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The Pleistocene Glaciation (LGP and pre-LGP, pre-LGM) of SE Iranian Mountains Exemplified by the Kuh-i-Jupar, Kuh-i-Lalezar and Kuh-i-Hezar Massifs in the Zagros

by Matthias Kuhle[1]

Abstract: Evidence has been provided of two mountain glaciations in the 4135 m high, currently non-glaciated Kuh-i-Jupar massif in the semi-arid Zagros: an older period during the pre-LGP (Riss glaciation, c. 130 Ka) and a younger one during the LGP (Würm glaciation, Marine Isotope Stage (MIS) 4-2: 60-18 Ka). During the pre-LGP glaciation the glaciers reached a maximum of 17 km in length; during the LGP glaciation they were 10-12 km long. They flowed down into the mountain foreland as far as 2160 m (LGP glaciation) and 1900 m (pre-LGP glaciation). The thickness of the valley glaciers reached 550 (pre-LGP glaciation) and 350 m (LGP glaciation). During the pre-LGP a 23 km-wide continuous piedmont glacier lobe developed parallel to the mountain foot. During the LGP the glacier termini mostly remained separated in the mountain foreland. During the pre-LGP glaciation the ELA ran at c. 2950 m and during the LGP glaciation at c. 3050 m asl, that is 1600 and 1500 m below the current theoretical snowline. Thus, a temperature depression of c. 11-16 °C and 10-15 °C must be assumed for the SE-Iranian highland, c. 130 and 60-18 Ka ago. The recessional moraines, which are preserved in the high valleys, document a Late Glacial glacier retreat in four stages (I-IV). These four Late Glacial stages can be identified at many places in the mountains of High and Central Asia. Apart from the Kuh-i-Jupar additional evidence of Pleistocene glaciation was found on the adjacent massifs of the Kuh-i-Lalezar (4374 m) and Kuh-i-Hezar (4469 m).

Zusammenfassung: Für das heute unvergletscherte 4135 m hohe Kuh-i-Jupar-Massiv im semiariden Zagros wurden zwei Gebirgsvergletscherungen nachgewiesen: eine während der Riss-Vereisung (pre-LGP, ca. 130 Ka) und eine jüngere während der Würm-Vereisung (LGP, MIS 4-2: 60-18 Ka). Während der pre-LGP-Vereisung bestanden max. 17 km lange und während der LGP-Vereisung 10-12 km lange Gletscher, die in das Gebirgsvorland bis auf 2160 bzw. 1900 m hinabgeflossen sind. Die Talgletschermächtigkeiten erreichten 550 bzw. 350 m. Während der Riss-Eiszeit (pre-LGP) entstand ein 23 km ausgedehnter, zusammenhängender Piedmontgletscherlobus parallel zum Gebirgsfuß; während des LGP blieben die Gletscherenden im Gebirgsvorland zumeist separat. Die ELA verlief während der Riss-Vergletscherung (pre-LGP) etwa 2950 m und während der Würm-Vergletscherung etwa 3050 m ü.d.M., das ist 1600 m bzw. 1500 m unter der heutigen theoretischen Schneegrenze. Dies legt eine Temperaturdepression von ca. 11-16 °C bzw. 10-15 °C für das SE-iranische Hochland vor ca. 130 bzw. 60-18 Ka nahe. Der sukzessive Gletscherrückgang während des Spätglazials über vier Rückzugsstadien (I-IV) ist durch Moränen in höheren Tallagen belegt. Diese spätglazialen Stadien sind in den Gebirgen von Hoch- und Zentralasien vielerorts anzutreffen. Weitere Befunde eiszeitlicher Vergletscherung werden als großräumige regionale Bestätigung aus den benachbarten Massiven des Kuh-i-Lalezar (4374 m) und Kuh-i-Hezar (4469 m) vorgestellt.

INTRODUCTION

Detailed investigations as to the maximum Pleistocene glacier cover have been carried out in the 4135 m high Kuh-i-Jupar massif at 29°40' N to 30°15' N and 56°50' to 57°35' E over a period of nine months in 1973 and 1974 (Fig. 1 No.1). In addition the Kuh-i-Lalezar massif (4374 m, 29°23'28.01" N 56°44'49.38" E) has been visited in April and May 1973. The results attained by Quaternary geological and geomorphological methods stand in contrast to earlier assumptions concerning the former glaciation of these semi-arid Iranian mountains. Parts – Kuh-i-Jupar massif – were already published in German. They are included in this paper in a summarized form. In continuation of these results new observations from the Kuh-i-Lalezar and also findings from the Kuh-i-Hezar attained by remote sensing are introduced. All that fits well with a very extended Ice Age glaciation in Tibet and surrounding mountains (KUHLE 1982, 2004).

The Kuh-i-Jupar crest trending from W to E reaches a height of approx. 4000 m (3700-4135 m) over a length of c. 20 km. It is drained by up to 12 km long cross valleys (Fig. 3). Between the outcropping edges of Cretaceous limestones and Old-Tertiary conglomerates (Kerman conglomerate = ck) (Djokovic et al. 1972) with an inclination of 20-35°, forming the highest summits, the cross valleys show structural asymmetry and short, consistently steep curves of incline, as well as bipartite inclinations. In the latter case – realized for instance in a 1450 m-high wall of the SW slope – a steep escarpment at the valley head continues as an only slightly inclined valley thalweg (Fig. 2 on the left below No. 2-6). A structural characteristic supporting the prehistoric glaciation, is the over 10 km-long Kuh-i-Jupar NE wall, the main part of which rises to a height of over 3700 m (Fig. 2 between No.1 and 14). In the northern hemisphere the NE exposition is most favourable to glacier development.

The Kuh-i-Jupar receives 168 mm of precipitation per annum in its piedmont area (measurements of the Kerman meteorological station, 1650 m asl, over twelve observation years) or c. 100-170 mm (after BAUER 1935, BOBEK 1952, GANJI 1960, METEREOLOGICAL YEARBOOK 1950-1973, LIETH & WALTER 1960-67). In accordance with the increasing altitude the mountain range itself may receive 200-500 mm/y (ibid.). The precipitation falls during winter. In the SW-adjacent Kuh-i-Lalezar massif (4374 m) precipitation even reaches 250 mm/y more. In the middle of summer, stratus clouds can be observed coming from the SE, which derive from monsoonal disturbances; they prove that the Kuh-i-Jupar is indeed situated in the southeastern border area of winter precipitation. Evidence of this is also provided by the heavy summer precipitation (July), which occurs in the Kuh-i-Hezar massif (4469 m) 50 km to the south, as described by STRATIL-SAUER (1937: 310, 1941).

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[1] University of Göttingen, Department of Geography and High Mountain Geomorphology, Goldschmidtstraße 5, 37077 Göttingen, Germany; <mkuhle@gwdg.de>

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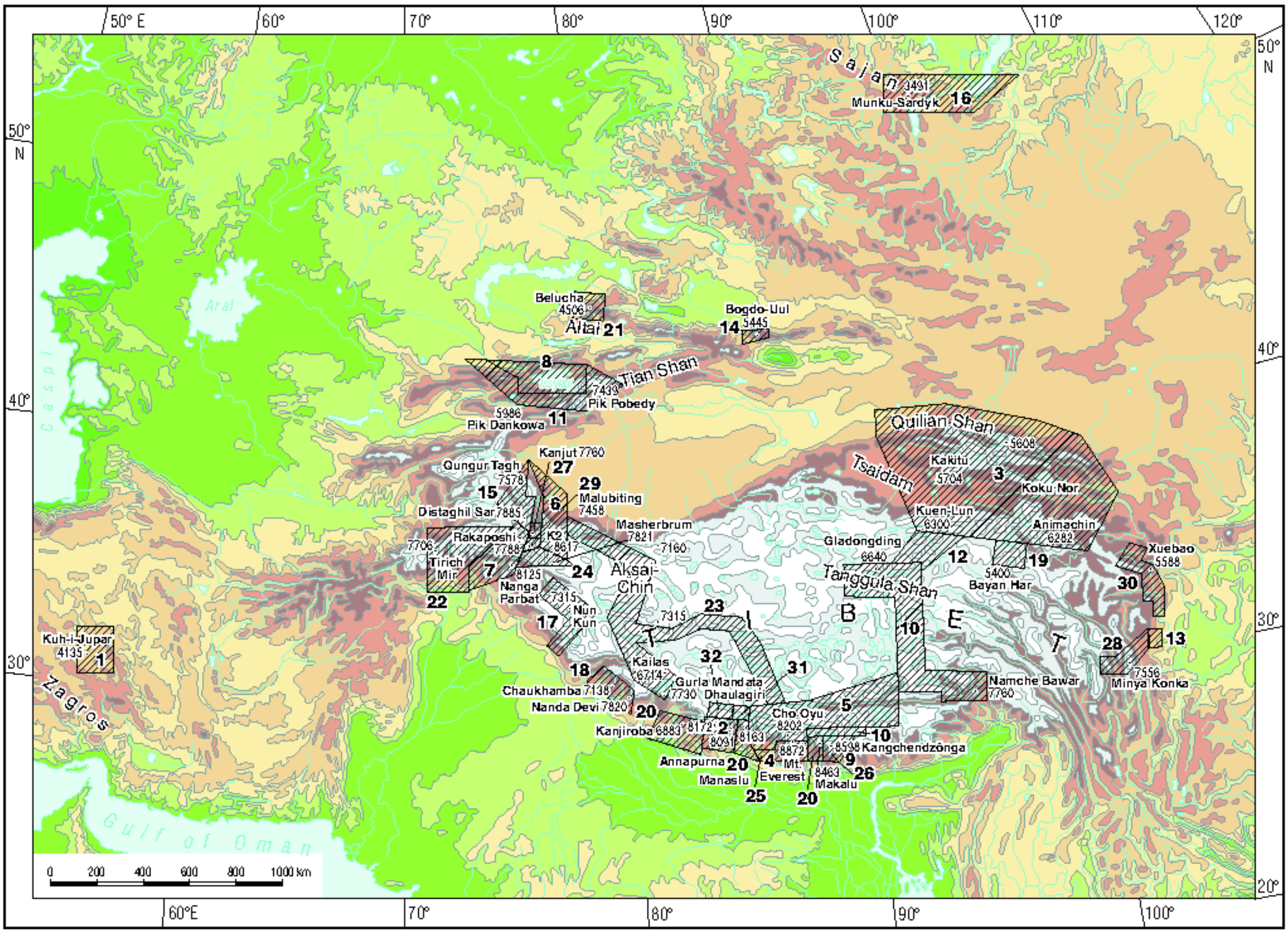


1: 1973, 1974 **2:** 1976, 1977, 1995, 1998, 2000, 2002, 2005 **3:** 1981, 1998 **4:** 1982, 2003 **5:** 1984 **6:** 1986 **7:** 1987, 1992, 1995, 2000 **8:** 1988 **9:** 1988/89
10: 1989 **11:** 1991 **12:** 1991 **13:** 1984, 1991 **14:** 1986, 1992 **15:** 1992, 2006 **16:** 1993 **17:** 1993, 1996 **18:** 1993, 2004 **19:** 1994 **20:** 1994/95, 2000, 2004, 2007
21: 1995 **22:** 1995 **23:** 1996 **24:** 1997, 2006 **25:** 1998 **26:** 1999 **27:** 1999, 2000 **28:** 2000 **29:** 2000 **30:** 2002 **31:** 2004, 2007 **32:** 2005

Fig. 1: Research areas in Central- and High Asia (Tibet and surrounding mountains) visited by the author. The study presented here introduces observations on the Pleistocene glaciation in the Zagros Mountains (area No.1).

Abb. 1: Untersuchungsgebiete des Autors in Zentral- und Hochasien (Tibet und umgebende Gebirgssysteme). Dieser Aufsatz beinhaltet Beobachtungen zur eiszeitlichen Gletscherbedeckung des Gebietes Nr. 1 im Zagros-Gebirge.

In January and February a 10 to 50 cm-thick snow cover is normal in the piedmont areas between 1650 and 2000 m asl. In March 1974 the uniform snow cover extended as far as 2450 m. A continuous snow cover regularly persists for more than one month above 2500 m and several months (between November and March) above 3000 m (Fig. 11) (KUHLE 1976a, 30/31, 1976b, Fig. 98, 154). In May 1973 camel nomads from the N-facing Hararun valley in the Lalezar massif told the author that in the confluence area of the tributary valleys about 3100 m asl the annual snow cover is c. 1 m thick.

On the summits of the Kuh-i-Hezar (4469 m) and -Lalezar (4374 m) several snowfields persist throughout the year (Fig. 12). In the only somewhat lower Kuh-i-Jupar the winter snow apers out completely with the exception of an avalanche accumulation at the foot of the shadowy NE wall (see above) at 3500 m (KUHLE 1976b, Fig. 124, 125).

Kerman metereological station (1650 m) recorded -4 to -5 °C average air temperature in December and January between 1950 and 1973. Here, in the lowest piedmont area, only the period from May till August is entirely free of frost. -12 to -14 °C are reached every year; the lowest value of -30.0 °C has been recorded in January 1973 (METEREOLOGICAL YEARBOOK 1950-1973). From these data one can extrapolate how much colder the arid-continental climate of the 2500 m higher mountain massifs is in winter. Even in the middle of summer freezing and thawing takes place on their summits nearly every day (for further details see KUHLE 1976a, 27-33). The average annual temperature in Kerman (1650 m) is 17.5 °C.

