western moist air masses from Mediterranean Sea and Atlantic ocean. Snow melting provides water flows in permanent tributaries of Zab-e-kouchak river. The many tributaries of the river drained the area from Piranshahr to Sardasht. The location of glaciers area, divide line, cirques and also periglacial area of Ghandil mountain illustrated in the Fig. 2.

MATERIALS AND METHODS

In this study, used data were contained topography Maps (1:25000), Aster elevation data that obtained by Terra satellite, field work survey and analyses of sediment samples. Since of study area located on the border of Iran and Iraq, we were unable to access full coverage of topography maps therefore we made Digital Elevation Model of stereo photos of Aster sensor.

Then we determined observation routes of maps and satellite images and based on climate and security conditions had continued-close observation from late August to early September in 2012-2014[24]. Based on field studies several cirques with unique characters were known. In Sheikh Aysh glacier valley as the conjunction of Eastern, Western, Churin and Deroy Sepi valleys, there are many evidence of glacial

Fig. 1: Location of Ghandil mountain in the border of Iran and Iraq

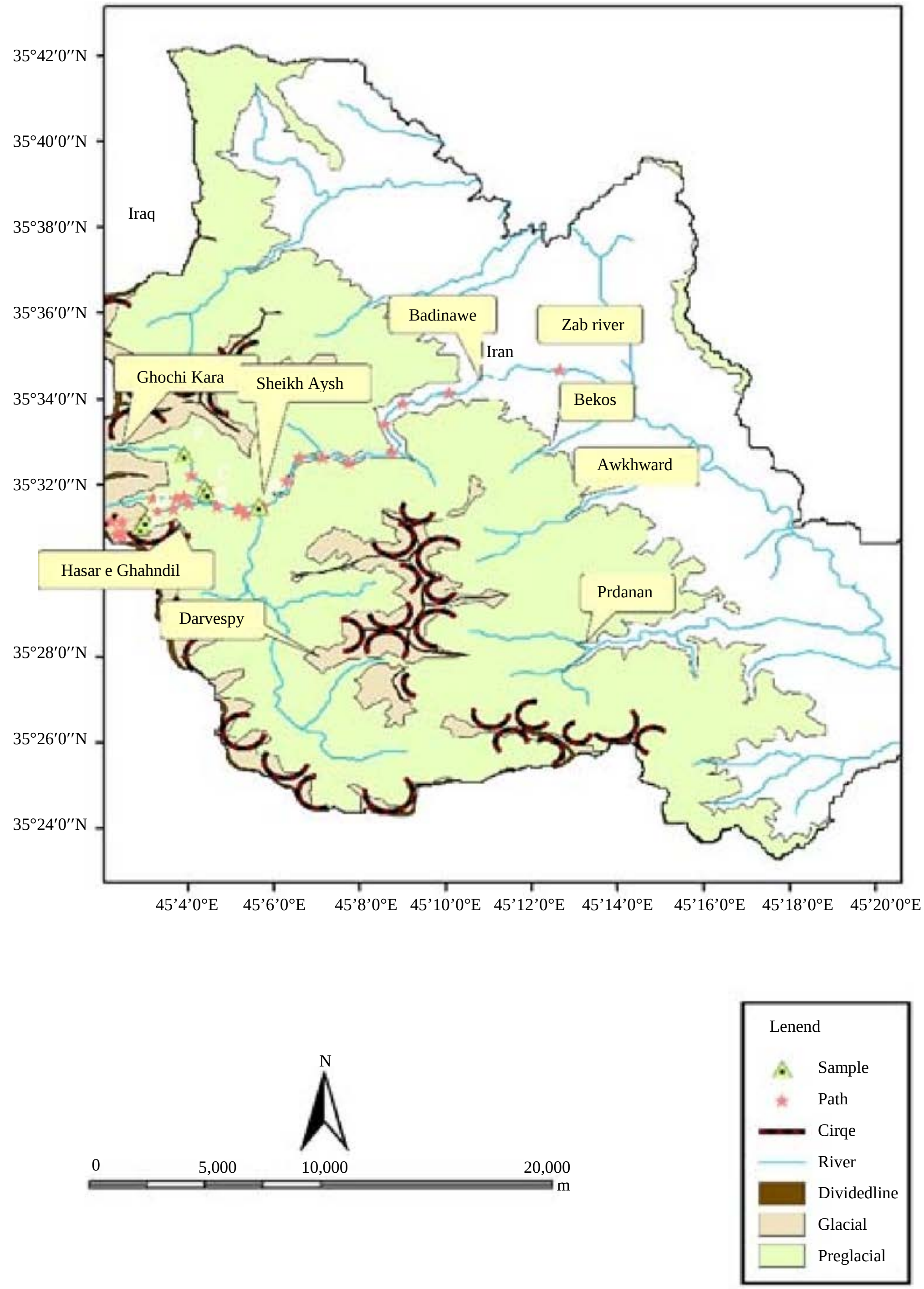

Fig. 2: Location of glaciers area, divide-line, cirques and also pre-glacier area of Ghandil mountain

sedimentation in altitudes of 1750-2200 m. Also, in the lower level of Badinawe, Prdanan and Awkhwarda rivers we found several alluvial terraces that are good signs of climate change in the past. For determining of glacier land forms barriers such as cirques, moraines and the fluvial evidence, research team estimated annual temperature regression that obtained of synoptic and climatology stations and elevation results that is extracted from aster satellite images as in Eq. 1. Based on average of annual temperature of regression model, the present ages estimated as:

