GeoJournal 33.2/3 133–272

Present and Pleistocene Glaciation on the North-Western Margin of Tibet between the Karakorum Main Ridge and the Tarim Basin, Supporting the Evidence of a Pleistocene Inland Glaciation in Tibet

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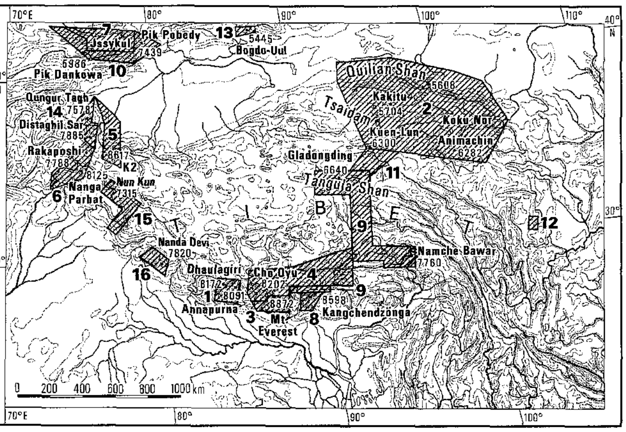
1. Description of the Project and Logistics of the 1986 Expedition

The author has been engaged in the reconstruction of the maximum extent of the Pleistocene glaciation in Asia since 1972, leading research expeditions to Tibet and to its surrounding mountain ranges since 1976 (Fig 1). Initially these were financially supported by the German Research Society (Deutsche Forschungsgemeinschaft = DFG), with additional support from the Max Planck Society since 1981. This, the sixth, expedition to High Asia took place between August and November 1986; the area under investigation was the extremely arid NW-edge of the Karakorum in the south and the Tarim Basin (Takla Makan desert) in the north (35°53'-39°N/76°-77°30'E) (Fig 1, No.5; Fig 138). Run as a joint Chinese-German enterprise of the Department of Geography of the Göttingen University and the Lanzhou Institute of Glaciology and Cryopedology of the Academia Sinica, the expedition was led by Professor Xü Daoming and the author, who had initiated the project. Eight Chinese and six German scientists took part in the expedition, together with a total of 30 technical support staff, camel drivers, high altitude porters and assistants, and last but not least a caravan of 70 camels. The area under investigation was the Karakorum N-side, where access is difficult; particularly the area of the K2 (Tschogori) and Skyang Kangri, including the Skamri, the Sarpo Laggo, the Skyang Kangri and the K2 glaciers, where little research had been undertaken. Though the glacio-geomorphological reconstruction of prehistoric glaciation is the subject of this paper, studies were carried out concerning current glaciology, botany and plant geography. In addition, four climatic stations were installed between 3980 m and 5330 m asl on surfaces of rock, debris and firn in the glacier catchment area, carrying out meteorological-climatological research into albedos and radiation balances, in order to calculate the *Ice Age energy losses* for the atmosphere on the basis of 80–90% of the reflection values of the expanses of ice, firn and snow which covered most of the rock and debris (cf. Kuhle 1988 c, 1988 d).

2. Characteristics of the Area under Investigation and their Methodological Significance

2.1 Topography and Climate

Extending over an area of 110 x 190 km, where key localities representative of prehistoric glaciation were investigated (Fig 138), the area covered by the expedition is divided into three diagonal mountain chains. They strike from NW to SE, with heights staggered from S to N, the



1: *1976 a. 1977* **2:** *1981* **3:** *1982* **4:** *1984* **5:** *1986* **6:** *1987* **7:** *1988* **8:** *1988 a. 1989*
9: *1989* **10:** *1991* **11:** *1991* **12:** *1991* **13:** *1986/92* **14:** *1992* **15:** *1993* **16:** *1993*