METHODS AND FURTHER INFORMATION AS TO THE UNDERSTANDING OF THE FINDINGS AND INTERPRETATIONS

Glaciogeomorphological observations in the research area (Fig. 1, No.1) have been mapped in detail. Locations of typologically unambiguous individual phenomena, i.e. glacier indicators, have been recorded with the help of numerous signatures (Fig. 3-11). In this study the significance of glacial striae, roches moutonnées and related features of glacial polishings like glacially streamlined hills or glacial flank polishings and abrasions is founded on the fact that they can be interpreted as glacigenic erosional forms (Fig. 3◗, 4◗ and ∩, 11● and x). Corresponding to the height of their position in the relief, i.e. up the valley flanks (Fig. 3, 4, 11) or even on mountain ridges or transfluence passes between two valleys (Fig.14 and 15 ➔), they provide evidence of a glacier filling up to the corresponding glacier level (Fig. 3 and 4 ---). This applies also to glacially triangular-shaped slopes (truncated spurs) (Fig. 3, 11 x). Here, segments of valley flanks between inflowing side valleys are concerned, which have been polished back glacigenically. At the same time they are elements of the larger "glacial trough" form (Fig. 3). According to roughnesses above, as e.g. wall gorges and gullies and a polish or abrasion line separating smooth and rough rock faces, the glacier trimline is recognizable (Fig. 3 ---). Corresponding observations can be made with the help of the trough cross section. The upper limit of the U-shaped part of the cross section has to be regarded as the minimum altitude of the glacial trimline (Fig. 3). Glacial horns are landforms of glacial erosion as well as the troughs. Horns are summits between two trough valleys, which received their significant steepness by glacigenic undercutting and back-polishing on two flanks (Fig. 11 x on the right side). They occur in mountain regions formerly occupied by glacier ice, giving evidence of a past valley glacier system. Also, there are strong gravitational mass movements on valley flanks over-steepened by glacier polishing, i.e. trough valley flanks. In many places disintegrating rock faces, as well as rock falls, are characteristic of past glacigenic forms. The typical postglacial reshaping of glacial troughs by fluvial undercutting of the valley flanks is a further factor which prepares rock crumblings on past flank polishings and rock falls. The widespread occurrence of these secondary features of erosion is characteristic of the development from a glacigenic trough valley to an interglacial V-shaped valley. Owing to this, it is a secondary characteristic of the past glacial relief. Gorge-like incisions are modifications of glacial troughs at a steep incline of the thalweg. Subglacial ravines cut into the floor of a glacial trough (Fig. 3 ↓) are indicators of subglacial meltwater erosion. Along the deepest valley courses they have been developed by High Glacial (LGP, LGM) activities and – when the snowline was uplifted – by Late Glacial activities along higher valley courses. In several mountain areas – and also in the Zagros – the latter also applies to cirques, because during the maximum of the pre-last and last glacial period the snowline was too low, so that cirques could not be formed in the highest mountains. Valley glaciers developed instead (Fig. 14, 15). In a position high above a fluvial thalweg and on a rock slope without a current fluvial catchment area the author found potholes as indicators of a former ice cover which, supra- or subglacially, chanelled the water needed for their development.

Accumulative glacier indicators, which may overlie the glacial erosive features include till with erratic boulders and/or large local boulders. The higher their position above the valley bottom, the greater the former thickness (Fig. 3 ■). The same applies to large boulders (erratic or non-erratic). Their edged, facetted or rounded form has been taken into consideration as an indicator of the nature of their transport. In addition to these ground moraines there are remnants of lateral and end moraines in these valleys (Fig. 6 retreating moraines). However, they have formed during the Late Glacial when the ELA (snowline) was much higher than in the maximum glaciations of the pre-LGP and LGP. The maximum glacier extent (Fig. 14, 15) is indicated by end moraines (Fig. 4 ■ ▼), ice marginal outwash ramps (IMR, transition cones, Bortensander) (Fig. 11 ▼, Fig. 5) and till (Fig. 10 ■, Fig. 7) as well as push moraines (Fig. 8 ▲, Fig. 12) in the mountain forelands (Fig. 5, 6, Fig. 4, 11). In many places the tongue basins are well preserved (Fig. 4-7,11). They are partly filled by younger outwash (Fig. 4, 8, 10, 11■, 5) deposited during the LGP and the Late Glacial. These sandurs reflect further regression of the glacier terminus (compare ice margin in Fig. 14 and Fig. 15). The sediment analyses: petrographical analysis, grain size analysis, determination of the position of boulders in the matrix and its positions in relation to the surrounding geomorphology (situmetrics) as well as the morphometric grain analysis provide proof of an extensive former glacigenic landscape. The content of erratics and also the carbonate content of the debris cover indicate that the material has been glacially transported. The sorting coefficient So (ENGELHARDT v. 1973) provides further evidence as to the differentiation of fluvial and morainic accumulations. Poor sorting is characteristic of moraine matrix. Accordingly, the bi/trimodal grain size distribution and the lack of sorting as well as the high percentage of glacially facetted, i.e. rounded and subround boulders provide evidence of moraine and especially ground moraine even up to very high positions in this steep valley landscape. Six photos and eight figures were chosen to document the Riss- and Würm glaciations (Fig. 14, 15) with – in relation to the aridity – their large dimensions. Combined with the two-dimensional, vertical representations in figures 1, 2, 6, 14 and 15, figures 5, 7 and 9 as well as Fig. 3, 4, 8, 10-12 from the oblique and horizontal perspective, give an impression of the three-dimensional arrangement of the indicators leading to the reconstruction of the glaciated area and the local ice thickness. The aim of this is a spatial proof-system based on the arrangement of the positions, so that Fig. 3, 4, 8, 10-12 and figures 5, 7 and 9, with their topographic profiles, complete the maps of the glacier areas (Fig. 14 and 15), also with regard to the indication of past glacier thicknesses. Apart from that, the reconstructed ice thickness provides local references as to the horizontal extent of the glacial cover. All indicators marked in the figures have been documented on the spot by analogue photos and photo panoramas (KUHLE 1974, 1976 Bd.II). In this study only six of these photos are shown as examples.

RESULTS OF THE GLACIOGEOMORPHOLOGICAL RECONSTRUCTIONS OF THE PAST GLACIERS

The maximum extent of the older glaciation (pre-LGP) in the Kuh-i-Jupar

Two Pleistocene glaciations can be identified by extensive frontal moraines (Fig. 4-6, 11). Both of them reach into the mountain foreland of the Kuh-i-Jupar. On the northern slope they are clearly divided into three older and two younger advance phases. Further recessional moraines are found in the catchment area of the piedmont glaciation (Fig. 6). The older glaciation is documented by very large-scale frontal moraine arcs, which are some tens to c. 110 m high and 10 to 13 km

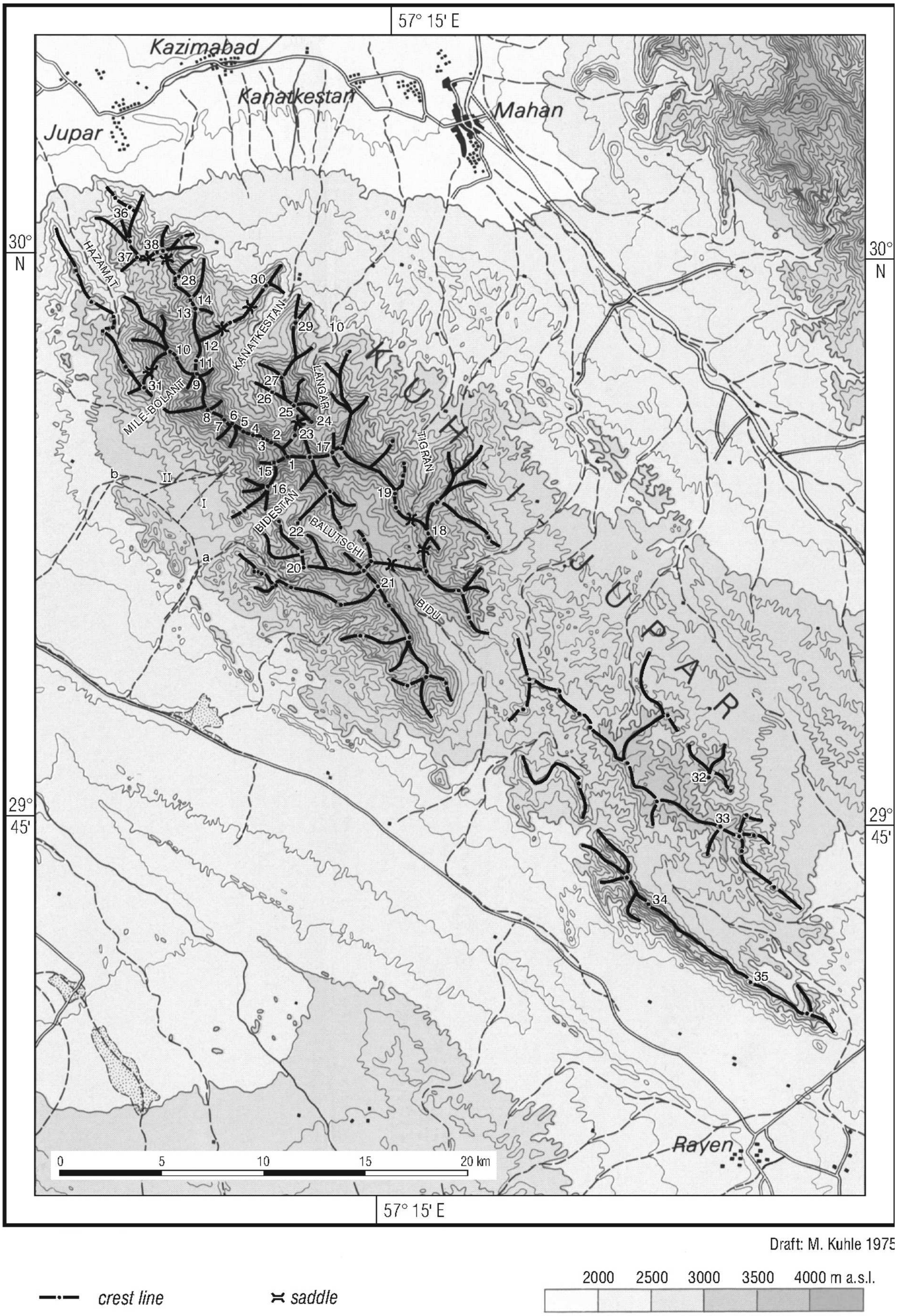
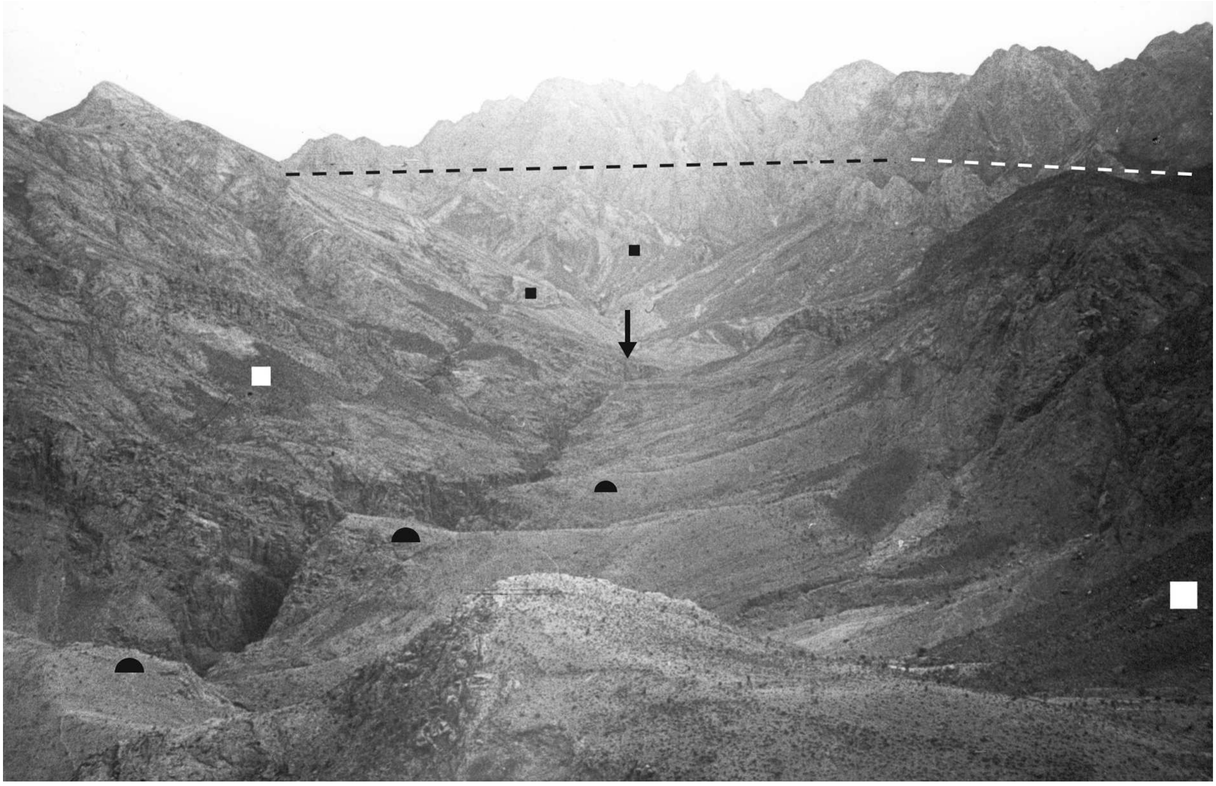


Fig. 2: Sketch map presenting the course of the Kuh-i-Jupar crest (cf. Fig. 1) and table of its highest summits.

Abb. 2: Skizze des Kuh-i-Jupar Kammverlaufs und Gipfelhöhen (vgl. Abb. 1). Nur die höchsten Gipfel sind dargestellt.



1	Kuh-Bidestan	4135 m
2	Kuh-e-Acharu	c. 4060 m
3	Talhuni	c. 3950 m
4	Seschach	c. 3860 m
5	Mil-e-Gare	c. 3840 m
6	Mil-e-Bozorg	c. 3850 m
7	un-named peak	c. 3810 m
8	Mil-e-Sarchu (Lakerar)	c. 4070 m
9	Mil-e-Bolant	c. 3960 m
10	Kuh-Sefäh	above 3800 m
11	Kuh Khochi	c. 3860 m
12	Kuh Jelal	c. 3800 m
13	Kuh-Solemat	c. 3770 m
14	Kuh-Arg	c. 3250 m
15	Tafke-Safid	c. 3850 m
16	Kuh-Amanussi	c. 3750 m
17	Kuh-Siachue (also Kuh Balutschi, Kuh-Kamuj)	c. 3850 m
18	un-named peak	3745 m
19	Kuh-Tigran (also Kuh Balutschi)	c. 3690 m
20	Schache Sawari	c. 3700 m
21	Kuh-Lokanderes (20 and 21 also Kuh Quermez)	3743 m
22	Kuh-Miche	c. 3500 m
23	N-satellite of Bidestan and Acharu	c. 3700 m
24	Talhuni-saddle	3420 m
25	Kuh-Tappe	c. 3750 m
26	Koffar-Kuh	c. 3540 m
27	Zartacht-Kuh	c. 3590 m
28	NW-summit of Kuh Arg	c. 3200 m
29	Ziach-Kuh	c. 3000-3100 m
30	Kuh-Karson	c. 2800 m
31	Kuh-je-Godare Hazamat	c. 3250 m
32	higher summit of Kuh-e-Dadashu	c. 3220 m
33	Kuh-e-Bondar	c. 3015 m
34	Kuh-e-Gazak	c. 3220 m
35	Kuh-e-Askaru	c. 2870 m
36	Kuh–Kalestan	c. 2600 m
37	Kuh-Chondere Chamsi	c. 2852 m
38	Zar-Kuh	c. 2960 m

I = main meltwater discharge on the southern slope during the older glaciation (pre-LGM).
II = main meltwater discharge on the southern slope during later times and today.
a and b = position of the two large glacier outlets on the southern slope during the older glaciation (pre-LGM).