$$y = -0.005x+21.78 \quad R^2 = 0.96 \tag{1}$$

Quantity of available cirques estimated based on elevation data that extracted of aster satellite images and 75 cirques in the elevation of above 2500 m determined[25]. For the snow-line in the past, at first based on Wright method line of 60% of cirques determined and then by estimate different elevation between cirques in combining with the line of 60% of cirques in elevation of 3162.8 the barrier of snowline in the past determined[26]. It means that in the coldest period in this area, above 3162.8 snow permanently exists or the average of temperature in this elevation was less than 0°:

$$x = \frac{\text{Max elevation cirque} - \text{Min elevation cirque}}{100} \times 60$$

$$x = \frac{3602 - 2504}{100} \times 60 = 658.2$$

$$x = 2504 + 658.2 = 3162.8$$

About 50 coarse grains of each sample have been prepared for roundness and sphericity analysis and also 100 g of each sample based on sieve shaker until 5 microns analyzed for granolometry.

The location of sampling in the way of field work showed in the Fig. 2. Roundness and sphericity are two widespread indices of sediment analyses. The roundness based on 2 dimension of particle was initially introduced by Wentworth[27] as the Eq. 2:

$$\text{Roundness} = \frac{\eta}{R} \quad (2)$$

where, r_i is the curvature of the sharpest angle of that particle and R is the radius of the smallest rounded section of that. The coefficient is also defined by Eq. 3 and its value is ranged from 0-1:

$$\text{Roundness} = \frac{\sum_{i-1}^{\eta} \left(\frac{r_i}{R} \right)}{n} \quad (3)$$

where, r_i is the radius of the curvature of the particle angle, R is the biggest angle of the rounded section of that particle and n is the count of edges[28].

