Glaciers of the Middle East and Africa—

GLACIERS OF IRAN

By JANE G. FERRIGNO

SATELLITE IMAGE ATLAS OF GLACIERS OF THE WORLD

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Glaciers are situated in two mountain ranges and on one volcano in Iran and have an estimated total area of 20 km²; Landsat images are of limited usefulness because of glacier size

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Abstract

Glaciers occur in the higher elevations of the Elburz Mountains of north-central Iran, the Zagros Mountains in the southwest, and Kūhhā-ye Sabālan in the northwestern part of the country. The glaciers have a total area estimated to be about 20 square kilometers. The greatest concentration of glaciers exists in the western part of the Elburz Mountains in the region of the Takht-e Sulaiman massif on steep northward-facing slopes. The largest glacier, the Sarchal, is estimated to be 7 kilometers long with much of the surface entirely covered with rock debris. In the eastern Elburz Mountains, two small glaciers are located on Qōlleh-ye Damāvand,, the highest peak in Iran. In the Zagros Mountains, five glaciers have been described, with the largest about 500 meters wide and spanning an elevation of about 150 meters. The Sabālan area has seven glaciers located on the northern, eastern, and western slopes of the summit peaks. During the Pleistocene, glaciation was much more extensive in Iran and included the present-day centers of glaciation and three other mountain areas. During that time the climatic snowline was 600 to 1,100 meters lower than the present level. The temperature structure was thought to be similar except that the mean temperature was 4 to 5 °C lower and the precipitation/evaporation ratio was higher. Cloud-free Landsat data exist for all the glacier areas of Iran. However, Landsat data are of limited usefulness for glacier studies and monitoring in Iran because of the resolution of the spacecraft sensors, the size of the glaciers, and the prevalent snow and debris cover.

Introduction

Before 1930, the consensus was that there were no present-day glaciers in Iran. Although Europeans had traveled widely in the country since the mid-l800's, including the high mountain areas, and published reports of their expeditions, either they had not seen the glaciers, had not recognized them, or their reports had been overlooked. The first European who recognized the presence of glaciers in the Elburz Mountains was Busk (1933). He was closely followed by Hans Bobek, who traveled widely throughout Iran. He carried out studies of the extent of contemporaneous and previous glaciation and published the results of his observations (Bobek, 1934, 1937). Since the 1930's, the Iranian glaciers have decreased in size but are still found in the same four main areas: in the higher elevations of the Reshteh-ye Kūhhā-ye Alborz (Elburz Mountains)' in the vicinity of Takht-e Sulaiman and Alam Kūh in the west, on Qōlleh-ye Damāvand in the east, on Kūhhā-ye Sabālan in the northwestern part of the country, and on Zard Kūh in the Kūhhā-ye Zagros (Zagros Mountains) in the southwest (fig. 1). The "General Introduction'' that precedes the subchapter "Glaciers of Turkey" gives climatic and historical background on glacier occurrence in the Middle East.

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[1]The geographic names used in this subchapter are from Gazetteer No. 19, Iran (U.S. Board on Geographic Names, 1956). Familiar names are given in parentheses. Where there are no officially approved names for a geographic feature, the name commonly accepted in the English scientific literature is used.

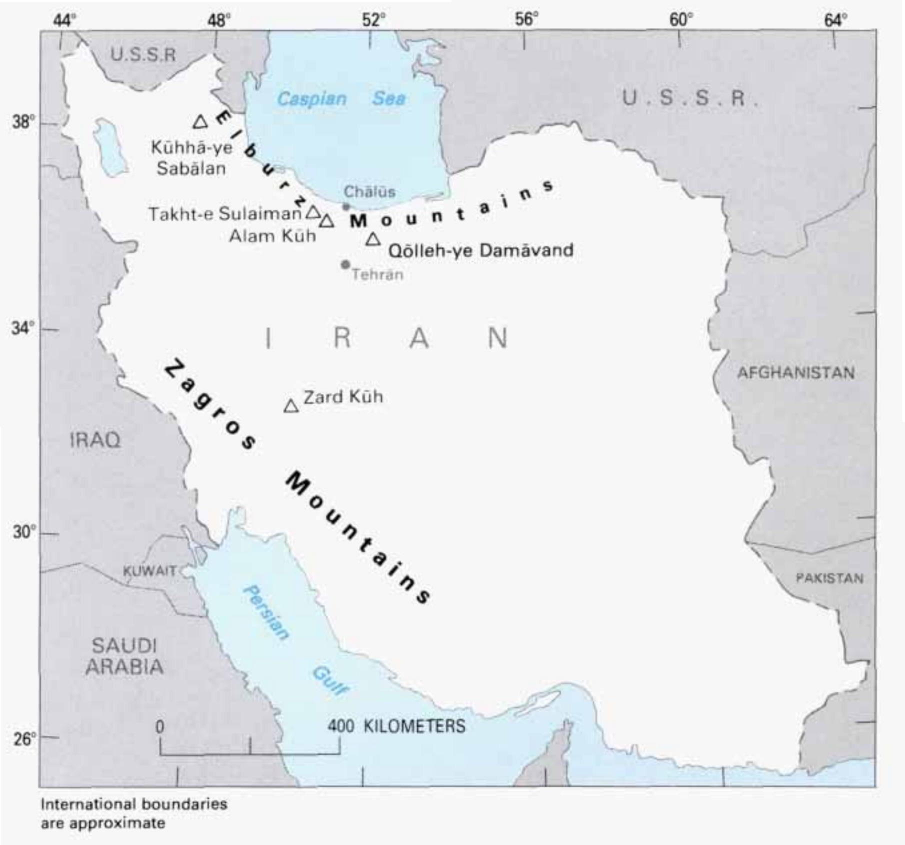


Figure 1. *—Location of present-day glaciers in Iran.*

The Elburz Mountains

The Elburz Mountains lie along the northern border of Iran at the southern shore of the Caspian Sea and extend about 650 km from west to east. The mountain range includes Qōlleh-ye Damāvand (5,670 m), the highest peak in Iran, and several other peaks that have summits higher than 3,000 m. The annual average precipitation in the vicinity of the range varies from 20 to 30 cm at Tehran just south of the mountains to 30 to 50 cm midway through the range to 150 cm at Chālūs, north of the mountains. The prevailing winds, usually from the south, and the intense solar radiation prevent snow from accumulating on southward-facing slopes. As a result, large amounts of snow tend to accumulate, and glaciers and snow patches are most likely to occur on north-, northeast-, and northwest-facing slopes. The large accumulations of snow also create the potential for serious avalanches (Roch, 1961).

The Western Elburz Mountains

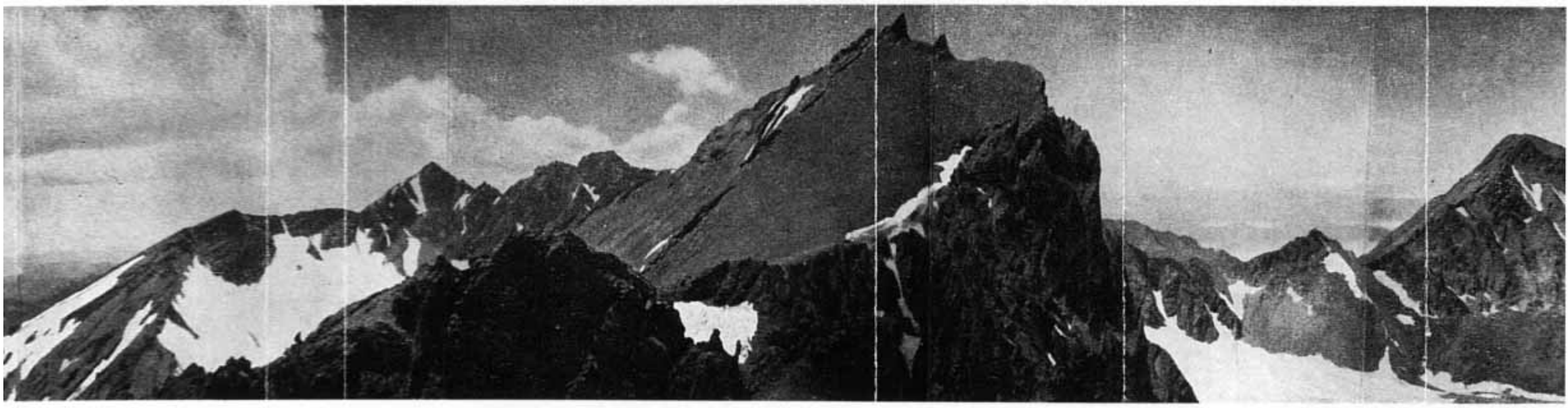
The greatest concentration of glaciers in Iran exists in the western part of the Elburz Mountains, in the region of the Takht-e Sulaiman massif (lat. **36°25'** N., long. 50°57' E.) about 90 km northwest of Tehran. The highest peak of the massif, Alam Kūh (4,840 m), is the second highest peak in Iran. The massif consists of several peaks over 3,000 m in elevation that are joined by high, narrow summit ridges (fig. 2). The glaciers are found mostly on the steep, northward-facing slopes of these peaks and ridges. The first European to travel in the Elburz Mountains and recognize the presence of glaciers was Busk (1933, 1935). He was followed by Bobek, who noted in 1934 the existence of several small

Figure 2.—Top, Panorama of Takht-e Sulaiman massif from the east with Alam Kūh (center) and Takht-e Sulaiman (right) (from Harding, 1957).