Fig 1 Research areas in High Asia visited by the author since 1976

highest being the main ridge of the Karakorum (8611 m or 8617 m) in the south; the next rising to 6858 m, but divided from the Karakorum by the Shaksgam valley, is the Aghil chain in the north. Still further north of this 20 to 30 km-wide mountain system, but divided by the Yarkand valley, is the here 60 to 70 km-wide mountain range of the Kuenlun, culminating at 6412 m in its western section. Longitudinal valleys and their transverse tributary valleys are embedded in these mountain chains. In the S/N cross-section of the area under investigation (Fig 138) their valley floor levels occur between 3400 and 4100 m asl (Fig 138). The mountain slopes, which rise up from there more or less abruptly, are thus 2000–4000 m high. The *concordant* elevation differences reach a maximum of about 5000 m. This is the *vertical distance* of the immediate catchment area, which made the local prehistoric glaciation drain off into the valleys. The two major *longitudinal valleys,* the Shaksgam and the Yarkand, drain the Tibetan plateau in the NW (Fig 1, No. 5). There the valley floors descend from altitudes which reach 5200 m or more on the Depsang plateau (an intact remnant of a western plateau) to give but one example, or even exceed 5570 m at the Karakorum pass. The convergence of the two mountain ranges, the Karakorum and the Kuenlun, is reflected in this W-Tibetan configuration of longitudinal valleys of the chosen study area. The highland of Tibet, which separates them further east, tapers towards the west, with the pointed ridge of the Aghil in the area under investigation forming its most westerly extension. The linking of a very high and - in the high mountains always immediately - *adjacent* local catchment area with *extensive, far distant* catchment areas by way of longitudinal valleys produces an *arrangement* which *favours* the reconstruction of Ice Age glaciation. On, that is in, the W-Tibetan Plateau areas proper, such a reconstruction would not be likely to succeed since they occur at too high an altitude, ie too close to the *present* ELA and thus too close to the present glaciation, to reveal either the *lowest former ice margins* by means of end moraines, or the *lowest glacial abrasions and* polishings (cf. Kuhle 1991 b, pp. 109-113; 1991 d, p. 134). Moreover, the glacigenic erosion forms which can only be brought about by guided, canalized run-off of the ice through the valleys, which cannot occur on plateaux but only in the adjacent valleys in the west, are most *clearly* recognized in the area selected for investigation. Trough cross-profiles are to be expected here which require a *shallow* profile of a *linear* valley, ie a *longitudinal* valley. The immediately adjacent, *steep cross-valleys* on the other hand, offer poor conditions for the preservation of U-shaped profiles as glaciated key forms (cf. Kuhle 1991 b pp. 1-5; 1983 pp. 154-155). Besides these two orographically *favourable factors* for the reconstruction of glaciers: (1) "the location on the edge of the high plateau, with immediate glacier run-off to far below the snow line" and (2) "canalization through valleys" this area as a *test-bed* for prehistoric glaciation is served by a *disadvantageous factor* related to this location: ie its *very marked aridity.* As far as it *can be assessed,* the aridity in the valley floors at about 4000 m nowadays amounts to 60–100 mm/year, and increases to 40 mm/year towards the Tarim basin below 2000 m asl. This fact indicates a *deterioration* of climatic conditions for *allochthonous* glaciation compared with those of the Tibetan highland, where precipitation at the 5000 m level is distinctly higher and would also have been so during the Ice Age. In western High Asia *precipitation* generally *increases* with *altitude.* In many places of the Karakorum, as well as the area under investigation in the stricter sense, it varies from 1200 to more than 1500 mm/year (max. 2000 mm/y) at altitudes between 5000 and 6000 m asl. Evidence of such quantities of precipitation was gathered by the 1986 expedition by snow accumulation measurements (snow profile pits) in the K 2 glacier catchment area and ablation measurements on the K 2 glacier, the Skamri glacier and the Sarpo Laggo glacier (cf. Ding Yongjian 1991, p. 244 and 1987, p. 25, Tab. 11; Xie Zichu et al. 1987 p. 7; Shen Yongping 1987 p. 1). These data indicate that in a cross-section stretching from W-Tibet to the adjacent mountain ranges in the west an ELA depression *did not assume the proportions* which the decreasing *mass elevation effect* would suggest. It was at least compensated in part by the *decrease in precipitation.* This line of thinking points to the fact that the local (autochthonous) glaciations of the Karakorum, the Aghil, and the Kuenlun mountains are *unlikely* to have been favoured climatically compared to the allochthonous glaciation experienced by the Tibetan plateau. *Primarily topographical reasons* also account for lesser productivity in glacier formation during the Ice Age among the mountain ranges on the western edge of Tibet. Though higher, their narrow crests and isolated peaks only offered *very small areas* for glacier development, whereas the Tibetan plateau, with its large undissected plateau, towered above the ELA depression. The resulting slow glacier drainage contributed in turn to a rapid *build-up* of the glacier surface, and thus to an *even higher* catchment area, leading to a further increase in the glacier feeding. These considerations suggest that

material	time	0°C-line (m asl) SEE	2SEE	temperature gradient (°C/100 m)	correlation	difference of altitude (m)	difference of temperature gradients (°C/100 m)
rock	0–24	6306	7781	−0.674	−0.567	---	---
rock	11–15	5701	7616	−0.827	−0.717	224	0.282
rock	15–11	5813	7392	−0.545	−0.536		
ice	0–24	4308	5018	−0.646	−0.837	---	---
ice	11–15	4566	5304	−0.671	−0.775	391	0.035
ice	15–11	4216	4913	−0.636	−0.852		

Tab 1 Statistically evaluated and summarized telemetric surface temperature measurements during radiation weather periods, taken with the aid of an infra-red long distance thermometer on mountain flanks with rock and ice surfaces on the Karakorum N-side (the K2 area in particular). The diameter of the measurement field is (Ø) 100 m for a measuring distance of 1500 m. Measurements: A. Schulze and M. Kuhle.

the traces of a *relief covering,* or a high-level relief-filling glaciation, could possibly be regarded as conclusive evidence of a total glaciation of western Tibet, in so far as its topography as well as its altitude ie lower temperatures and higher precipitation, draw Tibet closer to glaciation than the 1000 m-lower valley floors of the Shaksgam and Yarkand, which are already close to the permanent frost line.