Fig. 3: View from the Kuh-i-Jupar N-slope at 2870 m towards the uppermost catchment area (No.1 = Kuh-i-Bidestan; locality see Fig. 2 No.1) of a classical glacigenic trough valley at 4135 m. Today it is completely free of ice and even snow (locality see Fig.2; Kanatkestan). The structural asymmetry of the valley result-ing from the westward dipping massive limestone is almost totally transformed by the glacial U-shaping. (◗) = glacially polished bedrock thresholds; (■) = ground moraine remnants; (---) = the highest Pleistocene glacial level verifiable by rock polish. As for the names and altitudes of summits 1, 3-7 and 25 see Fig. 2. From 2800 m downwards a narrow subglacial meltwater channel (↓) has been cut into the rock bottom of the trough, suggesting an equilibrium line altitude (ELA) position a few hundred metres higher than suggested by the foreland moraines (Fig. 4-6, 8, 10, 11). Normally subglacial meltwater erosion is found 100 m to 300 m below the equilibrium line (ELA). Analogue photo M. Kuhle, 12.06.1973.

Abb. 3: Aus der Kuh-i-Jupar-Nordabdachung aus 2870 m ü.M. zum höchsten, max. 4135 m hohen, Einzugsgebiet (No. 1 = Kuh-Bidestan; Lokalität siehe Abb. 2 Nr. 1), eines klassischen glazigenen Trogtals gesehen. Heute ist das Tal vollständig eis- und sogar schneefrei (Lokalität siehe Abb. 2; Kanatkestan). Die aus dem nach Westen einfallen der Bänke des massigen Kalksteins resultierende strukturelle Talasymmetrie ist nahezu vollständig durch die glazigene Trogtalbildung überformt. (◗) = glazigen abgeschliffene Trogschwellen im anstehenden Fels; (■) = Grundmoränenreste; (---) = der höchste durch eine Schliffgrenze nachweisbare eiszeitliche Gletscherpegel. Die Namen und Höhen der Gipfel 1 und 3-7 sowie 25 siehe Abb. 2. Unterhalb 2800 m wurde eine enge subglaziale Schmelzwasserrinne, d.h. Klamm (↓), in den anstehenden Trogtalboden eingeschnitten. Sie belegt eine spätglaziale Schneegrenzhöhe (ELA), die einige hundert Meter über der die durch die Endmoränen im nördlichen Gebirgsvorland bewiesen ist, verlaufen ist. Generell setzt derartige subglaziale Schmelzwassererosion 100 bis 300 m unter der lokalen Gletscherschneegrenze (ELA) ein. Analogfoto M. Kuhle, 12.06.1973.

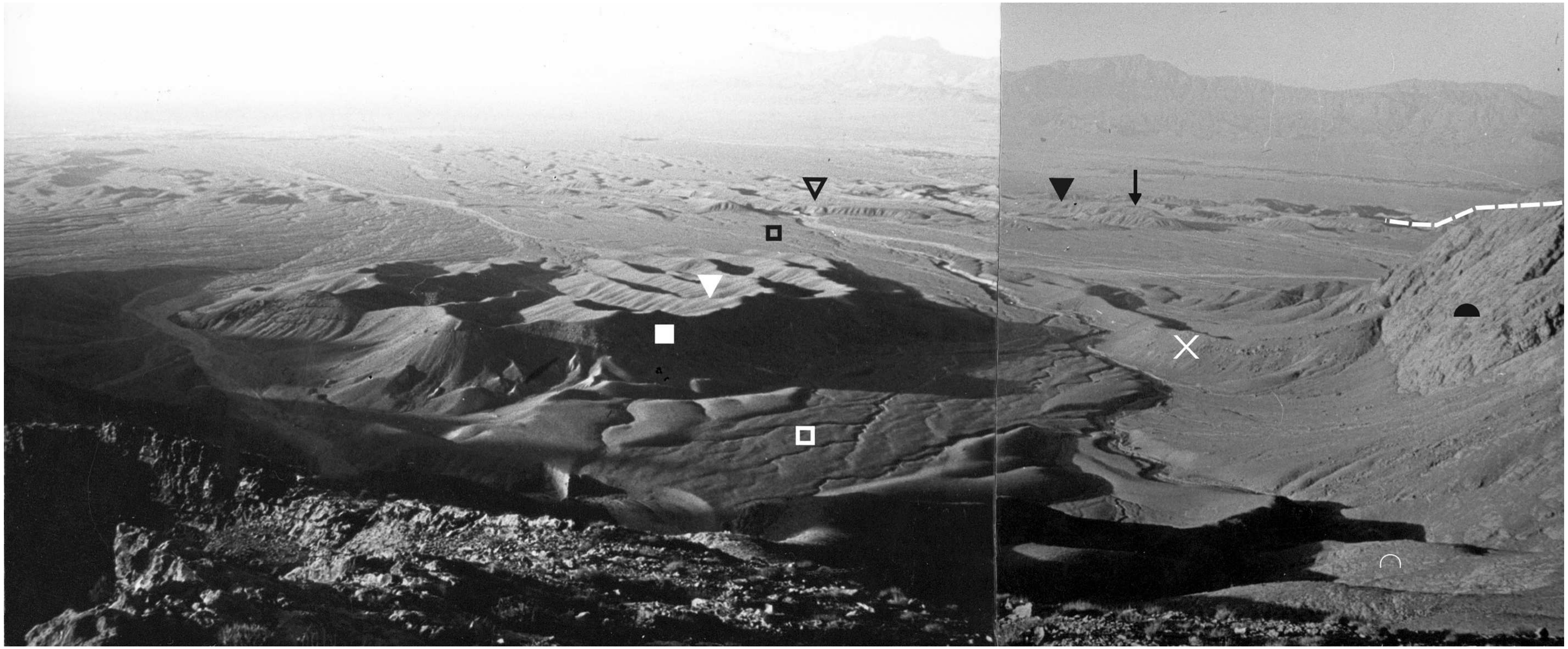


Fig. 4: View from 2650 m into a glacier tongue basin surrounded by ice marginal ramps (IMR) (▼ white and black) (cf. Fig. 7 and 9) in the northern foreland of the Kuh-i-Jupar (cf. Fig. 5, 6). An arcuate lateral moraine (X) is attached to the orographic right-hand mountain spur (◗). The material accumulated in the foreland begins at 2200 m asl (□ white) and extends down to 1650 m in the basin of Kerman in the background. Ice marginal ramps (▼ white) occur as transitional cones (Fig. 7 Type B) partly superposing the frontal moraines (■) and extend with a slope around 11° down into the foreland. Here, they disappear below the gently-sloping proglacial outwash plain (□ white). Seen from there, the ridges of the ice marginal ramps (IMR) (▼ white), which are cut and separated from each other by incised small ravines arranged at right angles to the forming ice edge, extend up to the mountains and cut out with a precipitous exposure at the edge of the glacier tongue basins. Previously they were misinterpreted as the remains of gravel fans eroded into glacial-tongue-like features. However, in this case there was no explanation of their change of material from glacial diamictite to sorted outwash plain sediments (Fig. 7-9), nor of their steep surface gradient implying a former considerable thickness of several hundreds of metres. The hills in the middle ground (▼ black) lie at 2050-1900 m asl. They are remains of the ice marginal ramps of the foreland glaciation during the pre-LGP? (Riss period) (see Fig. 5). (■ and X) are end moraines of the younger glaciation (LGP). (□ white) are Late Glacial outwash plains. (□ black) show younger outwash plains (LGM), dammed-up by old moraines (pre-LGP) (▼ black). (▽) is the locality of the compression in Fig. 10; (↓) is the position of large erratic limestone- and Kerman-conglomerate boulders on neogene sandstone bedrock. (∩) are glacially polished areas of limestone-rock. (---) marks the ice level of the pre-LGP glaciation. Analogue photo M. Kuhle, 09.07.1973.

Abb. 4: Aus 2650 m Höhe gesehenes Zungenbecken, umgeben von „ice marginal ramps“ (IMR) (= Bortensander) (▼ weiß und schwarz) (vgl. Abb. 7 und 9) im nördlichen Vorland des Kuh-i-Jupar (vgl. Abb. 5, 6). Eine bogenförmige Ufermoräne (X) setzt am orographisch rechten Bergsporn (◗) an. Das im Vorland akkumulierte Material setzt in 2200 m ü.M. an (□ weiß) und reicht hinunter bis auf 1650 m ü.M. im Kerman-Becken im Hintergrund. Bortensander (IMR) (▼ weiß) in Form von Übergangskegeln (Abb. 7 Typ B) überdecken teilweise die Endmoräne (■) und erstrecken sich mit einer Hangneigung von 11° ins Vorland hinaus. Hier tauchen sie unter der leicht geneigten Gletschertorschotterflur (□ weiß) ab. Vom Vorland aus bergwärts gesehen reichen die Rücken der Bortensander (IMR) (▼ weiß), die durch kleine Täler rechtwinkelig zum vorzeitlichen Eisrand zerschnitten und voneinander getrennt werden, bis zu den Endmoränen (■) und enden mit einem steilen Aufschluss am Rand des Zungenbeckens. Bisher wurden sie fehlinterpretiert als Reste von großen Schuttkegeln, welche zufällig in gletscherzungenförmiger Weise erodiert worden sind. Allerdings gab es bei dieser Möglichkeit weder eine Erklärung für den Materialwechsel von glazigenen Diamiktiten zu sortierten Schotterflursedimenten (Abb. 7-9), noch für ihr steiles Oberflächengefälle, welches eine erhebliche Mächtigkeit von mehreren Hundert Metern impliziert. Die Hügel im Mittelgrund (▼ schwarz) liegen in 2050-1900 m ü. M. und sind Überreste von Bortensandern (IMR) der Vorlandvergletscherung während der Riss-Periode (pre-LGP) (vgl. Abb. 5). (■ u. X) sind die Endmoränen der Jüngeren Vereisung (LGP). (■ weiß) sind spätglaziale Sander (Gletschertorschotterfluren), (■ schwarz) sind jüngere Sander (Gletschertorschotterfluren) (LGP), die von den alten Moränen (pre-LGP) (▼ schwarz) aufgestaut worden sind. (s) ist die Lokalität der Stauchung auf Abb. 10; (↓) ist die Position von großen erratischen Kalk- und Kerman Konglomeratblöcken auf anstehenden neogenen Sandsteinen. (◗) sind glazigen glattgeschliffene Kalkfelsflächen; (---) ist der Eispegel der Riss-Vereisung (pre-LGP). Analogfoto M. Kuhle, 09.07.1973.

long (Fig. 6; 11). These moraine ramps consist of diamicton of a clayey-silty to -sandy matrix into which polymictic, isolated boulders of biomicritic limestone and Kerman conglomerate are embedded, both of which outcrop in the Kuh-i-Jupar massif (Fig. 11). The largest boulders reach a size of c. 6 x 6 x 5 m (Kuhle 1976b, Abb. 33, 41). They lie in the mountain foreland, 4.8 to 6.5 km beyond the mountain foot, i.e. beyond the Darne Kanatkestan valley exit (Fig. 2), on Neogene sandstones and conglomerates which form the underlying substratum down to c. 1900 m asl. Accordingly, the large boulders in the end moraine ramps are erratics. The three old moraine ramps are dissected by meltwater paths in continuation of the mountain valleys (Fig.4 ▼; Fig. 5 +; Fig. 6 south of Kanatkestan settlement). The flanks of these moraine valleys expose glacigenic push zones (e.g. Fig. 5 +). The glaciotectonic deformations can very clearly be identified in the glaciolimnic silts and clays, in part also varved clays (Fig. 10). The varved clays were deposited when the ice margin first started to melt back. Apparently this deposition took place simultaneously in several tongue basins. Afterwards, during the second advance of the older glaciation (pre-LGP) they were thrust by the ice margin. During the third ice advance of the older glaciation for a second time the earlier deposited glacio-limnic clays were glaciotectonically deformed, but no large-scale thrust features developed (Fig. 10).

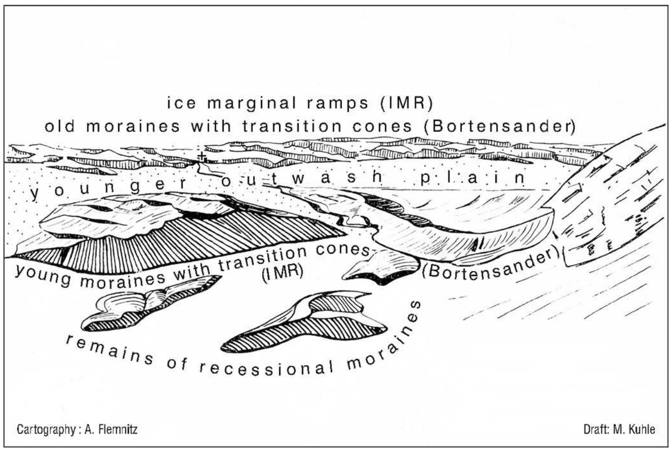


Fig. 5: Schematic sketch of the northern Kuh-i-Jupar foreland with end moraines and ice marginal ramps (IMR) of the older (pre-LGP) and younger (LGP) glaciation (see Fig.4). + marks the exposure of the push moraine in Fig. 10 (cf. also Fig. 6).

Abb. 5: Schematische Skizze des N-lichen Kuh-i-Jupar-Vorlandes mit den Endmoränen und Ice marginal Ramps (IMR) (= Bortensander) der Älteren (pre-LGPM) und Jüngeren (LGP) Vereisung (s. Abb. 4). + markiert den Stauchmoränenaufschluss von Abb. 10. (vgl. auch Abb. 6).

The three end moraine ramps are followed by outwash aprons (inclined 7 to 15°, Fig. 8) (Kuhle 1984, 1989, 1990). Distally their deposits are increasingly better sorted and layered (cf. Fig. 7). In the following the whole form of a frontal moraine and an outwash apron is referred to as "Bortensander", i.e. ice marginal ramp (IMR; cf. Fig. 5). It is marked by the change from isolated polymict coarse boulders "floating" chaotically and isolated in a fine-grained matrix to a distally well-sorted glaciofluvial, steeply inclined gravel body (Fig. 7).