Figure 3.—Bottom, Alam Kūh (left), Takht-e Sulaiman (right), and the head of Sarchal Glacier as photographed by Bobek in 1936 (from Busk, 1937).

cirque glaciers and a 3-km-long tongue glacier. He estimated the snowline to be at 4,000 m. In 1937 he described the tongue glacier more thoroughly. He said that it originated at about 4,200 m in a 2-km-wide cirque high on the north slope of Alam Kūh. The approximately 1-km-wide glacier gradually disappeared under an increasing cover of rock debris so that it was impossible to precisely locate the terminus, although it probably was between 3,700 and 3,600 m. The glacier became known as the Sarchal, named after the region in which it is located (fig. 3). Bobek located the snowline at 4,000 to 4,100 m.

In 1956, a group from Cambridge University climbed in the area and drew a sketch map (Harding, 1957). They mentioned four main glaciers in the area: the Sarchal Glacier, located northeast of the summit of Alam



Kūh, a northwest glacier, and two glaciers to the south of the summit, the Hazarchal and the Hazarcham (fig. 4) They also noted two small, unnamed glaciers. The sketch map produced by Harding and those made by earlier travelers (Busk, 1935) were the only available maps of the area until 1957, when Bobek produced an excellent map at 1:100,000 scale of the Takht-e Sulaiman region (Bobek, 1957). It remains the only map of Iran that shows the occurrence of glaciers.

In 1958, Péguy, a member of a French expedition in Iran, described and sketched the glaciers in the vicinity of Alam Kūh, although he concentrated on the Sarchal Glacier (fig. 5) (Péguy, 1959). He described the Sarchal as forming from the confluence of three unequal segments. He estimated its length at 7 km with two-thirds of the surface entirely covered with rock debris. In describing its motion, he said that the eastern third consisted of active ice bounded by an active lateral moraine and covered by debris 0.5 to 1.5m thick. The other two-thirds was mostly

***Figure** 4.—The glaciers in the Takht-e Sulaiman massif region (from Harding, 1957).*

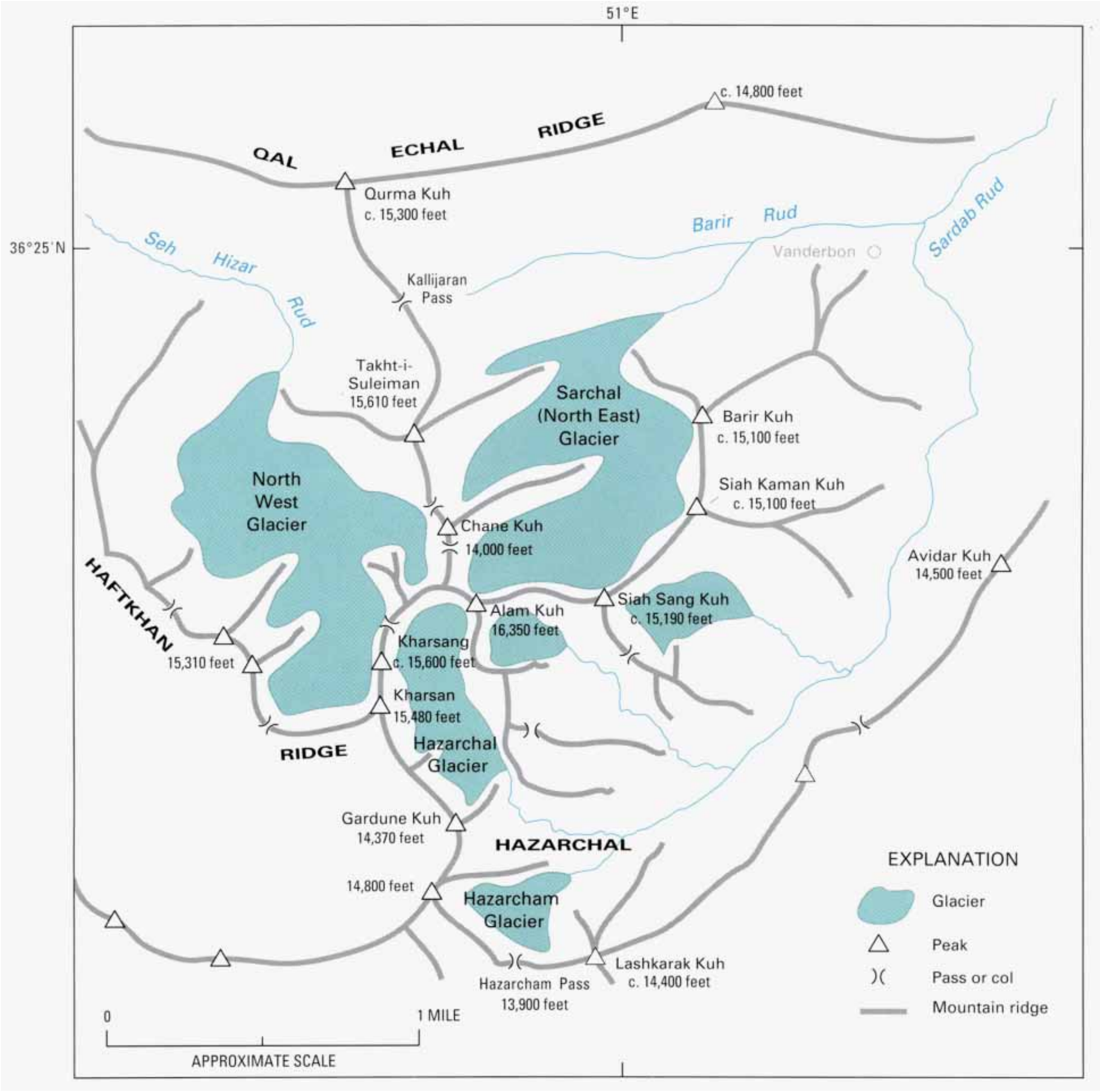
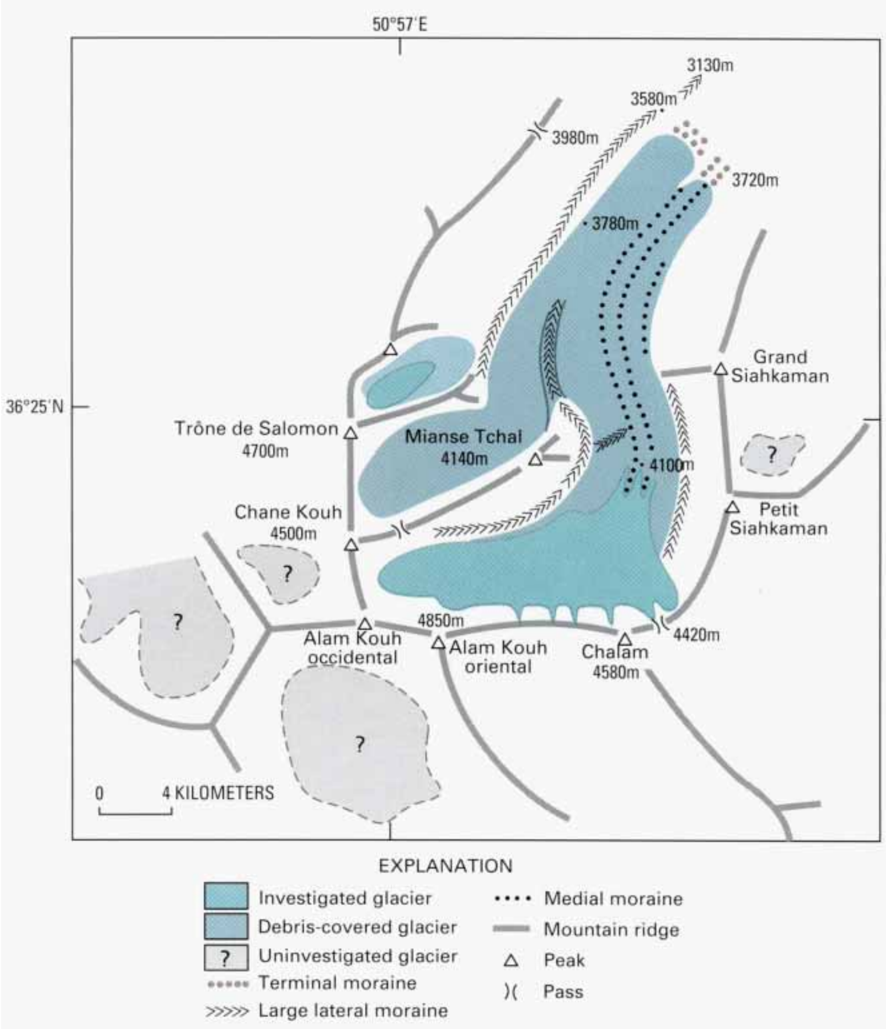