The area chosen for investigation presents an overall *vertical distance* of 7200 m from K2 peak (8611 m or 8617 m) to the Tarim basin (1400 m asl). Composed of several mountain chains, the extremely high and wide Karakorum barrier *prevents* precipitation approaching from the Arabian Gulf and the Bay of Bengal in the south from reaching this study area. Strikingly heavy precipitation during the summer of the 1986 expedition provided evidence of some *monsoon influence* even here in western High Asia. A mean annual temperature of + 3.1°C was recorded at the "Tashikuergan" weather station (3090 m), as the one nearest to the area researched by the expedition.

2.2 Surface Forming Rocks

The bedrock in the area under investigation is important for the *glacio-geomorphological* glacier reconstruction, as well as for the registration of former catchment areas; the direction of run-off is indicated by erratica. In the region of its high peaks and crests, the Karakorum main ridge is composed of dark grey granites and gneisses with strikingly large feldspar crystals (sanidin) (Y 6). They present a very massive structure and show high resistance (Fig 3). Desio (1968) subdivides the K2 structure into Falchan gneiss (Fg), which forms the base up to 6700 m, and K2 gneiss (K2g), which takes over from these and extends to the peak. Further north are crystalline schists of varying degree of metamorphosis with interspersed banks of quartzite, which strike NE to SW and crop out vertically in the area of the K2 glacier and the Muztagh valley (Pt 1: Y δ 2/5, see Chinese Geological Map 1:1 500 000, sheet 1) (Fig 10, 11, 15). The analyses (A. Heydemann) of the samples which the author had collected here at altitudes between 4200 and 5200 m asl served to identify rocks like hydrothermally decomposed, marked granites and epidote schists. In the area where the Muztagh valley joins the Shaksgam valley series of limestone (calcites, Fig 117) (Fig 31), consisting of massive reef limestone outcrops, exhibit well preserved *glacial roundings, abrasions and polishings.* Besides granites severely marked technologically by diaphthorisis, the Sarpo Laggo and Skamri valleys (the catchment area of the Muztagh valley) yield siltite-biotite-schist, chlorite schist, biotite- and di-mica granite, mica schist, and silt- and sandstone, all of which are more or less tectonically or hydrothermally marked. North of the fold on which the Shaksgam valley is situated, the dolomites (P 1; K 2) of the Aghil range set in, building up the immediately adjacent, steep, orographic right-hand valley flank (cf. Fig 117; Fig 85). The peak region of the Aghil, too, is partly composed of granites (Y δ 2/5). Limestone as well as granite outcrop in the valley N of the Aghil pass (Fig 87; 90). The Aghil N- slope consists of granites, quartzites and reddish sandstone series (P 1, K 2), which slope down to the orographic left- hand tributary valleys of the Yarkand valley, and to the valleys and gorges of the Surukwat (Fig 138, 22). The Yarkand valley extends from the confluence with the main Surukwat valley up to the military station at Mazar through phyllites of differing degrees of metamorphosis (S 2–3 and S 1) (Fig 103; Fig 105). A granite zone projects into its orographic right-hand side from the NW (Y δ 1/5), forming the very *resistant core* of the Kuenlun main crest (Fig 60, Nos. 1, 2; Fig 61, 64), and enables narrow, steep-flanked gorges and V-shaped valleys to develop among the transverse valleys.

Within the area under investigation, not only the rock composition of the main crest of the Kuenlun range but also of those further down to the N alternate between granites and crystalline schists (metamorphites). 4950 m high, the "Mazar Pass" consists of metamorphosed sedimentary rock (phyllites) (S 1) (Fig 54). According to the author's petrographic samples analysed by A. Heydemann, the metamorphic sedimentary rocks of the Yarkand valley E and W of Mazar contain quartziferous marble, tectonically marked greywacke and sandstone, chlorite schist, albite-amphibolite, chlorite-amphibolite, mylonite,