Due to the fact that in relation to the glacier accumulation area in the interior of the Kuh-i-Jupar massif the piedmont glaciation of the northern mountain foreland (cf. Fig. 15) is very extended (p. 11 ff), the ice margin did not react to minor fluctuations of the snowline. So, an uplift of the ELA (Equilibrium Line Altitude) after the glacier advance only seems to have resulted in decreasing ice thickness, but not in a glacier retreat. This led to truncation of the frontal moraines (Fig. 7B), which initially were up-thrust by the advancing ice margin (Fig. 7A). The advancing ice margin was inevitably – for this has caused the advance – the thickest. When ice thickness decreased, the supra-glacial meltwater, first seeping through the frontal moraine (Fig. 7A), finally removed it and displaced it by outwash deposits, resulting in the observed horizontal change of material found in the IMR. This process also resulted in truncation of the primarily steeper glaciofluvial layers in the distal area of the IMR and to the covering of this discordance by flatter layers of gravel (Fig. 7B right half). In the area of the old moraines up to three different levels of the former ice surface can be identified in exposures in the distal parts of the IMR (Fig. 8 and 9).

In the southwest-slope of the Kuh-i-Jupar two glacier lobes reached down into the foreland (Fig. 2, Milebolant; Fig. 6, 15). One glacier flowed down from the Dare Balutschi and Dare Bidestan in the east (Fig. 2), but no end moraine has been preserved to mark its lowest ice marginal position (Fig. 15 ?). To the west of this valley exit a 30-40 m-high old end moraine ridge runs down to the southwestern foothill chain at 2550 m (Fig. 6: southeasternmost moraine with IMR). There, the piedmont lobe, which flowed down from the high summits of the Kuh-i-Jupar main ridge (Fig.2 between No.1 and 8) and met the foothill chain, had been diverted up to the end of this chain in a westward direction. Its tongue basin as well as its marginal area has been strongly reworked by glaciofluvial and fluvial processes. Here in the W, the southwestern piedmont glacier of the Kuh-i-Jupar has reached its outermost marginal position at c. 2450 m asl during the older glaciation (Fig. 15, taken near the western margin in the south).

The maximum extent of the younger glaciation (LGP) in the Kuh-i-Jupar (Kuhle 1974, 1976a,b)

On the northern slope the glaciers of the younger glaciation flowed down to 2160-2200 m asl. They reached 1.5-3 km into the northern mountain foreland (Fig. 14). In contrast to the old moraines (pre-LGP), which show softer (Fig. 10, 11) and washed-out landforms (Fig. 8, 4 ▼), the 100-130 m-high young moraines are well preserved and have fresh steep slopes (dip of the inner slope 20-40°) (Fig. 4x and ■). The larger boulders on the young moraines are over 8 m long; the biggest boulder measured 20 x 10 x 9 m, i.e. it was house-sized (Fig. 4 on the right of x).

The older tongue basins within the old moraines in the lower mountain foreland have partly been buried by (glaciofluvial) outwash fans or sandurs of the younger glaciation (Fig. 5, 7). In turn, younger Late Glacial, i.e. post-LGM outwash plains were deposited in the tongue basins of the younger glaciation (LGP) (Fig. 7 tongue basin) partly burying the remains of recessional moraines (Fig. 5).

On the south-western to southern slope the ice flowed down in several tongue basins into the mountain foreland. The lowest two tongue basins, fringed by 20-25 m-high end moraines,

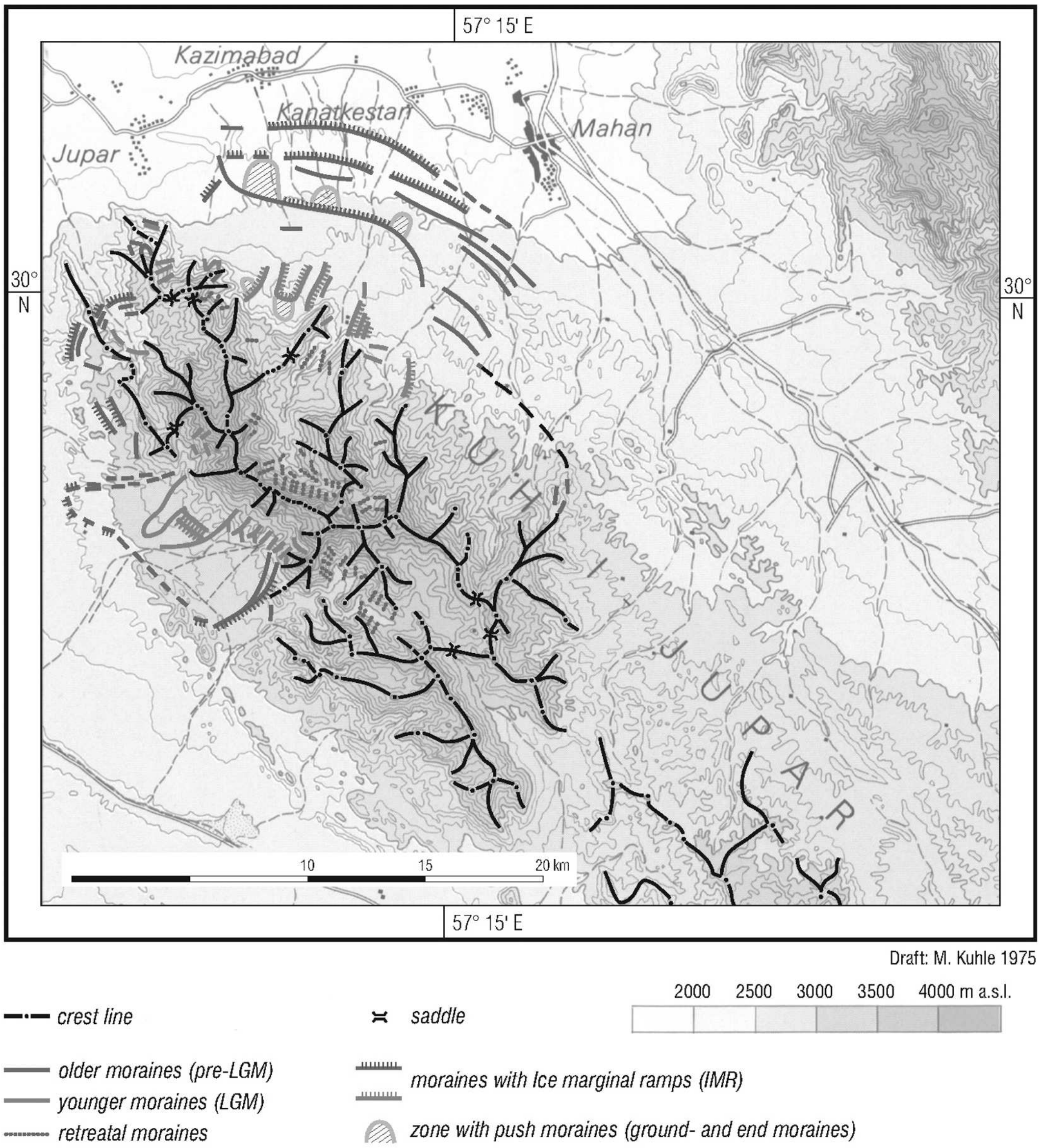
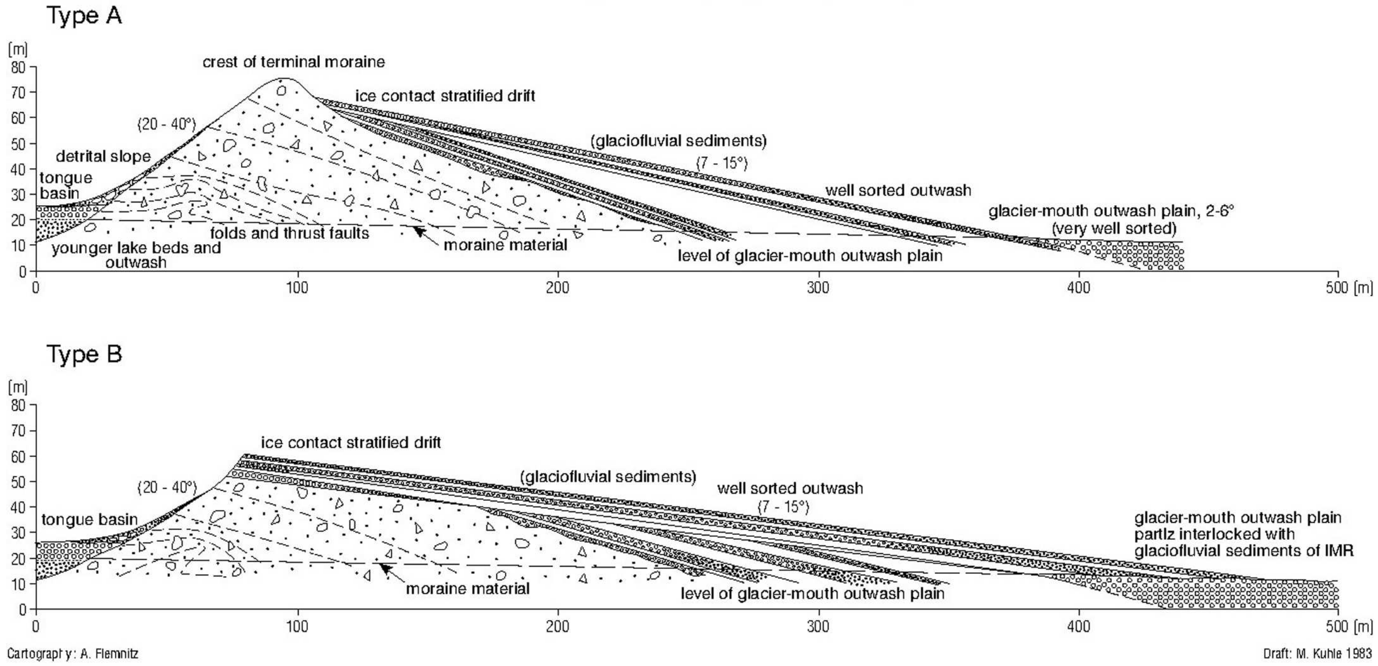


Fig. 6: Moraines and ice marginal ramps (IMR) of the Würm (LGP) and Riss (pre-LGP) glaciations in the Kuh-i-Jupar (SE Zagros, South of Kerman, Iran); see Figs. 4, 5, 7-11.

Abb. 6: Moränen und ice marginal ramps (IMR) (= Bortensander) der Würm- (LGP) und Riss- (pre-LGP) Vereisungen im Kuh-i-Jupar Gebirge (SE-Zagros, südlich von Kerman, Iran); s. Abb. 4, 5, 7-11.



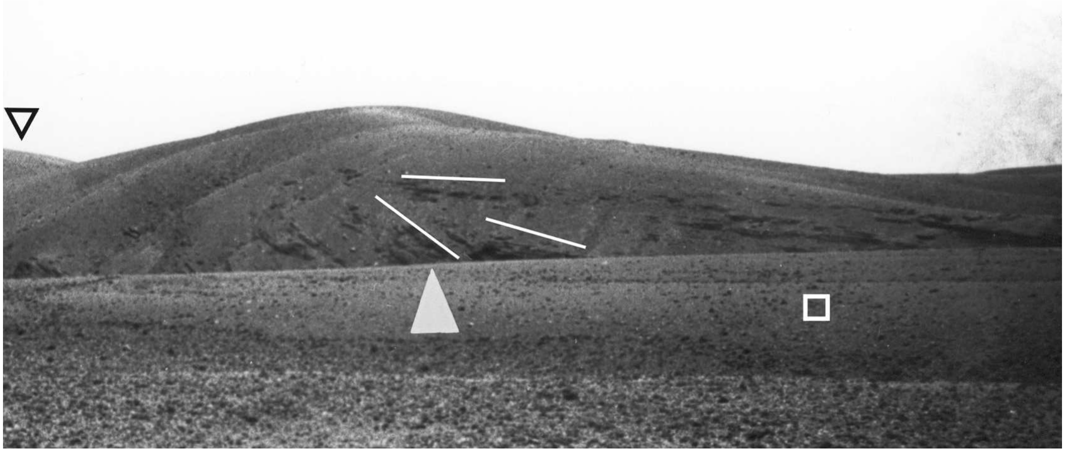


Fig. 8: At 1940 m asl, view from the Aab Kanatkestan creek (foreground), 2.5 km SSW of the Kanatkestan settlement (Fig. 6), 5.9 km from the northern foot of the Kuh-i-Jupar, towards the SW (225°) onto an IMR (▲), which is connected to the oldest and lowest pre-LGP end moraine (▽). The exposure of the morainic material (▲), which has been glaciofluvially flushed out down from the glacier margin, shows three slopes of the stratum (-). The lowest stratum is the steepest one whilst the uppermost stratum is the flattest one. The latter runs nearly parallel to the land surface at an angle of 9-11°. In the schematic presentation in Fig. 9 this exposure is seen in window section 2. (□) marks the proximal outwash gravel deposited by one of the pre-LGP meltwater creeks. Analogue photo M. Kuhle, 03.04. 1974.

Abb. 8: Aus 1940 m ü.M. vom Gerinne des Aab Kanatkestan (Vordergrund), 2,5 km SSW-lich der Siedlung Kanatkestan (Fig. 6), 5,9 km vom nördlichen Gebirgsfuß des Kuh-i-Jupar entfernt gen SW (225°) auf einen Bortensander (IMR) (▲) gesehen, der an die älteste und tiefste pre-LGP-Endmoräne (▽) anschließt. Der Aufschluss des vom Gletscherrand herab glazifluvial verspülten Moränenmaterials (▲) zeigt drei Schichtneigungen (-). Die unterste ist die steilste und die oberste die flachste. Letztere verläuft nahezu oberflächenparallel mit einer Neigung von 9-11°. Dieser Aufschluss befindet sich in der schematischen Darstellung in Abb. 9 im Ausschnittfenster 2. (□) ist die Gletschertorschotterflur eines der risszeitlichen (prä-LGP) Gletscherschmelzwasserbäche. Analogfoto M. Kuhle, 03.04. 1974.