This is a 2 dimensional index. Use of volume as index of sphericity was also presented by Wadell[29], Friedman *et al.*[30] and Krumbein[31]. Where, V_p is the particle volume and V_{cs} is the volume of the smallest circumscribing sphere Eq. 4 that estimate by Eq. 5. In this relation a, b and c are the long, intermediate and short axis dimensions, respectively, of the particle that are mainly in the range of 0.3-0.6[32]:

$$\psi = \frac{\left(\frac{V_p}{V_{cs}} \right)^{1/3}}{n} \quad (4)$$

$$\psi = \frac{abc}{a^3} = \left(\frac{bc}{a^2} \right)^{1/3} \quad (5)$$

RESULTS AND DISCUSSION

Ghandil is a folded mountain in Northwest-southeast direction with an arched convex towards Iran. Part of the mountain is stretched as a blade inside the Iraq borders. There are many valleys of North and Northeast direction in Iranian part. Field observations represented many cirques in the mountain, particularly in northern slopes. They are mainly small cirques but some are relatively huge glacial cirques. Hesar-e-Ghandil cirque is at 2650 m a.s.l., on the Northern slopes of small Ghandil. This is 800 m long and 300 m wide. The rock valley behind the landform is 400 m high. There are a plenty of huge boulders (from 1-10 m^3) in front of the flat surface cirque. This is ended in a headland of glacial deposits with 70 m high (Fig. 3). There are moraine embankments of 2 m high and tens of meters long inside the eastern valley. It was very interesting that we observed a secondary cirque inside the primary one. The deposits of the secondary cirque are more fine grain than those of the primary. The wall of the embankment is 7 m high, 150 m long and 100 m wide. The existence of the secondary cirque might be resulted from further development of glacier after Wurm III in Holocene. According to Brooks, a few of the studies about glaciers succeed to find glacial advances and recessions after

Fig. 3: Secondary cirque of Hesar-e-Ghandil, a view from West

Fig. 4: Snow-ice tunnel of the primary cirque of Hesar-e-Ghandil

Fig. 5: Outcrop of ice beneath the moraines, Hesar-e-Sakran Cirque

Fig. 6: Ghochy Karan peak, a view from East

Wurm III. Some of the studies are the works of Bobek[33] in Takhte Soleyman, Iran and the explorations of Klaer[34] in North

Fig. 7: Great valley of Sheikh Aysh, a view from West

part of Van lake, Turkey. There are now ice core inside the cirque. Due to a thick cover of snow, the fossil ices cannot be observed until the end of summer. After the snow cover is melt, the glacial ice can be observed in dark color as a result of mixture with rock sediments. Snow-ice tunnels likely created by glacial melting flows can be seen inside the ice cores (Fig. 4)[33,34].

The cirque of Hesar-e-Sakran is located in 2850-3000 m a.s.l., on the Northern slopes of big Ghandil. It is in a 1 and 2 km dimensions and has a massive embankment of huge boulders in its front. The surface of the cirque is covered by small sand dunes, addition to dispersion of rock deposits. There are also secondary cirques of ice cores on the Eastern and Northern parts of the Hesar-e-Sakran cirque. It seems that the thickness of ice in Hesar-e-Sakran cirque is much more than that in Hesar-e-Ghandil cirque. The recent ices can be observed in the ancient ice covers and some outcrops of the ices are also exposed beneath several meters of sediments (Fig. 5).

The existence of the dunes inside the cirques resembles hummock dunes. It is likely that the dunes composed of tills are stretched into ice holes due to either melt flows under the glacier or sink of the tills from top of the glacier[35]. However, the late reason may be more acceptable, though the role of avalanches and ice melt flows are considerable in drainage of the glaciers. There are also two big ice cores from 3200-3600 m a.s.l., in the Northern and Northwestern flanks of Ghochy Karan Peak. In the vicinity of the Ghochy Karan Peak a rock wall is stretched towards the West. The Northern flanks of the rock wall are located in Iraq border with several small cirques of ice cores in 3000 m a.s.l (Fig. 6).