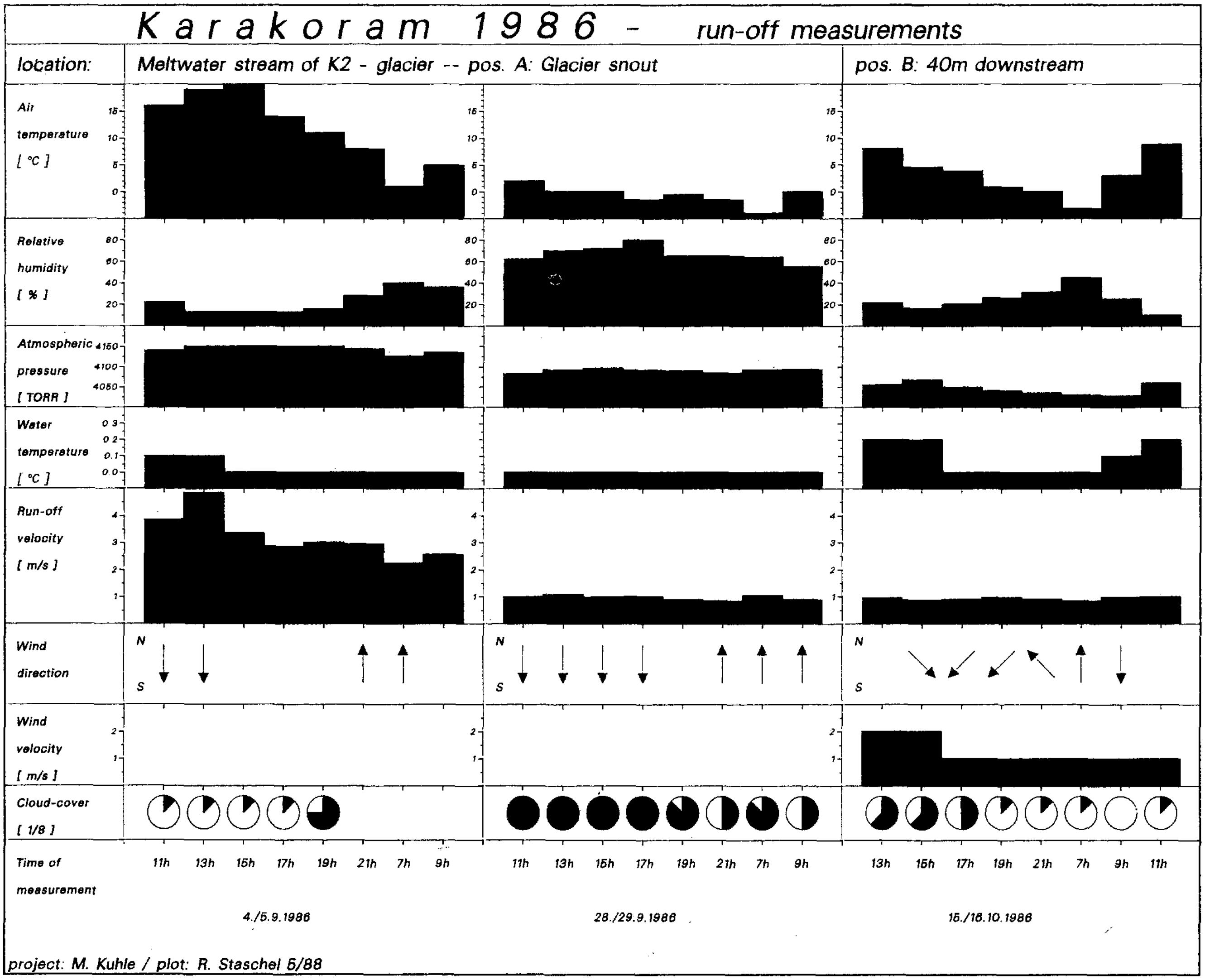


Fig 29 Climatic parameters and meltwater run-off on the K2 glacier (measurements by H. Dietrich). Representative interplay of the essential climatic parameters for the run-off situation in Karakorum glaciers of medium length (15–25 km). Increasing glacier length delays and mutes the reaction of the quantity of run-off on the weather.

di-mica schist, biotite schist, siltstone, muscovite-bearing quartzite, quartzitic sandstone and a quartz-pegmatite dyke. In accordance with resistance, the more than 6000 m-high main peaks of the Kuenlun are composed of the granites (Y 1/5; Pt 2/2) (Fig 21; 53; 58). In the N, the Kudi valley down-stream, crystalline schists in varying stages of development, metamorphic sandstones, marl, mud- and siltstone alternate with granites; together with limestones they present the surface-forming rocks on the northern edge of the mountains in places where the rocky ribs of the Kuenlun slope dip under the alluviones and foothill moraines towards the Tarim Basin (Pt 1/2; Pt 2/2; Pt 1/3:Z; Pt 3; P 2; C 3) (Fig 112). Information beyond the listed observations in the field and the laboratories and their petrographic classification may be found in the Chinese Geological Map 1:1 500 000 sheet 1 (see above).

3 Present Glaciers in the Karakorum, Aghil and Kuenlun and their Balance

3.1 The Karakorum North Slope

This is not the place to present a description of the present glaciers of the Karakorum, particularly since the exemplary research carried out by Visser (1934, 1935, 1938) during expeditions in the Shimshal area (NW Karakorum, leading to the S-slope) and to the Saltoro-Saser and Rimo-