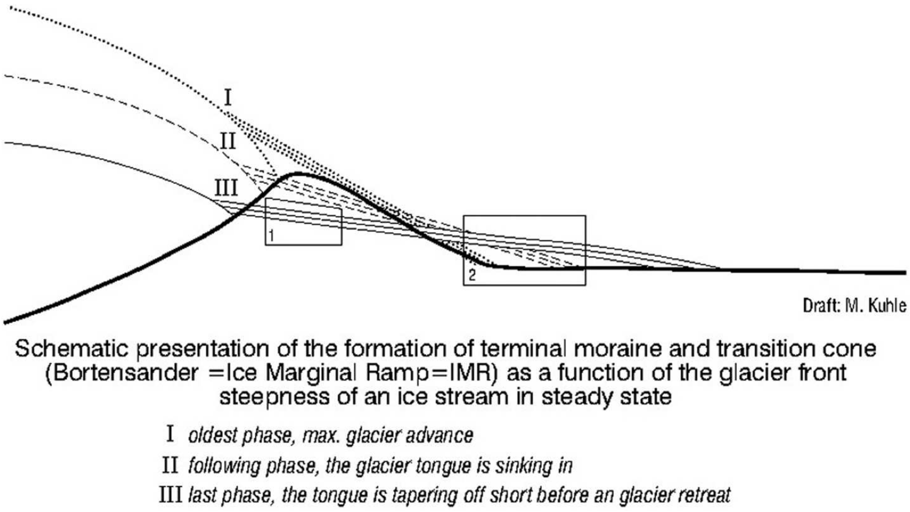


Fig. 9: Despite a climate-controlled rise of the ELA (snowline) the ice margin of the piedmont glacier in the northern Kuh-i-Jupar foreland remained in the same position (cf. Fig. 6 and 15). However, the ELA rise caused downwasting of the glacier surface. Consequently, the dip of the meltwater deposits changed from steep (I) to low angle (III). The oldest Phase I corresponds to Type A of the IMR in Fig. 7; Phases II and III to Type B in Fig. 7. Section 1 shows the left part of Type B in Fig. 7; section 2 the right part of Type B in Fig. 7. Section 2 depicts part of the area of the pre-LGP ice marginal ramps in Fig. 8.

Abb. 9: Trotz klimabedingter Anhebung der ELA (Schneegrenze) blieb der Eisrand des Piedmontgletschers im nördlichen Vorland des Kuh-i-Jupar während der Älteren Vereisung (prä-LGP) in gleicher Grundrissposition an der Endmoräne liegen (Abb. 6 und 15). Die ELA-Anhebung wirkte sich jedoch durch das Hinabschmelzen der Gletscheroberfläche aus. Dadurch veränderte sich der Schüttungswinkel des Schmelzwassers von steil (I) zu flach (III). Die älteste Phase I entspricht Typ A des IMR in Abb. 7; die Phasen II und III dem Typ B in Abb. 7. Ausschnitt 1 zeigt den linken Abschnitt von Typ B in Abb. 7; Ausschnitt 2 den rechten Abschnitt von Typ B in Abb. 7. Ausschnitt 2 ist aus dem Bereich der prä-LGP-„Ice marginal ramps“ auf Abb. 8 abgebildet.

Fig. 7: Types of ice marginal ramps (IMR) representing two stages of development. Type B evolves from Type A and, being the last stage, inevitably occurs more frequently; see Figs. 4, 5, 8, 9.

Abb. 7: Zwei Typen von „ice marginal ramps“ (IMR) (= Bortensander), die verschiedene Entwicklungsstadien repräsentieren. Typ B entwickelt sich aus Typ A und tritt als letztes Stadium zwangsläufig häufiger auf; s. Abb. 4, 5, 8, 9.

reach down to 2530 (2500- 2550) m asl (Fig. 6, 14). The most extended Mil-e-Sarchu S/SW glacier, which has developed the lowest ice marginal positions, flowed down from the 1450 m high, 40-50° steep limestone flank of the Mil-e-Sarchu (Fig. 2 No. 8 and 7). It has overflowed a counter slope of 60-70 m at the foot of the mountain, formed by a rock barrier of Kerman conglomerate (ck, see above). On this rock barrier a 40-70 m-thick moraine complex was found including up to 3.5 m-long limestone erratics from the Mil-e-Sarchu superstructure.

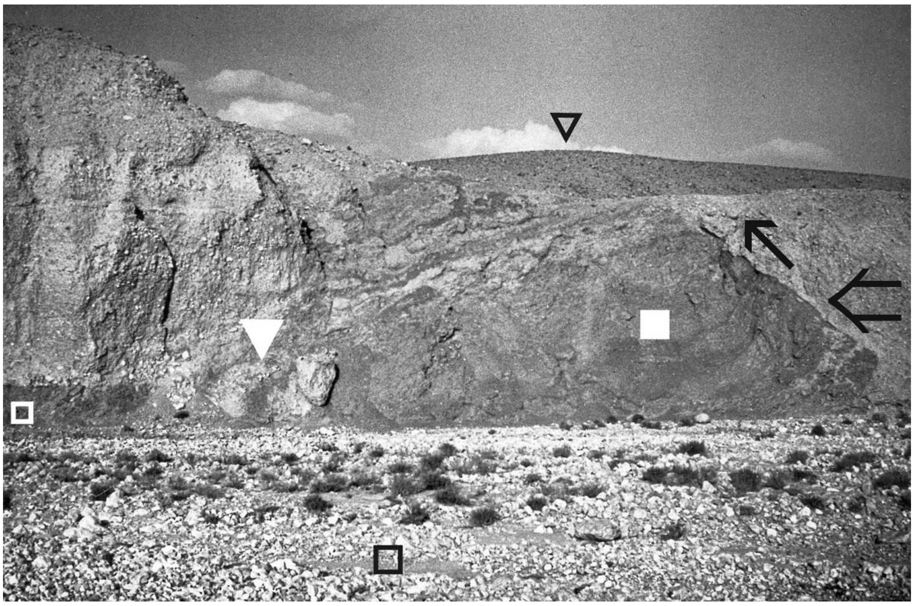


Fig. 10: View facing ENE (70°) looking onto a glacigenic thrust in the youngest old moraine circlet (pre-LGP) at 2050 m asl, which here is exposed by a small transverse valley (□ black = gravel floor of the valley) N of the Kuh Karson (Fig. 2, No. 30) (for location see Fig. 5+; Fig. 4 ▽). A glacier tongue coming from the S (from the right) (⇛), has thrust the stillwater sediment, which on the left is still undisturbed (□ white), to a visible thickness of 1.5 m (■). At the same time, front moraine (⇛) has been thrust (➚) against the compressed limnites (■) and metres-sized packings of boulders and gravels were compressed in (▼). (□ white) has been deposited within an older glacier tongue basin. (▽) is the corresponding frontal moraine ridge with polymict, metres-long erratic boulders of limestone- and Kerman-conglomerate. Analogue photo M. Kuhle, 29.09.1973.

Abb. 10: Nach ENE (70°) auf eine in 2050 m ü.M. gelegene glazigene Stauchung im jüngsten Altmoränenkranz (Riss, prä-LGP) gesehen, die hier von einem Moränendurchbruchstälchen (□ schwarz ist seine Schottersohle) nördlich des Kuh Karson (Abb. 2, Nr. 30) aufgeschlossen ist (Lokalität s. Abb. 5 +; Abb. 4 ▽). Die Gletscherzunge von S (rechts) kommend (⇛), stauchte das links (□ weiß) noch ungestörte, in einer Mächtigkeit von 1,5 m sichtbare Stillwassersediment, auf (■). Dabei wurde die Stirnmoräne (⇛) gegen die aufgestauchten Limnite (■) aufgeschoben (➚) und metergroße Block- und Schotterpakete eingestaucht (▼). (□ weiß) wurde innerhalb eines älteren Gletscherzungenbeckens abgelagert. (▽) ist der zugehörige Stirnmoränenrücken mit polymikten, meterlangen erratischen Kalk- und Kerman-Konglomeratblöcken. Analogfoto M. Kuhle, 29.09.1973.

The glaciogeomorphological indicators in the interior of the Kuh-i-Jupar mountains

In the glacial feeding and denudation area (KUHLE 1976) up in the Kuh-i-Jupar, many indicators of former glaciation are found. For instance, the Darne Kanatkestan (Fig. 2) is a classically glacial trough valley (Fig. 3). It was shaped by the largest glacier, the Kanatkestan, which during the older glaciation (pre-LGP) was 17 km long and during the younger glaciation (LGP) was still 10-12 km long. It extended well into the mountain foreland (Fig. 14 and 15 taken south of Kanatkestan). The rock base, polished by scouring, has been glacially over-deepened. This resulted in the development of three thresholds (Fig. 3 ◗). Remnants of moraines have been preserved only sporadically (Fig. 3 ■). The preserved abrasion limit (---) suggests a maximum ice thickness of 300 m in the upper valley section of the Darne Kanatkestan, the Dare Karson, which increased to 550 m in the middle to lower Darne Kanatkestan. This maximum ice thickness is also documented at a transfluence pass at 2700-2800 m with classically rounded landforms on the orographic left flank of the valley SW of the Kuh-Karson (Fig. 2 No. 30, Fig. 7 ↑ ↑ on the right). The ice has crossed it and then flowed down to the tongue basins and end moraines situated in the mountain foreland west and north of the Kuh-Karson (Fig. 4). Down-valley below 2800 m a ravine has been cut subglacially into the bedrock of the trough valley bottom (Fig. 3 ↓). The Pleistocene ELA was at 2800-2850 m asl during the older glaciation and at 2880-2980 m during the younger glaciation (see p. 13 ff). Only from this altitude downwards could enough meltwater with sufficient erosive capacity (cavitation corrasion) accumulate under the glacier and then drain subglacially in a concentrated form.

A 1.4 m-deep and over 1 m-wide pothole provides further evidence of former glaciation (KUHLE 1991). It has formed in Cretaceous limestone at 2570 m asl at the transfluence pass mentioned above (Fig. 4 foreground) down into the mountain foreland (KUHLE 1976 Abb. 78). Its glacial origin is deduced from its position on a limestone slope that shows no traces of any drainage channel.

In addition to the evidence cited, the former glaciation of the Darne Kanatkestan (Fig. 2) is also proved by erratics. On the orographic right flank of the valley up to 2 m-long boulders of Kerman conglomerate (ck) lie on limestone bedrock at 2675 m asl, 2.5 km up-valley from the valley exit into the mountain foreland and 270 m above the thalweg. This material outcrops on the opposite valley flank up-valley at an altitude of 3200-3300 m asl and at a minimum distance of 3.5-4 km from the erratics. If one does not want to assume that the valley was filled with debris up to 270 m, the boulders must have been laid down by an at least 270 m-thick Darne Kanatkestan valley glacier. At the same time the good preservation of the fragile conglomerate boulders suggests transport during the younger glaciation.

Not only the trough valleys, subglacially developed ravines and numerous cirques (KUHLE 1974, Photo 10, 1976, Abb. 90, 97, 155), potholes and erratic boulders but also most of the characteristic abrasional and polished landforms in the Kuh-i-Jupar massif are well preserved. In the area of the large transfluence pass on the orographic left side of the Darne Kanatkestan and the 600 m-high junction threshold (Fig. 2 between No. 14 and 30), with its western margin, well-devel-oped roches moutonnées are preserved (KUHLE 1976, Abb. 76, 80). Here, perfect polish lines (ibid. Abb. 70) and different forms of flank abrasion (Fig. 4 ◗ and ∩) (ibid. Abb. 67, 69, 72, 73, 75), e.g. with classic band polishings of outcropping edges of the strata (Fig. 11 x) (ibid. Abb. 75), can also be found. At the northern margin of the mountain, at the valley exit of the Dare Langar, a rock barrier (Riegel) had been partially eroded, leaving a glacial horn (Fig. 11 x on the right) rising above the glacigenically polished rock surfaces (Fig. 11 ●). During the older glaciation (Riss = pre-LGP = Stage-I after KUHLE 1982, 150-170; 1998, 82 Tab.1) the rock barrier had been completely overflowed. During the younger glaciation (Würm = LGP = Stage 0 after ibid.) its summit towered above the glacier level, which in comparison to the older glaciation had dropped, so that its slopes have been undercut and the horn accentuated by flank polishing (Fig. 11 x on the right).

The former glaciation of the Kuh-i-Lalezar and Kuh-i-Hezar massifs

In the Kuh-i-Lalezar massif (4374 m, 29°16' to 29°31' N and 56°38' to 56°53' E) situated c. 70 km south-southwest of the Kuh-i-Jupar, three stages of the lowest ice marginal positions are preserved in the largest north-facing main valley, the Hararun (Laleh Zar) valley (Fig. 12). The highest, southernmost one is at c. 3320 m asl, the middle one at 3090 m and the lowest one is furthest in the northwest at c. 2580 m asl (29°32'46.43" N 56°43'07.53" E), southwest of the c. 2700 m high Gudar-i-Pashimani (also Langbur) pass. Probably the lowest ice margin even reached down to 2420 m asl. This is deduced from landforms and sediments (lateral moraines and till), which at this altitude turn into an end moraine. This would mean a lowest ice marginal position c. 8.5 km further down-valley (29°36'55.85" N, 56°38'22.71" E). More field investigations are needed to confirm this assumption.

At the ice marginal position at c. 2580 m asl hummocks of coarse blocks have been accumulated. The large, sometimes even rounded, but mostly sub-rounded and facetted blocks consist of brown- reddish volvanic rocks from the valley head (Fig. 12). The largest ones are several metres-long, whilst most of them measure 40-80 cm in diameter. Their dark brown to black ferromanganese crusts give evidence of their dislocation dating back thousands of years. Their position does not allow any alternative interpretation for the origin of the hill-shaped diamictic accumulations with their fine-grained matrix but to explain them as glacial landforms. Because of the topographical situation, damming of lakes at the valley head, debris flows or sudden outbursts of glacier lakes from the upper catchment area can be ruled out. Currently a merely 2 m-wide creek flows in the valley. Only during the snowmelt it is much wider. Further up-valley the valley floor consists of till which also contains large, subrounded blocks (Fig. 12). In the fields of the Hararun settlement (also Laleh Zar) about 2740 m asl, i.e. still within the lowest tongue basin, till-covered rock ridges have been mapped. According to these observations the corresponding valley glacier, the Hararun glacier, must have been c. 25 km long. In the upper course of the valley tills and landforms of glacigenic abrasion (glacier polish) have been

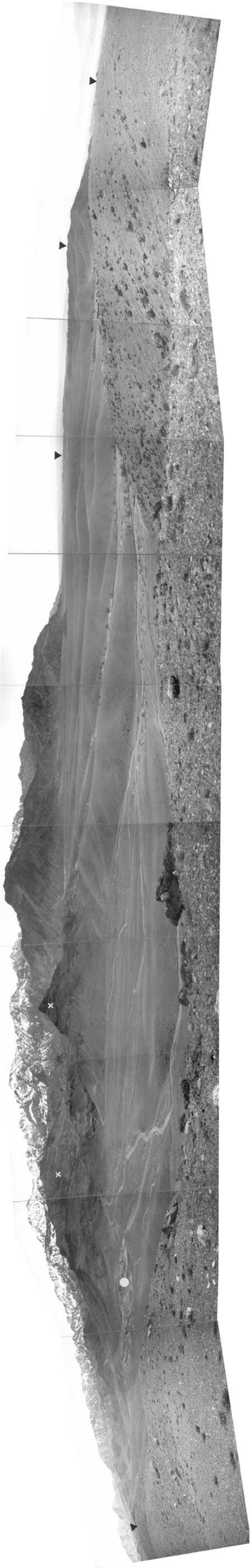


Fig. 11: At an altitude of 2310 m, 0.7 km SE of the settlement of Karnuj, view from the youngest old moraine circlet (pre- LGP) (cf. Fig. 6): a glacially moulded valley mouth (Dare Langar, see Fig. 2) on the Kuh-i-Jupar N-slope opening into the foreland at 2300 m asl. The 4135 m-high Kuh-i-Jupar massif covered with wintry snow is seen in the background. The rocks were polished by outlet glaciers up to 350 m above the valley floor (x x). A series of three older end moraines, tens of kilometres in length, occurs 5 to 10 km away from the mountain scarp. This end moraine rampart (▼ ▼) is the youngest moraine of the Older piedmont glaciation (pre-LGP = Riss glaciation, cf. Fig. 15). The end moraines consist of diamictites with a fine, clayey matrix and isolated polymict boulders of Cretaceous limestone and Kerman conglomerates (ck). The average size of the boulders ranges from 1.5 x 1.5 x 1 m up to 2 x 1.5 x 1.2 m (fore- to middle-ground). The limestone boulders generally show a better preserved surface and rounding (foreground) (see in detail: KUHLE 1976: 85-87). On the inner slopes of the moraines (fore- to middle-ground) which are 20-26°-steep, the here erratic ck-boulders (90 %) clearly predominate over the local limestone boulders (10 %). Limestone crops out in the underground (●). In the tongue basin a glacially abraded and polished rock barrier emerges at the surface (●). Analogue photo M. Kuhle, 26.03.1974.