Figure 5.—Sarchal Glacier, Takht-e Sulaiman massif (from Péguy, 1959).



inactive ice covered with several meters of inert cover. The most recent data for the area (Schweizer, 1972) locate the snowline at 4,150 m. This estimate is based on the work of Bout and others (1961).

The Eastern Elburz Mountains

At present all of the glaciers in the eastern Elburz are located on Qōlleh-ye Damāvand (lat. 35°56′ N., long. 52°08′ E.). Damāvand, a dormant stratovolcano, is located about 70 km northeast of Tehran. Because it is the highest peak in Iran and because it is not difficult to reach from the south, it has been climbed repeatedly. Notes of a visit by Watson in 1861 described a summit covered by snow and sulfur (Watson, 1862). He found places where there were sulfur fumes and the ground was too hot to sit on for more than a few minutes. It was not until Bobek's visit with the German climbing expedition of 1936, however, that the glaciers were mentioned (Bobek, 1937). He described the peak as almost entirely covered by firn above 4,500 m. The firn was continuous in the highest regions and separated into deeply eroded bands of snow and ice farther down. He recognized two small glaciers, one on the east slope, the other on the north slope (fig. 6). The eastern glacier descended from the peak to the steep, fragmented cliff walls at the head of the Talu Valley

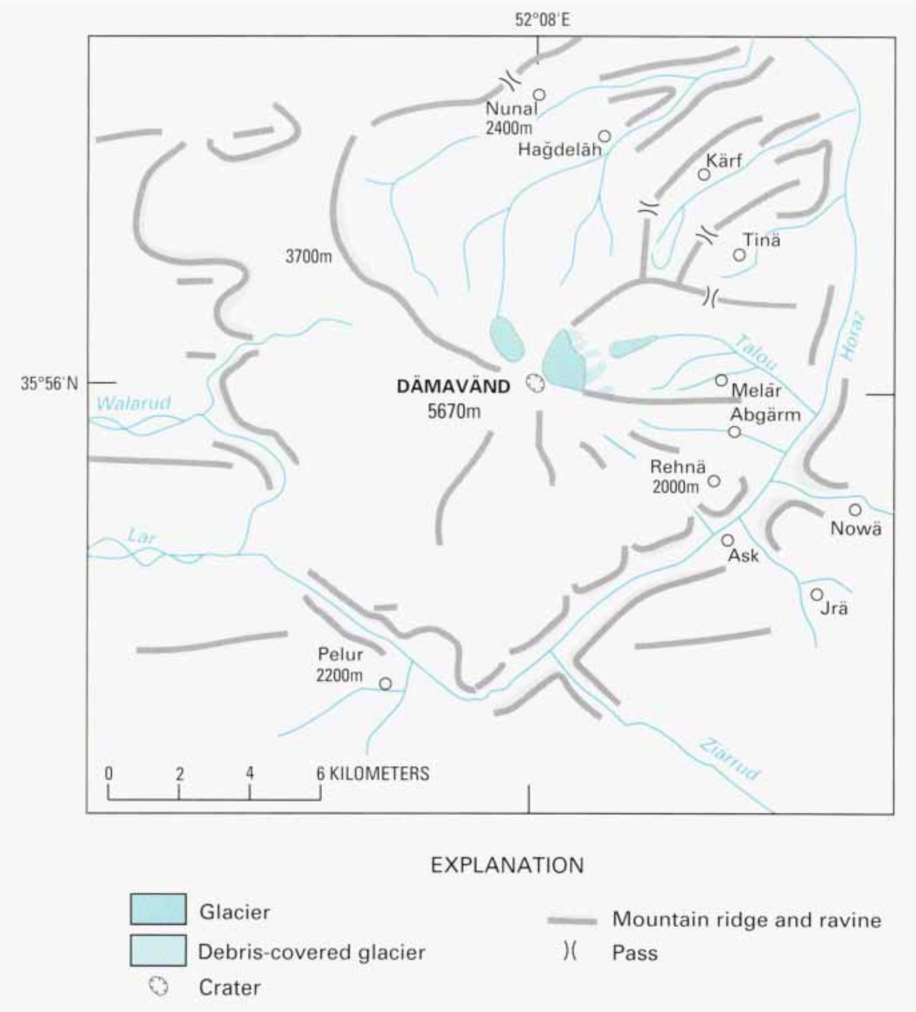


Figure 6. *—The glaciers on Damāvand (from Bobek, 1937).*

at about 4,800 to 5,000 m elevation. Here the glacier broke off cleanly, and the thickness was seen to be about 50 m. Glacier ice accumulated at the foot of the cliffs at about 3,900 m in ice debris cones and extended downward to about 3,400 m. The glacier on the northern slope started 600 to 800 m below the summit, extending downslope to about 4,400 m. At the lower elevations the glacier was broken and fragmented. Bobek placed the snowline at 4,500 m.

In September 1958, Péguy climbed the volcano with the French group and described the summit region (Péguy, 1959). He described a northeastern glacier (probably Bobek's eastern glacier) having a surface area of about 2 km². It formed a little below the summit at about 5,550 to 5,600 m and ended at about 5,100 m. The glacier was covered with large penitentes and a series of crevasses. There was not much debris cover. Penitentes, an annual phenomenon of snow sublimation related to solar radiation and arid climate, occur only on selected peaks in the region; they do not occur on similar peaks in nearby Turkey. Although penitentes form on the highest peaks in Iran—Damāvand, Alum Kūh, and Sabālan—climate is more important than elevation to their formation. The incidence angle of the Sun, the intensity of the radiation, and the dryness of the air in late summer and early fall, the time of maximum development, determine the occurrence, size, and shape of the penitentes (Schweizer, 1972). In addition, Péguy noted the southern side of the summit crater was covered by ice. Here and on the southern slope of the volcanic cone were penitentes 50 to 80 cm or more in height. The most recent data on the area are given by Schweizer (1972). He described the southern slope above 4,800 m and the summit crater of Damiivand as covered with firn and penitentes (fig. **7).**

South of Damiivand a small glacier referred to as a "tonsurgletscher" was observed on Tare Mumedsch at 3,035 m in September 1936 (Heybrock, 1940). However, no mention of the glacier has been made since that time, and it has most likely disappeared.

Figure 7. *—Penitentes in the summit crater of Damāvand (photograph by E. Durr, 7 September 1968; from Schweizer, 1972).*

Kūhhā-ye Sabālan

The Sabālan area (lat. 38°15' N., long. 47°49' E.) has a continental climate with hot, dry summers and extremely cold, snowy winters (Schweizer, 1970). Although there are no meteorological stations on the mountain itself, Schweizer was able to estimate the annual precipitation to be between 400 and 700 mm, on the basis of the elevation of the mountain and extrapolation of data from surrounding stations. The precipitation, which falls almost exclusively as snow in the late autumn, winter, and spring, nourishes the glaciers on the highest peaks. During the arid summer, there is considerable ablation, however.

The presence of glaciers on Sabālan (4,740 m) was first recognized in 1885 by Sjögren (1888), who described a small cirque glacier that was about 1 km long, 0.33 km wide, and descended to about 3,800 m. However, his report was not widely known. In 1934, Bobek observed the glaciers from a distance and estimated the snowline to be between 3,900 and 4,000 m (Bobek, 1934). A few years later, Bobek (1937) listed the height of the snowline on the north side of Sabālan as 4,000 to 4,100 m.