Muztagh (E-Karakorum) has produced a survey of this glaciation. Here only *some* of the *main features* of the Karakorum glaciers in the area under investigation on the Central Karakorum N-slope will be addressed with regard to *qualities* of the local high mountain glaciers already present during the *Ice Ages.* In former times, in the face of an ELA depression of 1000 m (cf. below), these glaciers even flowed down from lower mountain groups now no longer covered by glaciers. It follows that these remarks contain the intention to present the situation by means of the *actuality principle.* In the case of the Karakorum glaciers especially - which are now forming the world's most extensive valley glaciation outside the arctic regions - *compound glacier feeding* (cf. Visser 1934, pp. 137–139; H. J. Schneider 1962, pp. 278–281) from primary precipitation in névé basins (Fig 1a, O and 2, O) or on firn stream sections prevails, together with the secondary feeding from avalanches (Fig 1a ↓ and 2↓, 3 ↓▽, 4 ▽, 12 ↓▽). Measurements carried out in the highest catchment areas above the snow line along the 23 km long K2 glacier between mid-September and mid-October showed c. 70 cm of freshly fallen snow (Fig 1a □ left). At the same time, medium-sized to *very large ice avalanches* (Fig. 1a ↓) were observed with considerable frequency (cf. Shen Yongping 1991, pp. 249–254). Discharges of this kind left from the séracs of the 3400 m-high NNE and NW walls of K2 (Fig 3 ▽ ↓; 4 ▽). In the course of their 1500 m drop the large *ice avalanches* disintegrate into powdery ice avalanches. They continue along the two glacier source branches for some kilometres, and even surge up against the opposite slopes. In some cases the particles of such giant avalanches even leapfrog across the next transverse ridge (ie Fig 1a between 3 and 6). The author observed table- to room-sized gneiss boulders which had been torn out of the wall by such avalanches (cf. Fig 5 O, 6 O). In all four 15 to 43 km-long glaciers, with a total area of 710 km^2 have been investigated; they range from the firn caldron to the firn stream type with compound feeding (cf. Kuhle 1988, pp. 561, 562, Figs, 4, 5).

The examples of the K2 and Skyang Kangri glacier, together with the *largest* glacier in the study area, the 43 km-long Skamri glacier (Fig 9, 47), present classic dendritic valley glacier systems, the tributary components of which are often linked by *ice falls* extending over several hundred metre-high *confluence steps* (Fig 1a, 6, 9, 10, 11, 12, 15, 44). The formations of ice pyramids, up to 25 m-high (Fig 10, 11, 12, 13, 15) are not only the result of the combination of overlying and subjacent glaciers as defined by Visser (1938, pp. 57–74), but also of the hanging and overlying *avalanche cones* (cf. Kuhle 1987a pp. 207–212) (Figs. 1a, 2, 5, 12, 19) which dip towards the glacier. *Ice avalanche transport* also explains the up to one metre-thick and approximately *horizontal inter- morainic strata* between overlying and subjacent glaciers (Fig 17 ■). The *mechanism of ice avalanches* is able to tear the till out of its embedment in the steep and up to several kilometre-high glacier walls (see above). This explains the accumulation of debris at the foot of the overlying glacier (■) *without* preceding melting

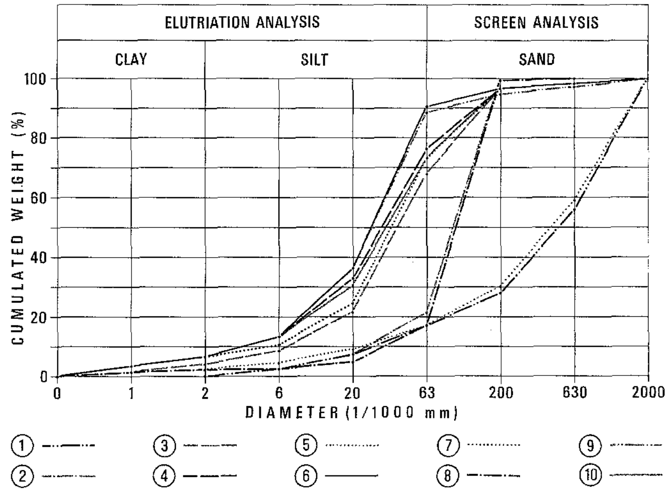


Fig 55 Cumulative Frequency Grain-Size curves from different clastic materials from the karakoram region. Quaternary sediments in the arid high-mountain environment between the Aghil main chain, over the western Kuenlun to the northern piedmont areas leading down into the Tarim Basin (37°46'N/36°24'N; altitud between 1480 and 3900 m asl), sub-2 mm fractions. Curves 2 and 8 show grain-size distribution from widespread, 1 to 2° inclined glaciofluvial fans on the piedmonts at 1480 m, more than 60 km away from the solid rock of the mountains. Curve 6 (till; 3740 m) shows the same characteristics as curve 9 (mudflow). In both cases the source rock is the Kuenlun granite, and the distance of transport amounts 15 km. Curves 1 and 5 are characteristic for alluvial terraces at the bottom of the Yarkand Valley (3800 m asl); the material contains granites from the Kuenlun slope and metamorphic rock (clay, silt and sandstones) from the Aghil slope.

processes of significance. It follows that it can also be brought about by the avalanche mechanism *only.* Having been torn out of the steep wall or wall gorge by the ice avalanches (cf. Fig 3 ↓) the boulder debris is taken up by the avalanche at the base, ie the bottom side. It will maintain this position among the downward-moving masses because its density is two and half times that of the falling ice debris, and is thus able to achieve a greater velocity of fall thanks to its *proportionately more limited* air resistance. The early *separation of the position* of the two materials as a result of their *specific gravity* during their fall from the wall is largely maintained right through to sedimentation in the ice avalanche cone at the foot of the wall, ie mixing does not take place.