Abb. 11: Aus 2310 m Höhe von 0,7 km südöstlich der Siedlung Karnuj vom jüngsten Altmoränenkranz (prä-LGP) (cf Abb. 6) aus aufgenommen. Eine glazigen geformte Talmündung (Dare Langar s. Abb. 2), der Kuh-i-Jupar Nordabdachung öffnet sich in 2300 m ü.M. in das Gebirgsvorland. Im Hintergrund sind die mit Winterschnee bedeckten bis 4135 m hohen Gipfel des Kuh-i-Jupar-Massivs sichtbar (s. Abb. 2). Die Felsen wurden bis 350 m über dem Talboden (x x) durch Auslassgletscher überschliffen. In 5-10 km Entfernung vom Gebirgsfuß befindet sich eine Serie von drei älteren, dekakilometerlangen Endmoränen. Dieser Endmoränenwall (▼ ▼) ist der jüngste der Älteren Piedmontvergletscherung (pre-LGP = Riss glaciation, cf Abb. 15). Diese Endmoränen bestehen aus Diamiktiten mit feiner, lehmiger Matrix und isolierten polymikten Blöcken aus kreidezeitlichem Kalkstein und Kerman-Konglomeraten (ck). Die mittlere Blockgröße beträgt 1,5 x 1,5 x 1 m bis 2 x 1,5 x 1,2 m (Vorder- bis Mittelgrund). Die Kalkblöcke zeigen generell eine besser erhaltene Oberfläche und Zurundung (Vordergrund) (s. im Detail: KUHLE 1976: 85-87). An den (Vorder- bis Mittelgrund) 20-26° steilen Moräneninnenhängen überwiegen die hier erratischen ck-Blöcke (90 %) die Kalkblöcke (10 %) deutlich. Im Untergrund steht Kalk an (●). Im Zungenbecken befindet sich ein glazigen abradierter und überschliffener Felsrücken (●). Analogfoto M. Kuhle, 26.03.1974.

preserved 200-300 m above the thalweg (Fig. 12 ■ and ◗).

Upward of the gorge between 2900 and 2980 m, both on the western and eastern flank, small tributary hanging valleys are found, terminating well above the flat, glaciofluvially modified till of the Hararun valley floor. Some 100 m further upvalley a medium ice margin position (3090 m) is situated. Above 3400 m asl in the main valley, beyond the end moraines of the highest ice margin position, active nivation moraines do still occur on the slopes with perennial snow patches (Fig. 12). Slope dynamics here are dominated by solifluction (Fig. 12), resulting in small terraces and lobes, but also by shoot deformities of the dwarf scrubs. Patterned ground is also found (Kuhle 1976, 1978).

In contrast to the Kuh-i-Jupar and Kuh-i-Hezar, not even the most extensive glacier terminus (2580 m) extended into the foreland. It is found in a basin-like widening of the valley NW of the Hararun settlement (Laleh Zar) at the point where the valley turns in a wide bend to the west. East of Hararun a transfluence pass (diffluence saddle) with a large, nearly horizontal valley floor is found. It was also covered by the very wide glacier tongue. Accordingly, this valley diffluence area, mediating to a northeast sloping further valley, has been filled by the tongue of the glacier like a tongue basin. It is not yet clear if the glacier had a second tongue down this valley. At the same time those end moraines (see above) built up of coarse blocks of volcanic debris have been overthrust and redeposited as till and end moraines on the flat valley slopes, as well as in the form of frontal moraines on the opposite slope in a northerly direction towards the Gudar-i-Pashimani pass. This advance created a tongue basin within this large-scale intramontane diffluence valley. A glacier discharge through two tongues in a northwest and northeast direction may be assumed. By eroding backwards it might have contributed to the shaping of this diffluence area.

The lowest ice margin then was situated c. 680 m higher than that during the older glaciation (pre-LGP), which existed in a comparable exposition on the northern side of the Kuh-i-Jupar (p. 7 ff.). So this lowest ice margin is classified here as belonging to the younger glaciation (LGP). This younger ice margin is found in the Kuh-i-Jupar at c. 2200 m asl (p. 8 ff.). Accordingly, the lowest ice margin there would be still c. 480 m too high. Apart from the geographical position of the Kuh-i-Lalezar 70 km to the south, which may have resulted in a rise of the ELA for about 70 m, the remaining difference may be explained by the topographic position of the ice margin.

In consequence, the glacier tongue increased in thickness and size resulting in an ablation area large enough to allow this higher lowest ice margin position to be compensated by the glacier mass budget. This means that a very large glacier ablation area prevented the lowest ice margin from flowing down to a very low altitude. It cannot be ruled out that the diffluence even compensated the difference in height of c. 610 (680-670) m to the altitude of the lowest ice margin position of the older glaciation (pre-LGP) in the Kuh-i-Jupar, so that the ice margins existed synchronously. Due to the very different topography of the two glacier areas, no ELA calculation has been attempted.

Owing to this, the two younger glacier stages at c. 3090 and 3320 m asl are assumed to be either of Late Glacial age (Stage I and Stage II after Kuhle 1998, 82 Tab. 1) or to belong to the LGP and the Late Glacial Stage I (see p. 11 ff.). The author prefers the first interpretation of an LGP-ice marginal position at 2580 m asl. Accordingly, the lower ice marginal position at 2420 m asl would be interpreted as pre-LGP.

Fig. 12: View from the N slope of the Kuh-i-Lalezar at 3440 m asl from the orographic left flank of the Hararun valley c. 250 m above the thalweg facing SSE diagonally across the valley looking up-valley into its right flank. The level slope in the foreground shows a rock face smoothed by glacigenic abrasion (◗) and framed by till material (■ large). This consists of subrounded boulders more than one metre in diameter (○ black) and boulders that are secondarily broken during their transport (○ white). They float in a clayey matrix. The slope of the right valley flank is covered by corresponding deposits of till (■ middle and small). Since the deglaciation they have been and still are buried by low-angle debris cones and slopes (△). Rill rinsing below the snow patches as well as small debris flows and solifluction participate in this reshaping of the ground moraine covers and the entire valley flank. Analogue photo M. Kuhle, 05.05.1973.

Abb. 12: In der N-Abdachung des Kuh-i-Lalezar aus 3440 m ü.M. von der orogr. linken Flanke des Hararun Tales, von ca. 250 m über der Tiefenlinie gen SSE diagonal über das Tal in die rechte Flanke talaufwärts gesehen. Die Hangverebnung im Vordergrund weist eine durch glazigene Abrasion geglättete Felsfläche auf (◗), welche von Grundmoränenmaterial (■ groß) eingefasst ist; das Grundmoränenmaterial ist aus bis über metergroßen kantengerundeten (○ schwarz), sowie beim Transport, d.h. sekundär zerbrochenen Blöcken (○ weiß), die in einer tonhaltigen Feinmaterialmatrix schwimmen, aufgebaut. Der Hang der rechten Talflanke ist von korrespondierenden Grundmoränenablagerungen bedeckt (■ mittel u. klein); diese wurden und werden seit der Deglaziation von flachgründigen Schuttkegeln und –halden (△) überschüttet. An derartiger Überformung der Grundmoränendecken und der gesamten Talflanke sind auch Runsenspülung unterhalb der Schneeflecken sowie kleine Murabgänge (debris flows) und Solifluktion beteiligt. Analogfoto M. Kuhle, 05.05. 1973.

The Kuh-i-Hezar (4469 m, 29°28' to 29°35' N, 57°10' to 57°23' E / 56°50' to 57°35' E) 50 km south of the Kuh-i-Jupar and 45 km east of the Kuh-i-Lalezar was not included in the field investigations. However, based on the empirical observations in adjacent massifs – above all in the Kuh-i-Jupar – the largest valley in the Kuh-i-Hezar leading down to the north from the highest summit into the mountain foreland will be considered by means of a satellite map (Fig. 13). In the middle reaches of the valley a trough valley profile has been developed for some 3 km (Fig. 13). Down-valley of the exit, i.e. in the mountain foreland, two series of landforms are found. They can be interpreted as end moraines with a connected IMR (ice marginal ramp). The oldest and lowest glacier margin in the foreland reached down to 2380 m asl (Fig. 13 X1), the median altitude of the catchment area of this valley is c. 3900 m so that according to the method of v. Höfer (1879) the orographic snowline (ELA; oSi) would be expected at 3140 m asl:

$$oSi = (pha-ti)/2+ti \qquad (1)$$

Where pha = height of the accumulation area, i.e. medium altitude of the crest fringe; ti = terminus of the glacier tongue; oSi = orographic equilibrium line (snowline, ELA)

$$oSi = (3900-2380)/2 + 2380 = 3140$$

For the younger ice marginal position at 2490 m asl (Fig.13 X2), which belongs to a narrower glacier tongue, an ELA of about 3200 (3195) m asl has been calculated:

$$oSi = (3900-2490)/2 + 2490 = 3195$$

Future geomorphological and sedimentological field investigations, however, are required to confirm the interpretation.

The reconstructed glacier types and their extensions

During the older glaciation (pre-LGP), which was more extensive than the younger one (LGP), wide-spread piedmont glaciers existed on the north and south slopes of the Kuh-i-Jupar (Fig. 15). Over a distance of 23 km the separate glaciers, flowing down from the valleys, merged to form a connected piedmont lobe (Fig. 11). On the south i.e. southwest slope the piedmont lobe was 8 m wide. Several valley glaciers on this slope still terminated within the mountains. The northern piedmont lobe was fed by mountain glaciers up to c. 8.5 km in length, flowing down from the central Kuh-i-Jupar main crest (compare Fig. 2 and 15). In some particular cases parallel valley glaciers communicated with each other across confluences (Fig. 15 ↑ ↑ right). A typical ice stream network, however, did not develop. Caused by the topography of the southwestern slope, hanging glaciers, connected over a width of more than 7 km, flowed down via steep slopes (without intermediate valleys) directly into the mountain foreland. In the Darne Kanatkestan a maximum ice thickness of 500-550 m was reached somewhat above the valley exits but below the snowline altitude (see Chapt. LGP and pre-LGP climatic snowlines (ELA) in the Kuh-i-Jupar).

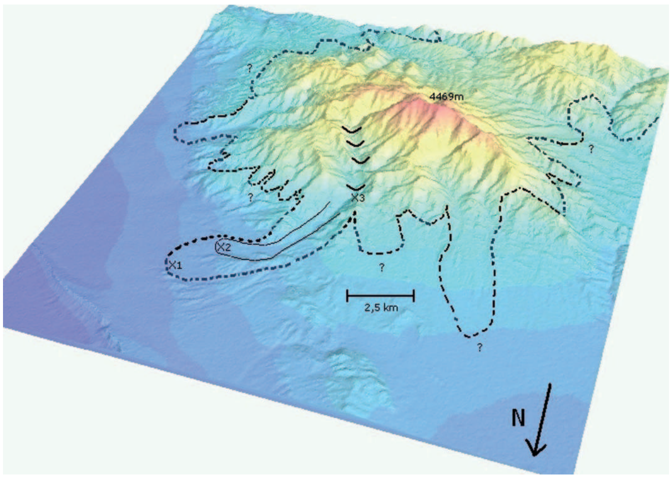


Fig. 13: Three-dimensional terrain model of the Kuh-i-Hezar massif: (---) marks the ice margin of an older Pleistocene glacier cover; (?) = uncertain ice marginal position; (——) marks the ice margin of a younger Pleistocene glacier tongue in the most extended valley exit exposed approx. to the north. (X1) is the lowest ice margin at 2380 m, (X2) that one at 2490 m asl. (v) are trough-shaped valley cross-profiles reaching down to (X3) at 2950 m asl. Draft M. Kuhle.

Abb. 13: Reliefkartenskizze des Kuh-i-Hezar Massivs: (---) markiert den Eisrand einer älteren pleistozänen Gletscherbedeckung; (?) = Eisrand sehr unsicher; (——) markiert den Eisrand einer jüngeren pleistozänen Gletscherzunge im größten nach etwa Norden exponierten Talausgang. (X1) ist der tiefste Eisrand in 2380 m, (X2) der in 2490 m ü.M. (v) sind trogförmige Talquerprofile die bis (X3) hinabreichen. (X3) liegt in 2950 m ü.M. Entwurf M. Kuhle.

During the younger glaciation (LGP) valley glaciers extended down to the mountain foot areas of the north and south, i.e. southwest slopes. Although the ice reached the mountain foreland they did not merge to form piedmont lobes (Fig. 14). The maximum ice thickness reached 350 m. Thus, the lower snowline depression by some 100 m during the younger (LGP) more than during the older glaciation (pre-LGP) resulted in a change from a piedmont glaciation to a mere valley glaciation (Kuhle 1988a) with glacier tongues reaching the mountain foreland but remaining separate (cf. Fig. 14 with 15).

With regard to the proportion of the glacier feeding- and ablation areas and the arrangement of their positions the valley glaciers of the older- (pre-LGP) and younger (LGP) glaciation were mixed types of small névé stream- and névé field glaciers as well as névé cauldron- and avalanche cauldron glaciers, after the nomenclature of v. Klebelsberg (1948, 187 ff.) and Schneider (1962). The more substantial filling of the relief by the valley glaciers during the older glaciation was due to larger portions of primary nourishment, whilst at the lower ice level during the younger glaciation the nourishment by avalanches must have increased proportionately (Kuhle 1988b).