In September 1955, a German mountain climbing group climbed the peak and photographed and described the glaciers (Klebelsberg, 1958). On the northwest slope, there were large, interconnected glaciers extending from the summit downward to 4,000 m. On the south to southwestern sides there were only limited snow fields.

In 1968 and 1969, Schweizer carried out extensive fieldwork in the area (Schweizer, 1970, 1972). His description of the glaciers is very detailed, and he included information on glacier size and orientation and the maximum and minimum elevations of the ice (table 1).He counted seven glaciers and sketched their locations (fig. 8). The largest glacier is located on the steep north slope of the principal, or east, peak. Slightly east of this glacier lies a narrow, twisting couloir that is partially filled with a small glacier, one of the smallest of the group. The middle and western summits contain the remaining glaciers observed by Schweizer. The only glacier that has an eastern exposure is a small cirque glacier, the most southerly of the cirque glaciers. There are three small glaciers side by side on the steep north wall of these peaks. The last glacier is a small ice patch on the western slope of the western peak. The glaciers on Sabālan are often characterized by a heavy, continuous debris cover, and many glaciers appear to grade into and (or) continue as rock glaciers. Schweizer listed the height of the snowline as 4,500 m. Penitentes are also found on the summit of Sabālan between 4,200 and 4,300 m and are best developed above 4,500 m.

The Zard Kūh Area

The climate of the Zagros Mountains is typically Mediterranean, with dry summers and precipitation in the fall, winter, and spring. The spring and summer precipitation is caused by cyclonic storms that move as cold fronts and are characterized by snow at higher elevations. The winter precipitation is a result of anticyclonic, more gentle fronts. The precipitation increases generally with the elevation of the land area and ranges from 300 mm per year in the outer foothills to more than 1,000 mm per year in the highest part of the range (Wright, 1962).

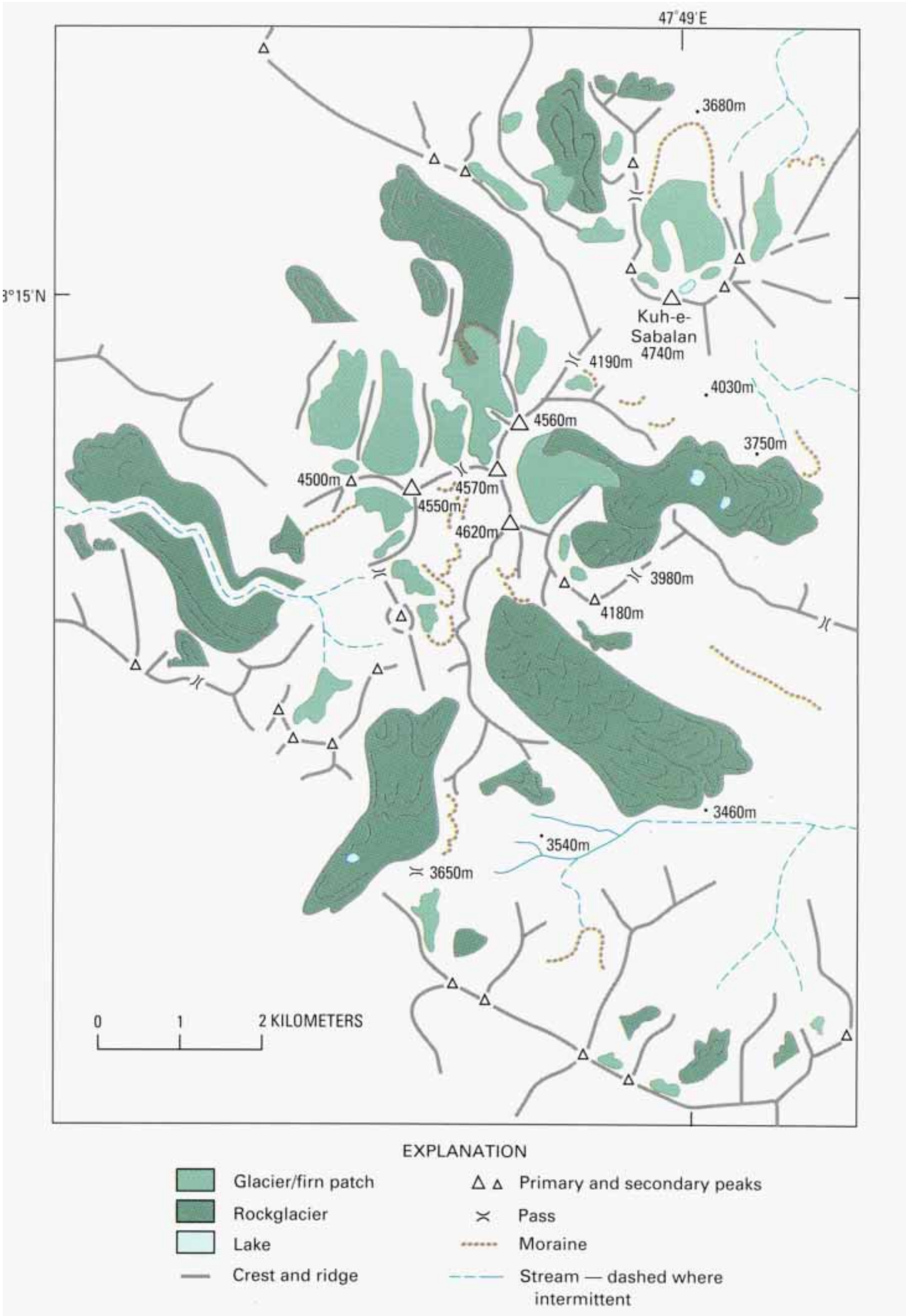
Small glaciers were first observed in the Zagros Mountains on the northern slopes of Zard Kūh (4,268 m) (lat. 32°22' N., long. 50°04' E.) during August 1933 (Desio, 1934b). Desio described, photographed, and named four small glaciers with a combined area of 150 hectares (ha). The largest glacier, which he called "Ghiacciaietto del Kulang-ci," had an area

TABLE 1.—*The recent glaciers of Kūhhā-ye Sabālan*

[Modified from Schweizer, 1970; —, no data; do., ditto]

Glacier	Glacier type	Orientation	Highest ice occurrence (m)	Lowest occurrence of clean ice (m)	Average height of surrounding ridges (m)	Orographic snowline (m)	Visible firn line (mid-Sept. 1968)	Maximum length (m)	Maximum width (m)
Large North Glacier	Cirque	North	4,700	3,980	4,700	4,340	4,000	900	650
North Couloir Glacier	Couloir	North	4,500	4,000	4,600	4,200	—	750	150
East Glacier	Cirque	East-northeast	4,250	4,020	4,500	4,260	4,100	750	600
Eastern Northwest Glacier	Slope	North	4,400–4,500	4,000	4,480	4,230	not continuous	850	550
Middle Northwest Glacier	Slope	North	4,540	4,050	4,550	4,300	do.	850	450
Western Northwest Glacier	Slope	North	4,420	4,000	4,500	4,210	do.	800	450
West Summit Glacier	Plateau	West	4,500	4,460	4,520	4,490	—	400	350

Figure 8.—*The occurrence of glaciers on Kūhhā-ye Sabālan (modified from Schweizer, 1972).*



of 70.4 ha. Each glacier occupied a span of about 200 m elevation, with the minimum occurring at about 3,600 m and the maximum at 4,200 m. In 1937, Bobek listed the snowline at 4,000 to 4,100 m. In 1963, Dr. H. McQuillan (1969) photographed the "Ghiacciaietto" (fig. 9). He estimated its width at 400 m. Comparison of his photograph with Desio's sketch shows that the glacier had thinned considerably and that the toe had receded at least 20 m of the total 100 m elevation it spanned.