3.1.1 The upper climatic glacier limit in the Karakorum

According to the detailed description of the Himalaya and the specific example of the Mt. Everest massif, an *upper climatic glacier* limit can be determined (Kuhle 1986, 1986 i). Wherever High Himalayan peaks rise above 7500–7700m, this limit can be seen distinctly not only between 7200–7400 m asl but can also be established at the same time on a numerical-statistical basis by regression analysis based on telemetric measurements of surface temperatures taken by infra-red thermometer. On Mt. Everest (27°59'16"N) a level is reached at 7200–7400 m where surface temperatures of the mountain flanks almost never reach temperatures near the melting point – it remains permanently frozen. On the contrary, average temperatures here remain at about -20 °C to -30°C, rarely rising above -10°C, so that a snow-to-ice metamorphosis as a result of sintering and ice bridge formation between the snow crystals *relatively warm* snow temperatures bring about, does not take place. At this altitude "temperature metamorphism" near the melting point is merely replaced by much slower bending processes of the *molecular diffusion* and by *pressure compaction,* so that the snow is blown off the steep mountain flanks before it is able to acquire sufficient local stability by adherence to the underlying rock (Fig 4 O). At this altitude *large* areas of rock are visible and the aforementioned *upper glacier limit* is reached. With ridges and summits rising to about 6500–7000 m asl, the peaks W of K2 have not penetrated that upper glacier limit (Fig 18) since even their steep parts are almost completely covered by *flank ice* (∇) and support permanent metre-to-decametre thick cornices of ice, firn-ice and firn (↑ ↓O). The same applies to the c. 6300–6500 m-high peaks of the orographic left-hand catchment area of the Skyang Kangri glacier (Fig 2). In spite of prevailing *high* wind velocities in the summit areas of the mountains, the ice and firn covers of the peaks are not diminished (Fig 12). Fig 4 shows the WNW wall of K2 (No. 1, 8611 or 8617 m), featuring a *vertical dissection.* The *lower* flank section is covered by steep flank ice which is pierced by similarly iced-up rock heads, ribs and precipices (Fig 4 ▽). On the *flattened* mountain shoulder, which borders on the lower steep section (Sla. Savoia, 6626 – c. 6700 m asl) decametre-thick superimposed layers of ice and firn can be identified at the break lines of the ice cascades (Fig 4 ∇ right). Higher up, at about 6850–6900 m, they are followed by almost ice-*free rock wall surfaces,* which form the final rise to the peak (Fig 4 O). *Small-scale* embedments of firn ice, firn and snow only appear in the ac- and ab- granite clefts and in its banking joints, on narrow rock ledges and cornices behind rock precipices, pillars and minarets, and in many scarfs left by smaller rock-falls (Fig 4 above - - - -). Up there the upper glacier limit has been reached and surpassed. The altitudinal value of the *upper glacier limit* at about 6900–7100m asl is, of course, only to be regarded as an approximation in this place (- - - -) since *steepness of walls* and *wind exposure* exert a modifying influence upon the *effective* upper limit between flank ice surface and exposed rock surface. *Corrasion* and *deflation* raise the snow particles from the underlying rock surface, while varying *inclinations of slopes and walls,* together with gravity, cause *downward displacement* of particles of snow and firn. The shifting of particles at the same altitudinal level which would take place on horizontally extended planes, is replaced by *downhill transport.* A glance into the N-wall of K2 (Fig 19) provides more detailed information on this correlation: in spite of even greater steepness (45- 70 ° overall) than that of the WNW-wall, 70% of its lower part is covered by thick flank ice which is forming a dump escarpment (Fig 19 ▽). But even the remaining 30% of the surface, where the rock is yet steeper and consequently unable to provide a hold for those flank ice ramps, is almost totally *encrusted* with ice and firn ice (Fig 19 below \↙). Higher up, between the altitudes of 6600 m and 6800–6900 m, this glaciation of walls ceases though there is *no change* in the angle of the wall (Fig 19 \↙). Lower temperatures on the N-wall are the reason for the upper glacier limit on the WNW-wall setting in at a higher altitude than on the N-wall. Even further above – and this provides a kind of counter-check – the wall recedes and becomes *flatter.* Yet once again the layers of ice and firn do not increase (Fig 19 over \↙; Fig 3), but remain as they were before and the same applies to the WNW-wall above 6900–7100 m (Fig 19 above - - - - right). There is one striking exception: the hanging glacier (Fig 19 □) in the lancette-shaped and widened gorge in the wall which, starting immediately below the summit, descends about 2000 m, from 8600m to 6600 m asl (Fig 3, from O to ↓). The hanging glacier insert (□) appears in the upper 1000 metres into steep spalling at about 7650 m asl (Fig 19 ♦, 3 ∇). Below, confined on both sides by marginal furrows (Fig 3 ∇ to ↓), the wall gorge sets in, its here still relatively wide front eroded by spalling ice avalanches; this hanging glacier in a wall niche owes its existence to a *stable leeward slope position.* Sheltered from winds, this position prevents deflation, whilst causing the continued supply of *drifting snow* from SW, S and E mountain flanks through the formation of *lee vortexes.* An analagous situation occurs on the N-wall of Mt. Everest where, protected from winds by the Norton couloir, a comparable hanging glacier with balcony-like spalling was able to develop in an equally stable leeward position at 7450 m asl (Kuhle 1986, p. 152, photo 3). This evidence of a *climatic upper glacier limit* includes a *reduction* of glacier feeding areas beneath very high mountains. In this case *only some* of the snow supply from the NE, N and WNW-walls of K2 enters the secondary feeding of the K2 glacier. The other part of the snow masses in question is *blown out* of its catchment area, and drifts several kilometres further E on the prevailing W wind into the catchment area of the adjacent Skyang Kangri glacier. These glaciological-geomorphological observations were supplemented by telemetric measurements obtained with infra-red tele-thermometers during the warmest part of the year and day and statistically evaluated for the *thermal validation* of the climatic upper glacier limit (see Tab 1). The *climatic upper limit of glaciation* is becoming much more important for the main glacial one because it had been depressed by c. 1200 m, and thus almost lowered to the wall-foot area of the peaks towering above the present valley glaciers (cf. Kuhle 1986 i,