On the only 2800 to 3300 m-high mountain spurs branching off from the main ridge, cirque glaciers developed contemporaneously with the comparatively large valley glaciers. Because of the difference in snowline altitude the cirque glaciation shifted to 100 m higher mountains and mountain spurs during the younger glaciation.

During the Late Glacial rise in snowline altitude, four Late Glacial stages of glacier retreat can be differentiated (Stage I, Stage II, Stage III and Stage IV, Kuhle 1998, 82 Tab.1). The glaciation then was reduced to hanging- and cirque glaciation even in the highest areas of the Kuh-i-Jupar massif.

Whether the glaciers were temperate with a seasonal meltwater discharge worth mentioning (p. 15 ff.) or cold-arid with high sublimation and ablation and a minor discharge must remain open.

Due to the preserved ice marginal ramps (IMR), which are typical of ice marginal positions in the foreland of glaciers in a semi-arid climate (KUHLE 1984, 1989, 1990), even the lowest ice margins of the younger and older glaciation may hardly have reached below the discontinuous permafrost limit (-1 to -3 °C average annual temperature).

LGP and pre-LGP climatic snowlines (ELA) in the Kuh-i-Jupar

Older glaciation – pre-LGP

As for the piedmont glacier of the north slope, the medium altitude of the crests limiting the catchment area is c. 3700 m. The lowest ice margin in the foreland reached down to 1900 m asl, so that according to the method of V. HÖFER (1879) an orographic snowline (ELA, oSi) at 2800 m asl can be calculated:

$$oSi = (pha-ti)/2 + ti \qquad (1)$$

Where pha = height of the accumulation area, i.e. medium altitude of the crests limiting the catchment area; ti = terminus of the glacier tongue; oSi = orographic equilibrium line (snowline, ELA)

$$oSi = (3700-1900)/2 + 1900 = 2800$$

For the northwest slope an ELA at 2860 m is calculated; for the west slope 2930 m; for the southwest and south slope in the west 3120 m and for the valleys further to the east 3050 m asl (Kuhle 1976a, 193/194). The average altitude of these real or orographic snowlines yields a regional climatic snowline (rSi) at c. 2950 (2952) m asl in the Kuh-i-Jupar.

$$rSi = (oSi1 + oSi2 + oSi3 + oSi4 + oSi5)/5 \qquad (2)$$

Where oSi = orographic equilibrium line (ELA); rSi = regional climatic equilibrium line (snowline, ELA)

$$rSi = (2800 + 2860 + 2930 + 3120 + 3050)/5 = 2952$$

The greatest expositional ELA differences found between the north and south slope are about 320 m. The current snowline (Sp) runs at 4500-4600 m. Consequently, perennial snow fields are situated 50 m southwards in the Kuh-i-Hezar as well as 70 km southwards in the Kuh-i-Lalezar at 4200-4450 m. The present-day snowline altitude of our investigation area is also confirmed by the snowline-map of HERMES (1965). Compared with this, the ELA depression (Sdepr) of the older

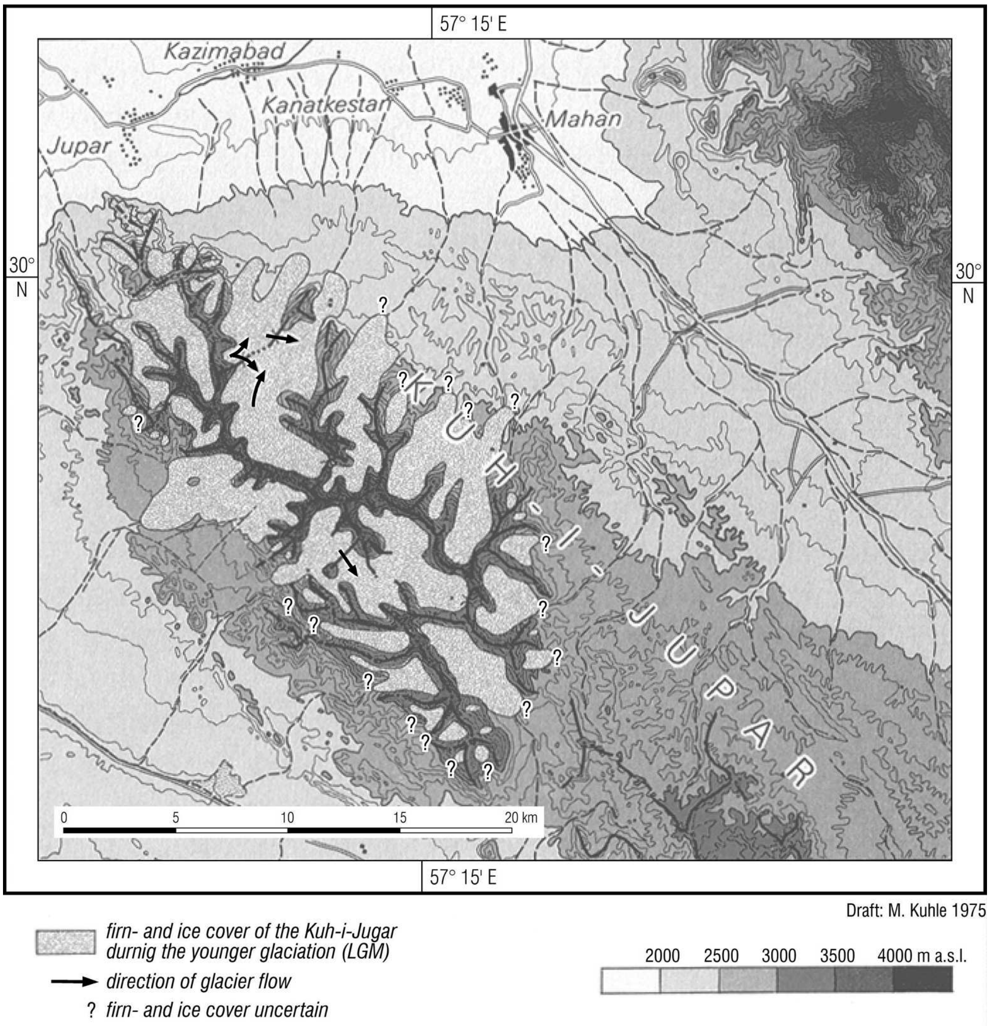


Fig. 14: Firn and ice cover of the Kuh-i-Jupar during the younger glaciation (Würm Glaciation = LGP) (Fig. 4-6).

Abb. 14: Firn- und Eisbedeckung des Kuh-i-Jupar während der jüngeren Vereisung (Würm-Vereisung = LGM) (Abb. 4-6).

glaciation was c. 1550-1650 m.

$$\mathrm{Sdepr} = \mathrm{Sp} - \mathrm{rSi} \qquad (3)$$

Where Sp = recent equilibrium line; rSi = former regional climatic equilibrium line (snowline, ELA); Sdepr = equilibrium line depression.

$$\mathrm{Sdepr} = 4500(4600) - 2950 = 1550(1650)$$

In this ELA calculation only the lowest, i.e. northernmost end moraine generations have been considered (Fig.15).

Younger glaciation (LGP)

On the north slope the ELA (oSi) for the younger glaciation (LGP) has been calculated at between 2880 and 2980 m; on the west slope about 3030 m; on the southwest to south slope between 3150 and 3220 m asl. The mean value of these real or orographic snowlines yields a regional climatic snowline (rSi) about 3050 (3052) m asl in the Kuh-i-Jupar.

$$\mathrm{rSi} = (\mathrm{oSi1} + \mathrm{oSi2} + \mathrm{oSi3} + \mathrm{oSi4} + \mathrm{0Si5})/5 \qquad (2)$$

Where oSi = former orographic equilibrium line (ELA); rSi = former regional equilibrium line (snowline, ELA)

$$\mathrm{rSi} = (2880 + 2980 + 3030 + 3150 + 3220)/5 = 3052$$

The greatest expositional differences in ELA were found to be between the north and south slope. They amounted to 170 up to 340 m. Accordingly, the ELA depression (Sdepr) was 1440-1540 m, that is 100 m less than during the older glaciation (see above).

$$\mathrm{Sdepr} = \mathrm{Sp} - \mathrm{rSi} \qquad (3)$$

Where Sp = recent equilibrium line; rSi = former regional equilibrium line (snowline, ELA); Sdepr = equilibrium line depression.

$$\mathrm{Sdpr} = 4500(4600) - 3050 = 1450(1550)$$

Evidence of the snowline altitude of the older as well as the younger glaciation is provided by a ravine setting in at 2800 m asl in the Darna Kanatkestan (Dare Karson). It has been developed by the subglacial glacier meltwater, which from this altitude on increased more and more in a downward direction (Fig. 3 ↓). The amount of meltwater needed for the development of such subglacial meltwater ravines proves that they must have been shaped immediately below the snowline.

Owing to numerous recessional moraines and moraine remnants (Fig. 6) four stages of the younger glaciation can be distinguished. They belong to the late glacial period (Late LGP: Stages I, II, III, IV) and might be c. 17-12 ka old. However, information about these ice margial positions from

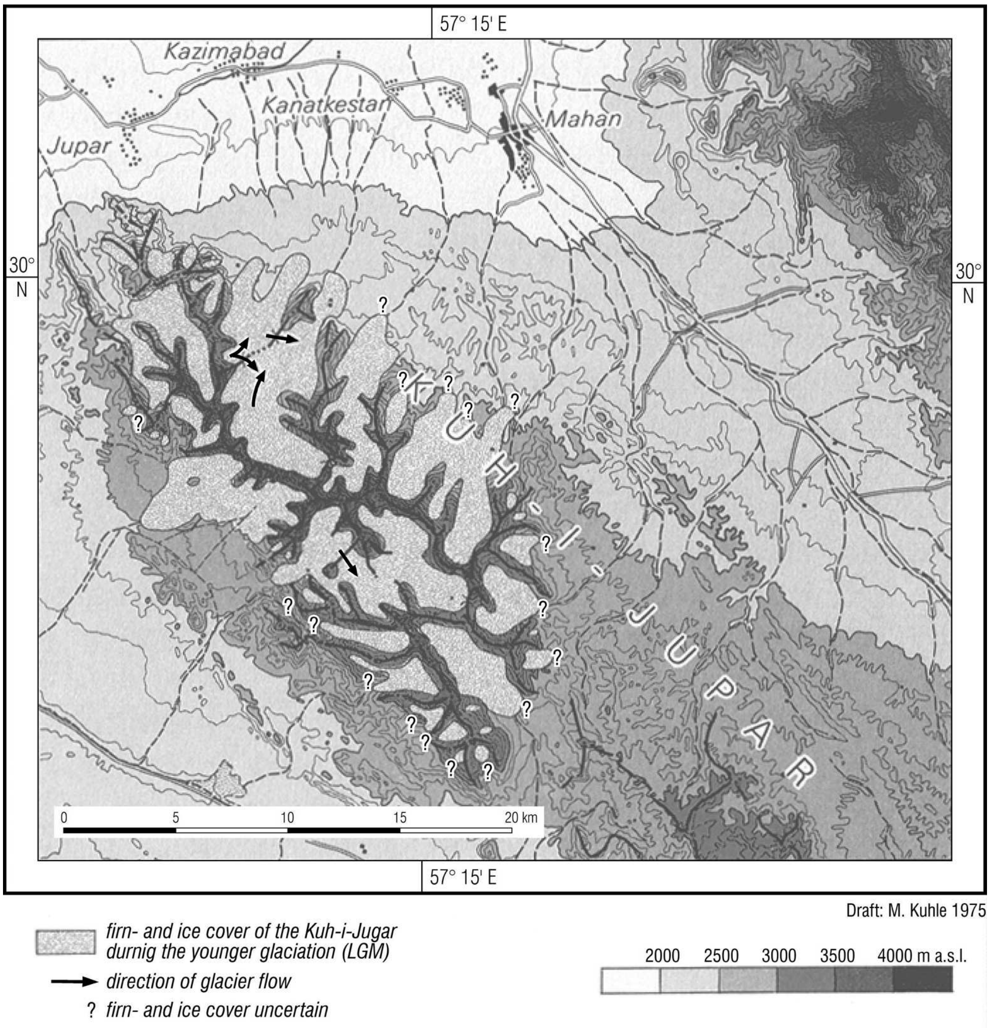


Fig. 15: Firn and ice cover of the Kuh-i-Jupar during the older glaciation (Riss Glaciation = pre-LGP) (Fig. 4, 5, 8, 10, 11).

Abb. 15: Firn- und Eisbedeckung des Kuh-i-Jupar während der älteren Vereisung (Riss-Vereisung = LGP) (Abb. 4, 5, 8, 10, 11).

several slopes is not sufficient for a reliable ELA determination.

On several proximal slopes of moraines of the younger glaciation, the corrasion rills in limestone boulders measured up to 1.7 m in depth. In the Dankow massif (southwest Tienshan), which currently is also semiarid, MEINERS (1996, 33/34) has found corrasion rills of 1.5-2.5 cm depth on boulders lying on the slopes of moraines, which – according to an age assignment backed up by C^{14} dating – were c. 5500-2000 years old. According to the climate history in the Kuh-i-Jupar, however, it has to be ruled out that the corresponding ELA depression of 1500 m on average for the younger glaciation is only 5500-2000 years old. During this neoglacial period the ELA depressions in High Asia amounted to 300 m at most (KUHLE 1998, 82 Tab. 1). Obviously, surface dating in mountain areas can be misleading. The different ages at which boulder surfaces were exposed as well as their continuous redeposition, are inconsistent with a logical moraine chronology.

DISCUSSION OF FURTHER INVESTIGATIONS WITH REGARD TO PAST GLACIER RECONSTRUCTIONS

As for the LGP we have established an ELA at 3050 m asl. This contrasts with a 350 m higher ELA value (3400 m) quoted by Bobek (1937, 153, Fig. 9) for Iranian mountains some 600 km to the northwest. It even more strongly contrasts with the map of FRENZEL (1960).

The course of the snowline at 3500-3400 m asl established by DESIO (1934a,b) for the Zardeh-Kuh, west of Isfahan, and confirmed by WRIGHT (1962), also lies at least 300 m above that one of the LGP and 400 m above that one of the pre-LGP in the Jupar massif. No older glaciation (pre-LGP) had been mentioned in the corresponding literature.

However, independent of our investigations, HAARS et al. (1974) attained results with regard to the Pleistocene glacier extension in the 4074 m high Shir-Kuh- massif, situated 380 km WNW of the Jupar massif that correspond well with our investigations.