There are also some big glacial valleys on the Iranian part of the Ghandil mountain. The main valley called Sheikh Aysh in East-west direction (Fig. 7). Figure 8 shows the end part of

Fig. 8: Kavbaz valley in the West part of big Ghandil

Fig. 9: Secondary cirque in the Northern slope of Ghandil

Fig. 10: Terrace of Awkhwarda river

Kavbaz valley in the west part of big Ghandil. Following the snow mass as seen in the Fig. 8, a headland and waterfall is formed. At this point the Kavbaz valley is joined to the Sheikh Aysh valley. Upstream the location, there exist a canyon wall on which shelves are created in rocks possibly due to long time contact of ice, snow and limestone solution. In Fig. 9, a secondary cirque can be observed in the Northern slope of the Ghandil with dispersion of moraines along the cirques towards Kavbaz valley. East valley, West valley and Chavrin valley are divided into three separate valleys upstream. They are initially from Ghochy Karan Peak towards East and then Northeast. The long valley of Darve Spy separates the Havshin and Taty Do from Kotral mountains. There are also the valleys of Prdanan, Bekos, Awkhwarda and Trkash from Zavyan and Sharga to Bekos. They are ended in cirques in 2650-2850 m a.s.l. The great valley of Sheikh Aysh is terminal site of these glacial deposits.

The traces remained from sediments in the glacier forehead is formed as a great semi-circle (2 km). The evidence of middle moraines of the East valley and West valley that created an embankment 20 m high can easily be observed. The marginal moraines of Sheikh Aysh valley are mixed with head moraines of East valley and West valley and created an ice platform in their conjunction. The marginal moraines of the Sheikh Aysh valley are 22 m high. It seems that the glacial sediments blocked the entire valley but following the end of ice age the deposits are incised by fluvial drainage. The Sheikh Aysh is a perfect sample of glacial valley in the region. It has a U shape to 1750 m a.s.l.

At the site of the glacial valley of Sheikh Aysh as the conjunction point of East valley, West valley, Chavrin and Darve Spy, there are evidence of glacial sedimentation in 1750-2200 m a.s.l. From three to four river terraces can be seen downstream the rivers of Badinawe, Prdanan and Awkhwarda. These terraces indicate past climate changes in the region. Heavy snowfall in Ghandil mountain is continued from October to May in the region and the rivers originating from the mountain have also ephemeral fluvial system. The exit of the rivers from mountainous areas left sediments as alluvial fans and terraces. Snow melting after the end of ices ages produced powerful flows draining the materials evacuated from mountainous areas. The investigation indicated that the sediments of the terraces have very angular grains originated from Ghandil mountain. The loose and steep flanks of the terraces are highly susceptible for landslide and threaten human activities. Figure 10 shows the terrace of Awkhwarda River.

The main path for climbing the Ghandil and location of the samples has been depicted in Fig. 2. We used cumulative frequency chart of the granulometric analyses to represent dynamic sources of the sediments. The samples were taken

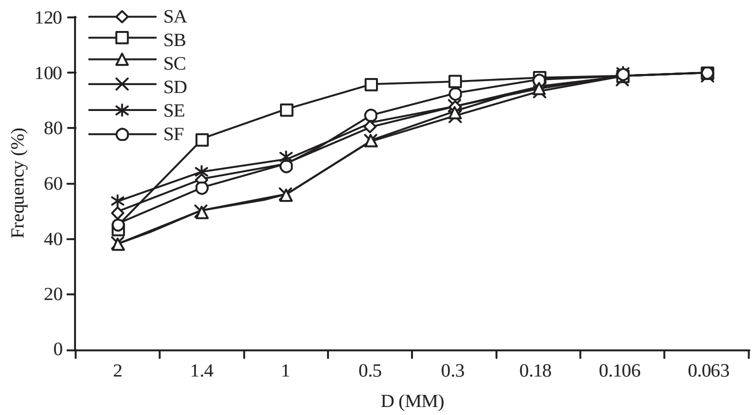

Fig. 11: Cumulative percentage of the diameters of the sample particles

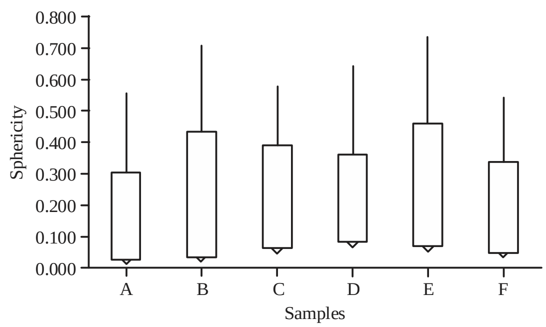

Fig. 12: Bar graphs; color bars show averages and color lines of the range represents sphericity coefficient in micro-feature of samples