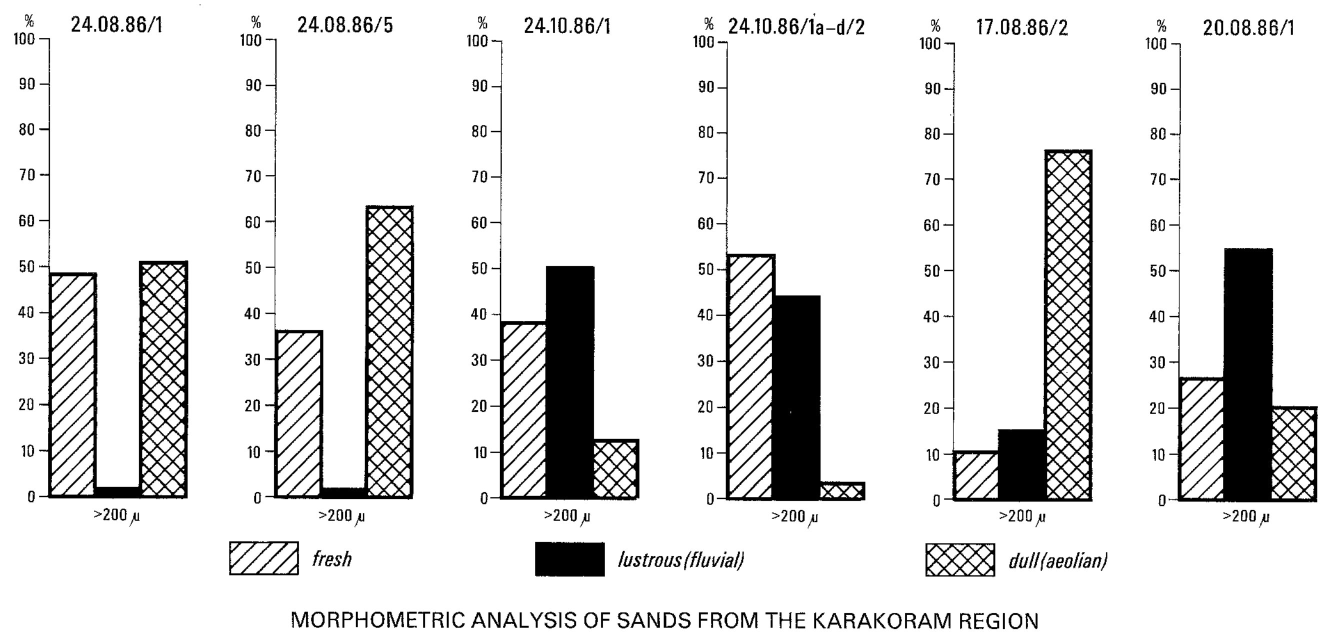


Fig 56 Surface texture of sediment grains greater than 200 μm. Samples 24. 8. 86/1 and /5 (cf. Fig 66, Nos. 1,7) show the characteristics of very briefly transported (less than 10 km) gravel and talus material from a canyon in the Kuenlun: fresh, angular grains (I) have the same portion as the aeolian grains (III), while the fluviatile-polished material (II) is almost completely lacking. Samples 24. 10. 86/1 and 24. 10. 86/1a-d/2 were all taken from outwash terraces in the semi-arid Yarkand valley; however, the distance to the source areas varies. With a greater transport distance, sample 24. 10. 86/1 shows a predominance of group II (fluvial grains), followed by the aeolian material (III) and has only a very small portion of group I. Due to the comparably long fluviatile transport of sediment 17.08.86/2(cf. Fig 55, No. 8) group I (angular, fresh) takes almost no part in it. In group III aeolian transport predominates which is typical for sediments of 200 μm in full-arid environments. Sample 20. 8. 86/1 (cf. Fig 55, No. 6) shows the characteristics of a till at a distance of up to 15 km from the source area. The fluviatile-polished grains (II) are predominant; it cannot be determined on each grain whether the group I grains must attributed to normal weathering or to glacial erosion and transport, but most of this substratum has been pounded and fractured by the glacier and shows cresent-shaped chattermarks on the grain surfaces. The aeolian material (III) still has a portion of 20% and seems to have been blown from a distance.

pp. 344/45). This resulted in a *widespread lack* of Ice Age valley feeding from the high peaks and steep flanks towering above the extensive glacier areas as "dry" rock structures, free of ice and firn. At the same time this was also validated by raised glacier levels. The relative height of the steep flanks was thus shortened from below. Hence *primary feeding* prevailed during the Ice Age, whereas avalanche feeding predominates now and is recognized as a characteristic feature of the Karakorum glaciers (cf. Ch. 7).