In 1972, Schweizer used the work of others and his own analysis of aerial photographs to estimate the height of the snowline at Zard Kūh at 4,050 m. In 1975, Grunert and others (1978) studied the glaciers, firn patches, snowline, and climate of the Zard Kūh area. They described and

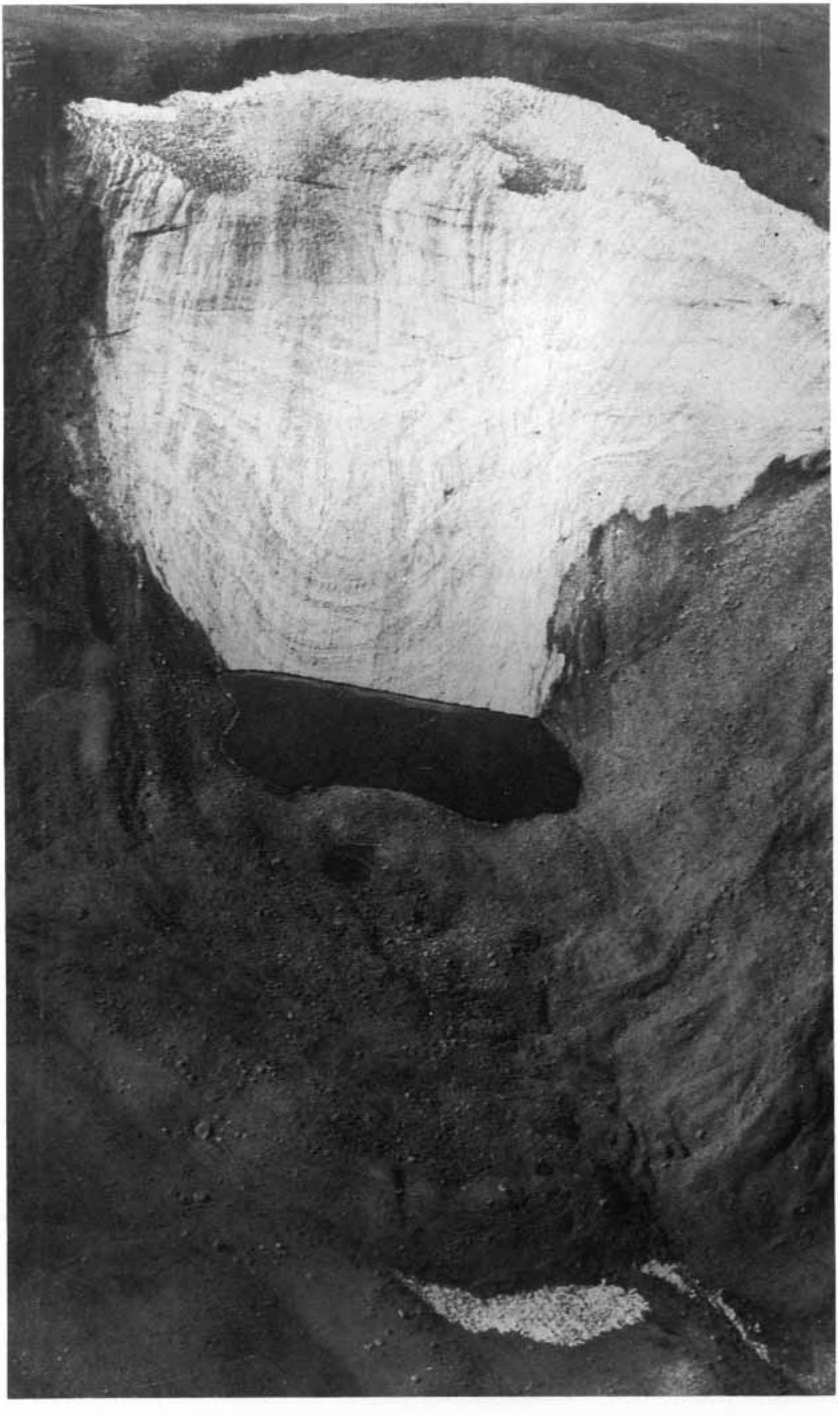
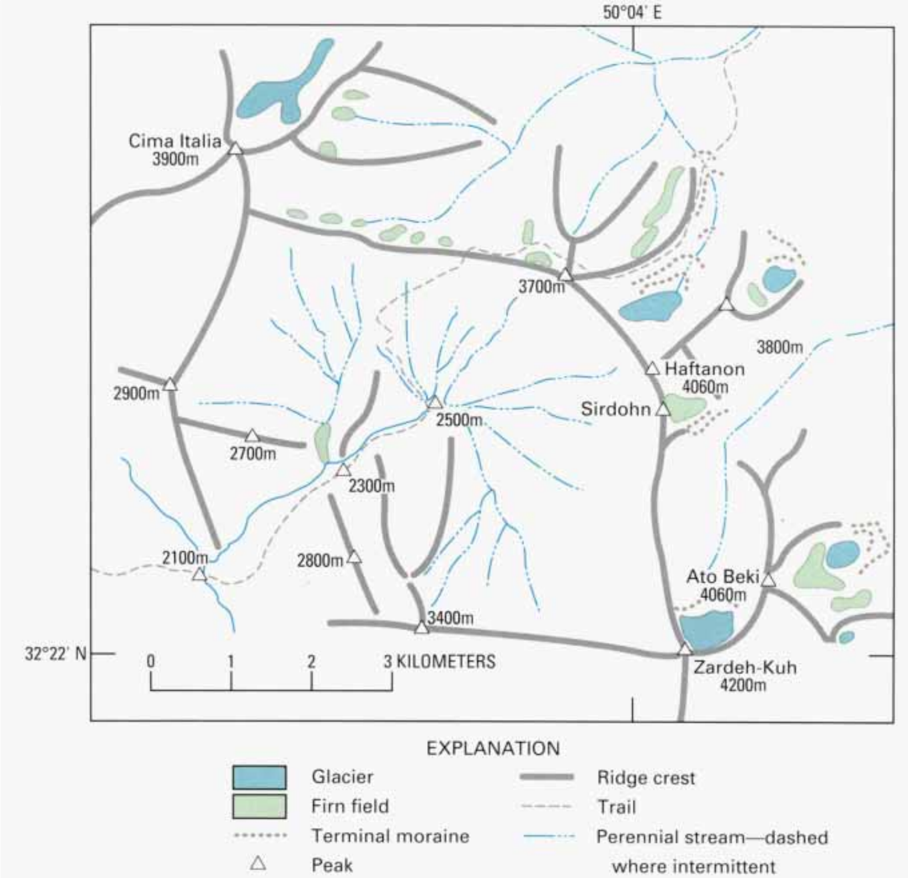


Figure 9. *–The largest glacier on the north slopes of Zard Kūh as photographed by H. McQuillan, 1963 (from McQuillan, 1969).*

Figure 10.—The glaciers of Zard Kūh (modified from Grunert and others, 1978).



sketched the location of five glaciers (fig. 10). The largest was described as 500 m wide and spanned an elevation of 150 m from 3,900 to 4,050 m. On the basis of the location and condition of the glaciers and firn patches, they concluded the snowline had dropped to 3,900 m. They noted that the Zagros Mountains contain glaciers, while equally high mountains to the east do not because of the weather pattern. Other areas eastward fall within the precipitation shadow of the Zagros Mountains and are much more arid.

Glacier Fluctuation

During the Pleistocene, there were six centers of glaciation in Iran, according to Bobek (1963), including the central Elburz Mountains, Kūhhā-ye Sabālan, Zard Kūh, and three other mountain areas. The most important single area was the Takht-e Sulaiman massif of the central Elburz. Here the Sarchal Glacier, currently the largest in Iran at about 7 km, extended between 20 and 25 km. Two other glaciers, one 13 km and the other 11 km long, also were present. Bobek (1963) also maintained that during the Pleistocene the climatic snowline throughout the country was 600 to 800 m lower than the present level and that the temperature structure was similar to current patterns except that the mean temperature was 4 to 5° C lower. On the basis of a study of the playas, Krinsley concluded that, during the Würm maximum, the outward-facing slopes of the northern Zagros and Elburz Mountains had mean annual temperatures 5 to 8° C colder than at present. The snowline was depressed as much as 1,800 m (Krinsley, 1970). Krinsley also (1968) added that the Pleistocene climate of Iran was more compartmented than in other countries in similar latitudes. He stated that, although the Pleistocene climate of northern Iran was similar to the present climate, the precipitation/evaporation ratio was higher because of decreased evaporation resulting from lower summer temperatures (Krinsley, 1972). Schweizer (1970) compared Pleistocene and present snowlines on the basis of his own and earlier studies (table 2). Since the end of the Pleistocene, there is evidence of a series of stadia1 retreats and readvances of the glaciers as the climate cycle progressed. The cool, dry climate of the Pleistocene gave way to a warm, dry climate, and the level of precipitation increased slowly during the Hypsithermal until about 5,500 years ago (Wright, 1968). This period was followed by the colder temperatures of the Neoglacial. Minor temperature fluctuations occurred until the generally cooler times of the "Little Ice Age" of the 16th and 18th centuries. Since the 19th century the glaciers of Iran have probably followed the same general pattern as described for Turkey by Erinç (1952). He stated the trend has been toward general recession interrupted by periods of growth. Since 1930, the rate of recession has accelerated. The contemporary glaciers, however, are not relict but have regenerated in post-Pleistocene times and at one time covered an area twice their present size.