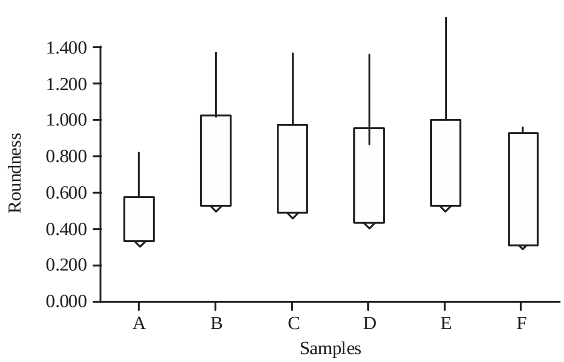

Fig. 13: Bar graphs; color bars show averages and color lines of the range represents sphericity coefficient in micro-feature of samples

from the possible glacier path where the snow is melt just in late August and September. In the cumulative chart, more than 40% of the grains are more than 2 mm in dimensions (Fig. 11). The results of sphericity coefficient of 50 grains of each average sample, with 1 standard deviation are less than 0.4[27]. The results of roundness coefficient of each average sample with 1 standard deviation, are up to 1.30. A comparison between the results of roundness and sphericity with the researches of Powers[36] indicated that the particles are almost angular and stretched, not completely rounded and that getting distance from the Ghandil cirque no significant difference can be observed in the samples. Thus, it is likely that they have glacial origin (Fig. 12 and 13)[36].

This research results in comparison Seif and Ebrahimi[3] in Zardkooh shows that elevation of basement of cirques are not suitable for determining permanent snow-line[3]. Also determine 2500 m a.s.l., for cirques area is like Seif and Abtahi[2] research results that studied for Salt lake. For moraines elevations, Seif[4] described that elevation of moraine are located in the 3121 m while in the Ghandil mountain this elevation for determining moraine area is located in the 1750 m[2]. This conflict is based on West flows and also latitude of this area. This research results are similar to Yamani *et al.*[1] that researched for west of Kurdistan[5]. Study area of this research is so similar with location of Ghahroudi *et al.*[10]. Based on this cause the results of filed observation in the Ghandil ridges and moraine areas are like result of lately research[10]. While, in this research the elevation of snow-line in the last cold period is determined based on regression between winter temperature and elevation.

CONCLUSION

Glacier periods remained their signs such as cirques, valleys and lines that illustrated in the hard stones. Deposit signs are exponent ice and permanent snows area dispensation. Glacier compactness signs including moraines that periglacial area or frosty activity and also ice melting in quaternary. In this mountain has three important peak big Ghandil, Small Ghandil and Ghochy Karan that Ghandil crest line is Iran and Iraq border. Field study and sedimentology show that in the last period of cold era, glaciers be in this area that signs of this activity are as cirques and glacier valleys. Also, signs shows that elevation of 3162.8 m a.s.l., was border of glacial and periglacial systems. The movements of ice in the valleys were dominant in the glacier morph dynamic that had signs as moraines and valleys. In that period in the lowest elevation of this area, frosty and melting made small sediment. Sediment that made based on glacier movement and physical weathering in the periglacial period in combine with flood that made of precipitation and ice melting flows and covered the lowest areas. Analyses of sediment samples grains in the Zab-e-kouchak river trace shows that water had an influence when shrink of cirques but range of sediment roundness shows that sediments don't have extension and roundness that is cause of sediment movement in the ice. The reduce of circularity of sediments illustrate particles had roll ness. This action shows glacier activities in the Gandil mountain.

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