PALEOCLIMATIC RELEVANCE OF THE RECONSTRUCTED GLACIATION FOR THE SOUTHEAST IRANIAN MOUNTAINS

One indicator of paleoclimatic conditions is provided by the snowline depressions. In our investigation area, during the older glaciation (pre-LGP = Riss = Stage-I) the depression of the climatic snowline (ELA) amounted to c. 1600 m (p. 12 ff.). Accordingly, at a probably semi-arid gradient of 0.7 °C/100 m, the depression of the annual temperature was 11.2 °C on equal humid conditions. During the younger glaciation (LGP = Würm = Stage 0) the ELA depression was c. 1500 m (p. 13 ff.). The depression of the LGP average annual temperature amounted to 10.5 °C compared with today. During the LGP it was about 0.7 °C warmer than during the pre-LGP.

Thus, the average annual temperature at the snowline level (2950 m) during the older glaciation was -2.8 °C, during the younger glaciation (at 3050 m) it was also -2.8 °C. At a present-day average annual temperature of c. 15.75 °C at c. 1900 m asl and 13.66 °C at 2200 m (cf. Introduction), this means that the most extensive foreland glacier tongues during the older glaciation flowed down into an environment of 4.55 °C average annual temperature and of 3.16 °C during the younger glaciation. Accordingly, these might have been temperate glaciers, similar to the current glaciers in the European Alps.

This suggests a Pleistocene glaciation under noticeably more humid conditions than they are today. However, if the currently semi-arid conditions should have existed at that time as well – and this will probably be proved by future indicators of the flora and fauna – the temperature depressions must have been far greater than the postulated 11.2 °C during the pre-LGP, and far greater than 10.5 °C during the LGP. For this the ice marginal ramps as markers of the ice margin positions (Fig. 6), which were formed repeatedly during both glaciations in the Kuh-i- Jupar massif, might be important geomorphologic indicators (p. 11 ff.). Thus, under semi-arid conditions, which during the glacial period might have been even drier than today, temperature depressions of 15-16 °C would have been necessary to enable the glaciations, the traces of which have been described above. Because the height of the snowline (ELA) is a function of radiation budget, temperature and precipitation, the analogous results of KUHN (1980, 1981, 1983) have to be mentioned here: in the more humid European Alps a lowering of the ELA by 100 m requires either a 300 mm/y increase in precipitation or a 0.6 °C decrease in temperature.

CONCLUSION

The geomorphological analyses of the southeast Iranian, 4135, 4374 and 4469 m high subtropical-semiarid Kuh-i-Jupar, Kuh-i-Lalezar and Kuh-i-Hezar massifs – with field investigations being limited to the Kuh-i-Jupar – has led to the conclusion that two extended Late Pleistocene glaciations occurred: the pre-LGP and the LGP. These involved valley glaciations, which flowed down into the mountain foreland (Kuh-i-Jupar, Kuh-i-Lalezar and Kuh-i-Hezar) and, during the older glaciation (pre-LGP), merged into extensive ice-lobes (Kuh-i-Jupar). During the younger and less intensive glaciation period (LGP), the glacier tongues reaching the foreland remained isolated due to the projecting high mountain spurs. For the pre-LGP glaciation transfluences were observed on five saddles, whilst for the LGP-glaciation only two transfluences could be identified (Kuh-i-Jupar).

In the lower areas of the mountains around 3000 m asl, the glacial landform inventory provides evidence of a former cirque glaciation. The largest glacier of the pre-LGP in the Kuh-i-Jupar measured 17 km in length during its greatest extension; during the LGP the glacier of the same catchment area was 10-12 km long. During its maximum stage the northern piedmont lobe measured c. 23 km across, whilst the southern lobe reached 8.5 km during the pre-LGP. The greatest thickness of valley glaciers at that time was 500 to 550 m, as opposed to a mere 350 m during the LGP.

All Quaternary geological and geomorphological indicators of mountain and foreland glaciation are present and clearly marked from the accumulation area down to the denudation area of the Kuh-i-Jupar. So, in the distal basin area, proglacial outwash plains follow the rhythmically deposited stillwater sediments and, across ice marginal ramps (IMR), lead upwards to the end moraines of the pre-LGP glaciation. These moraines are divided into three ramparts, situated one behind the other. They represent three stages of glaciation. In the direction of the mountains the tongue basins of the pre-LGP glaciation follow, covered with younger outwash, and then the moraines and tongue basins of the LGP-glaciation. In the mountain areas there are trough valleys and trough-like forms (Kuh-i-Jupar, Kuh-i-Lalezar and Kuh-i-Hezar) with thresholds and polished ground, polished bands and clearly identifiable upper abrasion limits (Kuh-i- Jupar). Even higher in the Kuh-i-Jupar, cirques and cirque stairways do occur. The glacigenic valley flanks and wall fronts are dissected by steep gorges and gullies (Kuh-i-Jupar). Between them lie truncated spurs and triangular slopes of glacial origin. In places, polished ground and thresholds are dissected by ravines (Kuh-i-Jupar). The recessional moraines in the Kuh-i-Jupar, which are also preserved in the high valleys, provide evidence of the Late Glacial glacier retreat via four stages (I-IV). They reflect the gradual deglaciation interrupted by minor re-advances.

During the older glaciation (pre-LGP) the regional climatic snowline (ELA) of the Kuh-i-Jupar, determined by evaluating the orographic (local) snowlines of the individual slopes, ran at c. 2950 m asl. This corresponds to a snowline depression of c. 1600 m as compared to the current snowline at c. 4550 m. During the younger glaciation (LGP) the ELA was c. 100 m higher, at c. 3050 m asl, i.e. 1500 m below the current snowline. Under the assumption of a semi-arid temperature gradient of 0.7 °C/100 m difference in height, a depression of the average annual temperature of 11.2 °C, as compared to the present, can be inferred for the pre-LGP and of 10.5 °C for the LGP. In this case the average temperature at the ELA level was -2.8 °C, which is a value typical of temperated glaciers.

However, if cold glaciers about 8 °C at the ELA level should have occurred, the temperature depressions might even have amounted to c. 15 or 16 °C during the glacial periods under discussion.

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References

Bauer, G. (1935): Luftzirkulation und Niederschlagsverhältnisse in Vorderasien.- Gerlands Beitr. Geophysik 45: 381-548.

Bobek, H. (1937): Die Rolle der Eiszeit in Nordwestiran.- Z. Gletscherkd. 25: 130-183.

Bobek, H. (1952): Beiträge zur klima-ökologischen Gliederung Irans.- Erdkunde 6: 65-84.

Desio, A. (1934a): Appunti geografici e geologici sulla catena dello Zardeh Kuh in Persia.- Memorie geol. E geogr. Di G. Dainelli 4: 141-167.

Desio, A. (1934b): Sull' esistenza di piccoli ghiacciai nella Persia occidentale.- Boll. Comitato Glaciol. Ital. 14: 39-52.

Djokovic, J., Dimitrijevic, M.N., Dimitrijevic, M.D. & Cvetic, S. (1972): Geol. Map of Iran 1:100 000 Sheet 7449 Rayen.- Geol. Surv. Iran.

Engelhardt, W.v. (1973): Die Bildung von Sedimenten und Sedimentgesteinen.- In: W.v. Engelhardt, H. Füchtbauer & G. Müller (Hrsg.), Sediment-Petrologie, Teil III, Schweizerbart, Stuttgart 133 Abb., 55 Tab.: 1-378.

Frenzel, B. (1959): Die Vegetations- und Landschaftszonen Nord- Eurasiens während der letzten Eiszeit und während der postglazialen Wärmezeit. Teil I.- Abhandl. Math.-naturwiss. Kl. Akad. Wiss. Lit. Mainz 13: 939-1099.

Frenzel, B. (1960): Die Vegetations- und Landschaftszonen Nord-Eurasiens während der letzten Eiszeit und während der postglazialen Wärmezeit. Teil II. Rekonstruktionsversuch der letzteiszeitlichen und wärmezeitlichen Vegetation Nord-Eurasiens.- Abhandl. Math.-naturwiss. Kl. Akad. Wiss. Lit. Mainz 6: 289-453.

Ganji, M.H. (1960): Iranian Rainfall Data.- Arid Zone Research Entre Univ. Teheran, 3. Teheran: 3-49

Haars, W., Hagedorn, H., Busche, D. & Förster, H. (1974): Zur Geomorphologie des Shir-Kuh-Massivs (Zentral-Iran).- Marburger Geograph. Schr. 62: 39-48.

Hermes, K. (1965): Der Verlauf der Schneegrenze.- Geogr. Taschenbuch 1964/65: 58-712.

Höfer, H.v. (1879): Gletscher und Eiszeitstudien.- Sitz. Ber. Akad. Wiss. Wien. Math. Phys. Kl. I, 79: 331-367.

Klebelsberg, R.v. (1948): Handbuch der Gletscherkunde und Glazialgeologie, Bd.1.- Springer Verlag, Wien: 1-403.

Kuhle, M. (1974): Vorläufige Ausführungen morphologischer Feldarbeitsergebnisse aus den SE-Iranischen Hochgebirgen am Beispiel des Kuh-i-Jupar.- Z. Geomorphol. N.F. 18: 472-483.

Kuhle, M. (1976a): Beiträge zur Quartärgeomorphologie SE-Iranischer Hochgebirge. Die quartäre Vergletscherung des Kuh-i-Jupar.- Göttinger Geograph. Abhandl. 67/ I: 1-209.

Kuhle, M. (1976b): Beiträge zur Quartärgeomorphologie SE-Iranischer Hochgebirge. Die quartäre Vergletscherung des Kuh-i-Jupar.- Göttinger Geograph. Abhandl. 67/II: 1-105.

Kuhle, M. (1978): Über Solifluktion und Strukturböden in SE-Iranischen Hochgebirgen.- Builetyn Periglacjalny 27: 117-131.

Kuhle, M. (1982a): Der Dhaulagiri- und Annapurna-Himalaya. Ein Beitrag zur Geomorphologie extremer Hochgebirge.- Z. Geomorphol. Suppl. 41, Bd. I (Text): 1-229.

Kuhle, M. (1982b): Der Dhaulagiri- und Annapurna-Himalaya. Ein Beitrag zur Geomorphologie extremer Hochgebirge.- Z. Geomorphol. Suppl. 41, Bd. II (Abb. Geomorph. Karte 1:85 000): 1-183.

Kuhle, M. (1984): Zur Geomorphologie Tibets, Bortensander als Kennformen semiarider Vorlandvergletscherungen.- Berliner Geograph. Abhandl. 36: 127-138.

Kuhle, M. (1987): Subtropical Mountain- and Highland-Glaciation as Ice Age Triggers and the Waning of the Glacial Periods in the Pleistocene.- GeoJournal 14: 393-421.

Kuhle, M. (1988a): The Pleistocene Glaciation of Tibet and the Onset of Ice Ages - An Autocycle Hypothesis.- In: M. KUHLE & W. WENJING (eds), Tibet and High-Asia. Results of the Sino-German Joint Expeditions (I), GeoJournal 17 (4): 581-596.

Kuhle, M. (1988b): Topography as a Fundamental Element of Glacial Systems. A New Approach to ELA-Calculation and Typological Classification of Paleo- and Recent Glaciation.- In: M. KUHLE & W. WENJING (eds), Tibet and High-Asia. Results of the Sino-German Joint Expeditions (I), GeoJournal 17 (4):545-568.

Kuhle, M. (1989): Ice-Marginal Ramps: An Indicator of Semiarid Piedmont Glaciations.- GeoJournal 18: 223-238.

Kuhle, M. (1990): Ice Marginal Ramps and Alluvial Fans in Semi-Arid Mountains: Convergence and Difference.- In: A.H. Rachocki & M. Church (eds), Alluvial fans - A field approach, John Wiley, Chester- New York-Brisbane-Toronto-Singapore: 55-68.

Kuhle, M. (1991): Glazialgeomorphologie.- Wiss. Buchgesellschaft, Darmstadt: 1-213.

Kuhle, M. (1998): Reconstruction of the 2.4 Million km^2 Late Pleistocene Ice Sheet on the Tibetan Plateau and its Impact on the Global Climate.- Quat. Internat. 45/46: 71-108 (Erratum: 47/48:173-182, 1998 included)

Kuhle, M. (2001): The Tibetan Ice Sheet; its Impact on the Palaeomonsoon and Relation to the Earth's Orbital Variations.- Polarforschung 71: 1-13.

Kuhle, M. (2002): A relief-specific model of the ice age on the basis of uplift-controlled glacier areas in Tibet and the corresponding albedo increase as well as their positiv climatological feedback by means of the global radiation geometry.- Climate Research 20: 1-7.

Kuhle, M. (2004): The High Glacial (Last Ice Age and LGM) ice cover in High and Central Asia.- In: J. Ehlers & P.L. Gibbard (eds), Development in Quaternary Science 2c (Quaternary Glaciation - Extent and Chronology, Part III: South America, Asia, Africa, Australia, Antarctica, Elsevier B.V., Amsterdam: 175-199.

Kuhle, M. (2005): Glacial geomorphology and ice ages in Tibet and surrounding mountains.- The Island Arc 14 (4): 346-367.

Kuhn, M. (1980): Die Reaktion der Schneegrenze auf Klimaschwankungen.- Z. Gletscherkd. Glazialgeol. 16/2: 241-254.

Kuhn, M. (1981): Climate and Glaciers.- In: Sea Level, Ice and Climatic Change, Proceedings of the Canberra Symposium, Dec. 1979, IAHS, 131: 3-20.

Kuhn, M. (1983): Die Höhe der Schneegrenze in Tirol, berechnet aus Fliris klimatischen Profilen.- Innsbrucker Geograph. Stud., Arbeiten zur Quartär- und Klimaforschung 8 (Fliri-Festschrift): 85-91.

Lieth, H. & Walter, H. (1960-67): Klimadiagramm-Weltatlas: etwa 8000 Klimastationen (etwa 9000 Diagramme), 33 Haupt-kt., 22 Nebenkt.- G. Fischer. Jena.

Meiners, S. (1996): Zur rezenten, historischen und postglazialen Vergletscherung an ausgewählten Beispielen des Tien Shan und des Nord-West-Karakorum.- GeoAktuell 2: 1-200.

Meteorological Yearbooks of Iran (1950-1973).

Schneider, H.J. (1962): Die Gletschertypen. Versuch im Sinne einer einheitlichen Terminologie.- Geograph. Taschenbuch 1962/63: 276-283.

Stratil-Sauer, G. (1937): Eine Route im Gebiet des Kuh-e-Hezar (Südiran).- Petermanns Geogr. Mitt. 11: 309-313 und 12: 353-356.

Stratil-Sauer, G. (1941): Beobachtungen zur Sommerwitterung einer südpersischen Höhenstation (Ra´in).- Gerlands Beiträge Geophys. 57: 193-225.

Wright, H.E. (1962): Pleistocene glaciation in Kurdistan.- Eiszeitalter Gegenwart 12: 131-164.