Information on the total areal coverage of glaciers in Iran is nonexistent. Previous reviews of Iran's glaciers have discussed occurrence, but not areal extent (Klebelsberg, 1949; McCauley, 1958; Horvath, 1975). Drygalski and Machatschek (1942) estimated the total glacier area of Turkey, Armenia, and Iran to be about 100 km^2. Recent estimates by Kurter for the total glacier area of Turkey, included elsewhere in this chapter, are 22.9 km^2. A very rough estimate for the current size of Iran's glaciers is 20 km^2. This estimate is based on estimates of 14 km^2 for the glaciers of the Takht-e Sulaiman massif made from sketch maps listed on table 3, 2.0 km^2 for Damāvand (Péguy, 1959), 2.4 km^2 for Sabālan (Schweizer, 1970), and 1.5 km^2 for Zard Kūh (Desio, 1934b).

TABLE 2.—*The height of the present and Pleistocene snowlines in selected mountain areas of Iran*

[Modified from Schweizer, 1970]

Mountain area	Summit height (m)	Present snowline (m)	Pleistocene snowline (m)	Source
Takht-e Sulaiman	4,840	4,0004,100	3,000	Bobek, 1937; Bout and others, 1961.
Damāvand	5,670	4,500	3,700–3,800	Bobek, 1937; Bout and others, 1961.
Sabālan	4,740	4,500	3,6004,700	Schweizer, 1970.
Zard Kūh	4,268	3,900	3,3504,400	Desio 1934a; Grunert and others, 1978.

Available Data for Glacier Studies

Maps

There are a very limited number of maps available for glacier studies of Iran. The first maps available were the sketch maps produced by early travelers and climbers. Later researchers also produced sketch maps because of the absence of accurate maps showing glacier occurrence. The only published map that shows the occurrence of glaciers is a map by Bobek at a scale of 1:100,000 of the Takht-e Sulaiman massif area, published in 1957. Later maps, which have been produced at various scales, do not show the glaciers but depict the topography of each of the glacier areas. Information about the available maps is given in table 3.

TABLE 3. —*List of maps covering the glacier areas of Iran*

Map or author	Scale	Glacier areas covered
Published maps and charts		
U.S. Defense Mapping Agency–Operational Navigation Chart ONC G-5	1:1,000,000	All areas
U.S. Defense Mapping Agency–Joint Operations Graphic, Series 1501	1:250,000	
Sheet NJ 39–14, 15		Takht-e Sulaiman
Sheet NI 39–3		Damāvand
Sheet NJ 38–8		Sabālan
Sheet NI 39–14		Zard Kūh
Kartog Anstalt Freytag-Berndt und Artaria, Vienna–Karte der Takht-e Sulaimangruppe in mittleren Alburzgebirge, Nordiran	1:100,000	Takht-e Sulaiman
Geological Survey of Iran–Geological Map of the Central Alborz Sheet Damāvand	1:100,000	Damāvand
Sketch maps		
Busk, 1935	~1:90,000	Takht-e Sulaiman
Harding, 1957	~1:90,000	Takht-e Sulaiman
Péguy, 1959	~1:50,000	Takht-e Sulaiman
Bobek, 1937	~1:300,000	Damāvand
Schweizer, 1972	~1:70,000	Sabālan
Grunert and others, 1978	~1:90,000	Zard Kūh

Aerial Photographs

Some aerial photographs were acquired by the U.S. Air Force for the U.S. Army Map Service in the late summer and fall of 1955 and 1956 and the summer of 1970. The photographs are valuable for getting an accurate view of the glaciers at that time. The photographs that cover the glacier areas are listed in table 4. The photograph taken of Damāvand in August 1955 is particularly good (fig. 11). It was taken at a time of minimum snow cover, and the two glaciers described by Bobek are clearly visible.

TABLE 4. —*Aerial photographic coverage of the glacierized areas of Iran*

Date	Project	Sortie	Frame	Approximate scale
Takht-e Sulaiman area				
03 Oct 55	158	M99	15938–15940	1:60,000
03 Oct 55	158	S99	15937A–15940	1:30,000
03 Oct 55	158	S99	15904–15909	1:30,000
Damāvand area				
13 Sept 56	158	M231	33578	1:45,000
01 Aug 55	157	LS23A	3736-3736A	1:30,000
Sabālan area				
08 Jun 70	NW-IRAN	R25	1553–1555	1:60,000
Zard Kūh area				
31 Aug 55	158	R64A	10774A-10775	1:30,000
31 Aug 55	158	R64	10773–10775	1:60,000
29 Aug 55	158	R59A	9861A–9862A	1:30,000
29 Aug 55	158	59	9951–9953, 9961–9963	1:50,000

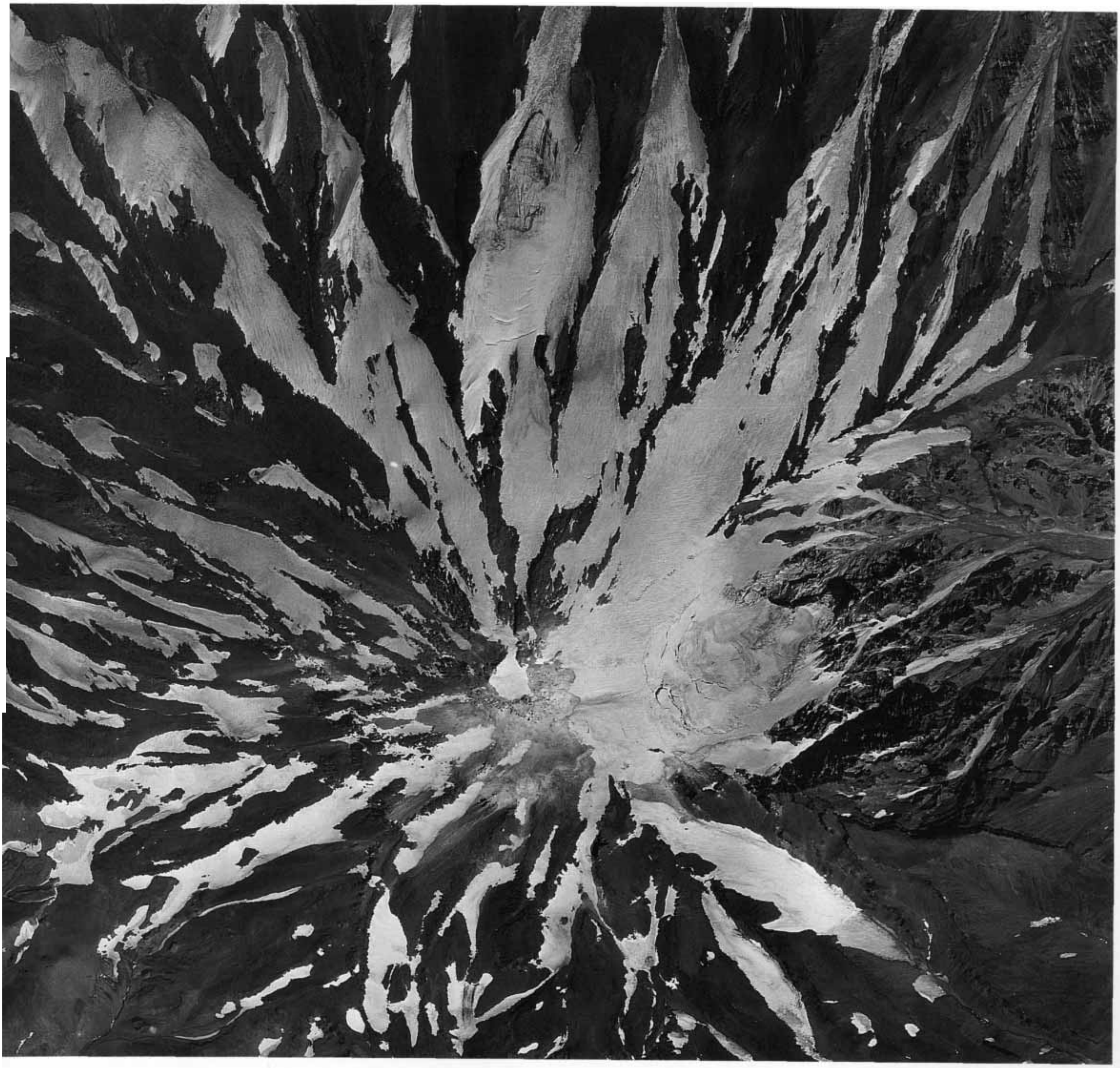


Figure 11.—Aerial photograph of the glaciers on Damāvand acquired in August 1955 by the U.S. Air Force for the Army Map Service, Project 157, Frame 3736A. Approximate scale 1:30,000.

TABLE 5.-*Optimum Landsat 1, 2, and 3 images of the glaciers of Iran*

[A filled-in circle in the "Code" column means an excellent image, 0 to ≤5 percent cloud cover over glacier areas]

Path-Row	Nominal scene center (lat-long)	Landsat identification number	Date	Solar elevation angle (degrees)	Code	Cloud cover (in percent)	Remarks
176-35	**35°58'N. 52°45'E.**	**21263-06052**	08 Jul **78**	**55**	●	0	Damāvand; color composite available
177-35	**35°58'N. 51°19'E.**	**2580-06240**	**24** Aug **76**	**50**	●	0	Damāvand, Takht-e Sulaiman
177-37	**33°07'N. 50°26'E.**	**1044-06443**	**05** Sep **72**	**53**	●	0	Zard Kūh
180-33	**38°49'N. 47°57'E.**	**1083-07001**	**14** Oct **72**	**38**	●	0	Sabālan
180-34	**37'24'N. 47°29'E.**	**2187-06485**	**28** Jul **75**	**56**	●	0	Sabālan; color composite available

Satellite Imagery

Cloud-free Landsat data exist for all the glacier areas of Iran (table 5, fig. 12). However, standard Landsat multispectral scanner (MSS) photographic data have limited usefulness for glacier studies in Iran. The glaciers are all very small, with only a few (Sarchal and the northwest glacier on Alam Kūh and the northeast glacier on Damāvand) being larger than 0.5 km², and they are difficult to resolve on standard Landsat imagery. The situation is made more difficult by the fact that snow cover and debris cover, which are common on most of Iran's glaciers, make glacier features harder to discern. Photographic enlargements and color composites make it easier to see the glaciers, but the glacier features are still hard to distinguish (figs. 13 and 14). Figure 13, a section of a color composite image, shows the snow and ice cover on Damāvand, but it is impossible to separate snow from ice. Figure 14, a 1:250,000-scale enlargement of band 7 MSS image of Sabālan clearly shows some of the individual snow and ice patches, but detailed features and glacier areas covered by debris or hidden by shadow are not distinguishable. Digital enhancement techniques have been successfully used for glacier studies in some areas such as described in the subchapters on Irian Jaya, Indonesia, and the Italian Alps. Such techniques have not been tried in Iran but might offer additional information.

In some areas it is possible to use Landsat imagery to **(1)** delineate glacier distribution, (2) map glacier outlines, **(3)** monitor glacier fluctuations, **(4)** distinguish transient snowlines, (5) inferentially determine changes in mass balance, and (6) indicate the former extent of glaciers by showing the location of abandoned moraines or by showing traces of glacial erosion such as cirques, aretes, or glaciated valleys. However, the size of glaciers in Iran and conditions of snow cover, debris cover, and, in the case of Damāvand and Sabālan, surrounding recent igneous rocks that are resistant to glacial erosion, make this difficult. Data from sensors having greater spectral and (or) spatial resolution are becoming available, including data from the Landsat Thematic Mapper (TM), the Large Format Camera (LFC), and the French Système Probatoire d'Observation de la Terre (SPOT). Such new data will be able to contribute to glacier studies and monitoring in Iran and in other glacierized regions of the world where the resolution of the Landsat MSS sensor is not adequate.

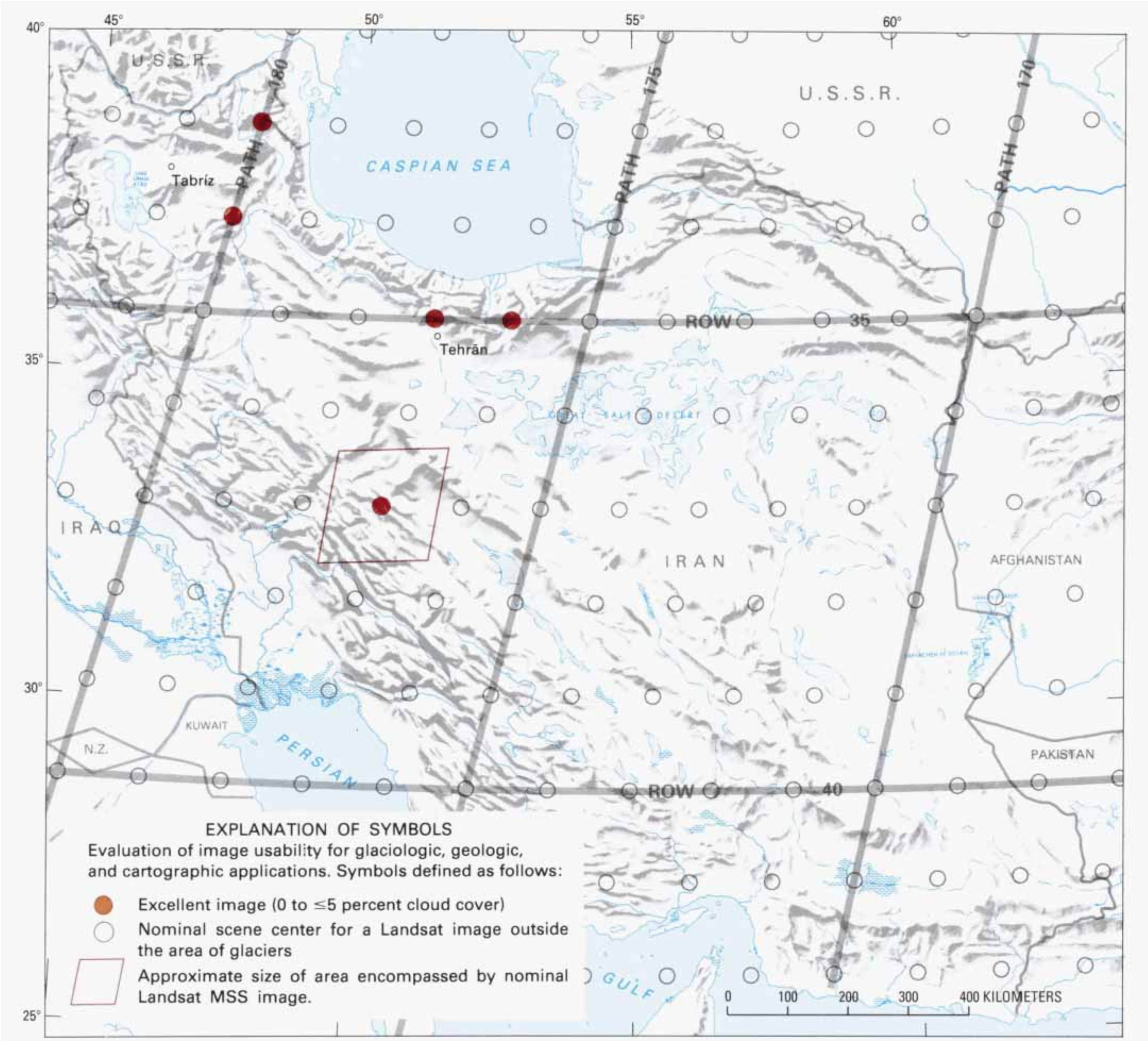
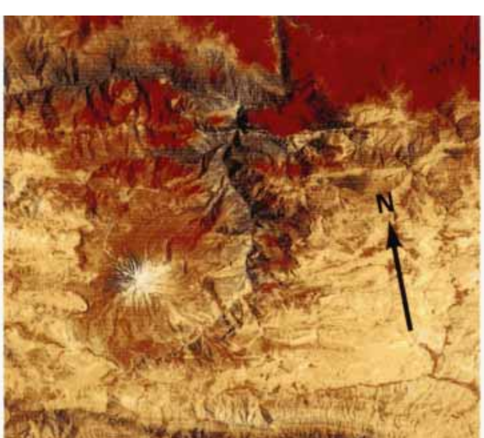
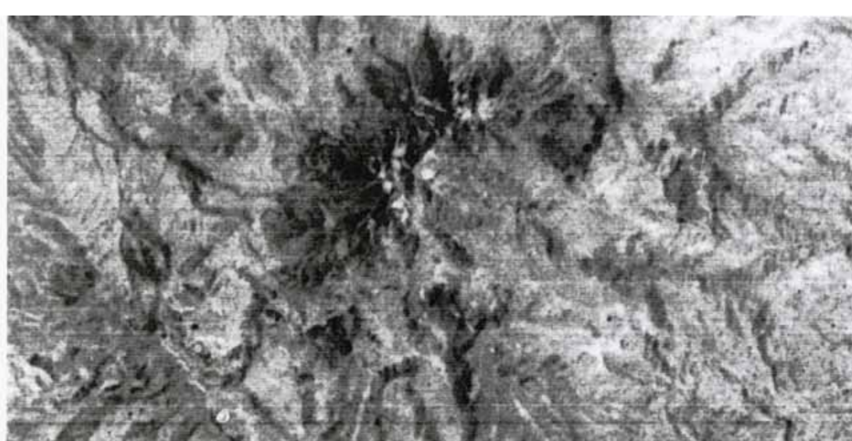


Figure 12.—Optimum Landsat 1, 2, and 3 images of the glaciers of Iran. The vertical lines represent nominal paths. The rows (horizontal lines) have been established to indicate the latitude at which the imagery has been acquired.





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References Cited

Bobek, H., 1934, Reise in Nordwestpersien 1934 [Travel in northwest Persia 19341: Zeitschrift der Gesellschaft für Erdkunde zu Berlin, v. 9/10, p. 359–369.

———1937, Die Rolle der Eiszeit in Nordwestiran [The role of the ice age in northwestern Iran]: Zeitschrift für Gletscherkunde, v. 25, p. 130–183.

———1957, Die Takht-e Sulaimangruppe im mittleren Alburzegebirge, Nordiran, *in* Wiche, K., ed., Festschrift zur Hundertjahrfeier der Geographischen Gesellschaft in Wien 1856–1956 [Anniversary Publication for the Centennial of the Geographical Society of Vienna 1856-1956]: Geographische Gesellschaft Vienna, p. 236–264.

———1963, Nature and implications of Quaternary Climatic changes in Iran, *in* Changes of climate, Proceedings of Symposium on Changes of Climate with Special Reference to And Zones: Rome, 1961, UNESCO, p. 403413.

Bout, P., Derruau, M., Dresch, J. and Péguy, Ch.P., 1961, Observations de geographie physique en Iran septentrional. Expedition 1958 sous les auspices du C.N.R.S. [Observations on the physical geography of northern Iran. Expedition of 1958 under the auspices of C.N.R.S.]: Memoires et Documents 8, Paris, p. 9–112.

Busk, D.L., 1933, Climbing and ski-ing in the Elburz Range, North Persia, 1931–2: Alpine Journal, v. 45, no. 247, p. 334-341.

———1935, Climbing in the Takht-i-Suleiman Group, N. Persia: Alpine Journal, v. 47, no. 251, p. 299-309.

———1937, The German expedition in the Elburz Range, N. Persia: Alpine Journal, v. 49, no. 255, p. 245–247.

Desio, A., 1934a, Appunti geografici e geologici sulla catena dello Zardeh Kuh in Persia [Geographic and geologic information concerning the Zard Kuh mountains in Persia]: Memorie Geologiche e Geographiche di G. Dainelli, 4, p. 141–167.

———1934b, Sull'esistenza di piccoli ghiacciai nella Persia occidentale [Concerning the existence of small glaciers in western Persia]: Bollettino del Comitato Glaciologico Italianao, no. 14, p. 39–52.

Drygalski, E. von, and Machatschek, F., 1942, Enzyklopädie der Erdkunde: Gletscherkunde [Encyclopedia of Earth Sciences: Glaciology]: Wien, Franz Deuticke, 261 p.

Erinç, S., 1952, Glacial evidences of the climatic variations in Turkey: Geografiska Annaler, v. 34, no. 1–2, p. 89–98.

Grunert, J., Carls, H.-G., and Preu, C., 1978, Rezente Vergletscherungsspuren in zentraliranischen Hochgebirgen [The present-day glaciers of the central Iranian high mountains]: Eiszeitalter und Gegenwart, v. 28, p. 148–166.

Harding, J.G.R., 1957, Cambridge Expedition, 1956, to the Elburz Mountains, Iran: Himalayan Journal, v. 20, p. 112–121.

◄ ***Figure** 13.—Left, Section of a 1:1,000,000-scale Landsat 2 MSS color-composite image 27263-6052 (Path 176, Row 35, acquired 8 July 1978) showing Damāvand.*

◄ ***Figure** 14.—*Right, A *1:250,000-scale enlargement of a section of Landsat MSS image 2187-06485 (band 7; Path 180, Row 34, acquired 28 July 1975) showing some of the glaciers and snow patches on Sabālan.*

Heybrock, W., 1940, Naturwissenschaftliche Beobachtungen in Iran: Petermanns Geographische Mitteilungen 86, no. 4, p. 124–131.

Horvath, E., 1975, Glaciers of Turkey, Armenian S.S.R. and Iran, *in* Field, W.O., ed., Mountain glaciers of the Northern Hemisphere, pt. 111, Glaciers of Southern Asia: Hanover, N.H., U.S. Army Cold Regions Research and Engineering Laboratory, p. 343–359.

Klebelsberg, R. von, 1949, Handbuch der Gletscherkunde und Glazialgeologie [Handbook of glaciology and glacial geology]: Wien, Springer-Verlag, 1028 p.

———1958, Von der Vergletscherung des Kuh-i-Sawalan (4,821 m), Nordwest-Persien [The glaciers of Kūhhā-ye Sabālan (4,821 m) northwest Persia]: Zeitschrift für Gletscherkunde und Glazialgeologie, v. 4, no. 1–2, p. 119–120.

Krinsley, D.B., 1968, Geomorphology of three kavirs in northern Iran, *in* Neal, J.T., ed., Playa surface morphology: Miscellaneous investigations, chap. 5: Air Force Cambridge Research Laboratory, Environmental Research Papers, no. 283, p. 105–130.

———1970, A geomorphological and paleoclimatological study of the playas of Iran: U.S. Geological Survey Interagency Report IR–Military–1, 329 p.

———1972, The paleoclimatic significance of the Iranian playas, *in* Zinderen Bakker, E.M. van, ed., Palaeoecology of Africa, v. 6: Cape Town, A.A. Balkema, p. 114–120.

McCauley, C., 1958, Glaciers of Turkey, Iran, and Soviet Armenia, *in* Glaciation in the Northern Hemisphere, pt. 6, Western, arctic, and eastern Asia: New York, American Geographical Society, p. 6.1.1-6.1.4.

McQuillan, H., 1969, Small glacier on Zardeh Kuh, Zagros Mountains, Iran: Geographical Journal, v. 135, pt. 4, p. 639.

Péguy, Ch.P., 1959, Les glaciers de l'Elbourz [The glaciers of the Elburz Mountains]: Bulletin de I'Association de Géographes Français, no. 284–285, p. 44-49.

Roch, A., 1961, Avalanche danger in Iran: Journal of Glaciology, v. 3, no. 30, p. 979–983.

Schweizer, G., 1970, Der Kuh-e-Sabalan (Nordwestiran). Beiträge zur Gletscherkunde und Glazialgeomorphologie vorderasiatischer Hochgebirge [Kūhhā-ye Sabālan (northwest Iran). Contributions on the glaciology and glacialgeomorphology of the high mountains of the Near East], *in* Beitrage zur Geographie der Tropen und Subtropen: Tübinger Geographische Studien, no. 34, p. 163–178.

———1972, Klimatisch bedingte Geomorphologische und Glazialogische Züge der Hochregion vorderasiatischer Gebirge (Iran und Ostanatolien) [Climatically based geomorphological and glaciological characteristics of the high-altitude regions of Near Eastern mountains (Iran and Eastern Anatolia)]: Erdwissenschaftliche Forschung, v. 4, p. 221–236.

Sjögren, H., 1888, Beiträge zur Geologie des Berges SaveIan in nordlichen Persien [Contributions to the geology of the Sabālan Mountains in northern Persia]: Verhandlungen der Russisch-Kaiserlichen Mineralogischen Gesellschaft zu St. Petersberg, Series 2, v. 24, p. 36–66.

U.S. Board on Geographic Names, 1956, Gazetteer No. 19, Iran: Washington, D.C., U.S. Government Printing Office.

Watson, R.G., 1862, Notes of a visit to the Elburz Mountains and ascent of Demavend: Royal Geographic Society Proceedings, v. 6, p. 103–105.

Wright, H.E., Jr., 1962, Pleistocene glaciation in Kurdistan: Eiszeitalter und Gegenwart, v. 12, p. 131–164.

———1968, Climatic change in the Eastern Mediterranean region: Limnological Research Center, University of Minnesota, Minneapolis, 15 p.