3.2 The Aghil Range and the Kuenlun Section of the Study Area

In contrast to the Karakorum, the present extent of the glaciation of these mountain groups is small. Higher peaks reach altitudes of max 6858 m, but there are no major expanses above 6000 m asl, so that significantly *smaller* catchment areas are available for glacier feeding when the climatic snow line runs at about 5300 m asl (Fig 138). In this respect even the *valley floor levels* are important; thanks to its central position in the mass uplift area of western High Asia, ie its greater distance from the relative erosion level of the piedmont areas, their mean elevation in the Karakorum is several hundred metres higher (at about 4100–5500 m on the Karakorum N-slope) than in the Aghil and Kuenlun. But even in the Karakorum *hanging glaciers* and *corrie (cirque) glaciers* (Fig 20 □) occur wherever catchment areas as lowered, upper denudation level on marginal narrow peaks (interferences of slopes and walls in the peak) rise somewhat above 6000 m. In contrast to the Karakorum, these small glaciers represent the *characteristic type* in the Aghil and Kuenlun (Fig 26 ○). The small, several hundred to a few kilometres-long hanging glaciers certainly *dominate numerically,* whereas in the Aghil only a single valley glacier extends to 8km; it is located on the N-exposition of the 6750m massif (36°20'N/ 76°20'E). The remaining 15 valley glaciers in the area under investigation in the Aghil are shorter, and have smaller surface areas (Fig 22 □, 138). In spite of the larger glacier area in the Kuenlun section of the study area, the 13 fully formed valley glaciers do not reach more significant length either (Fig 21 ○). The *small vertical distance* of the Aghil and Kuenlun glaciers results in glacier tongues dipping only a few hundred metres below the ELA, so that these small glaciers move within a relatively small climatic altitudinal belt. As these are *arid* mountain areas, the *mass turn-over* of these glaciers is *small* (Kuhle 1990 c).

These glaciers are chiefly maintained by *low* mean annual temperatures, and less so by the small quantities of precipitation. These conditions correspond to those of the extensive Karakorum glacier near the ELA where relevant measurements were carried out during the 1986 expedition. The ELA on the K2 glacier was determined by the Lichtenecker method (1938: uppermost middle moraine boulders emerging from glaciation plus 50m) as running at 5300 m asl. According to the gradient of 0.6–0.7 °C/100 m measured on the K2 glacier between 3960 and 5330m asl, the mean annual temperature at the ELA is −10.1° to −12.3 °C. This is the equivalent of the ice temperature +1 °C at a glacier depth of more than 10 m, and establishes the identity of *cold-continental* glaciers (Kuhle 1987 i, pp. 413–414). On 6.10.1986 Xie Zichu et al (1987, p. 10) measured −6 °C at an ice depth of 10 m at 5300 m asl.

In contrast to amounts of ablation measured in the Karakorum (cf. below) these values are transferable to Aghil and Kuenlun. These are evidence of a *cold type of glacier* found there, corresponding with the terminology of Lagally (1932) and Ahlmann (1935). Only glaciers with tongues that descend a little too deeply produce seasonal run-off, thereby changing from the typological categories of cold to *temperate glaciers*. This applies only to the *valley glaciers* of the Aghil and Kuenlun (Fig 21 ○, Fig 22 □). Unlike the Aghil and Kuenlun this *thermal* glacier type is *representative* of the Karakorum (Fig 9, 23 ◇, 45, 46 left quarter). This juxtaposition explains an essential dependence of the thermic glacier type on *vertical distance:* the further the glacier catchment areas rise above the ELA, the further the glacier tongue ends descend into warmer climatic belts, with the result, that their part in *melting ablation* is strikingly more important than that of the smaller glaciers of the Aghil and Kuenlun, which are almost exclusively concerned with *sublimation ablation* (evaporation ablation). Thanks to their small thickness, the very short glaciers and *firn shields scarcely flow at all,* and thus form soft, cushion-shaped, convex, marginally rounded, superimposed strata of ice lacking séracs (Fig 24, 87 upper margin, 1 a ◇ left 5 ◇); some of these contours are caused by *wind forms* such as wind flutes and snow ridges due to drifting (Fig 25 ○). The rather larger, more dynamic hanging glaciers, on the other hand, which already taper off in tongues ceased in downward direction with scarped margins, typical of cold glaciers (Fig 6 ◇◇, 20 □ left, 21 ○, 26 ○, 27 ○, 86 left side, above). Though typical of Karakorum glaciers there is a *lack* of ice pyramids in the Aghil and Kuenlun glaciers. This is not the result of climatic differences, as *global radiation* responsible for *ice pyramid formation* does *not* decrease significantly over the short distance of a few kilometres to the north. To begin with, this difference is due to the much smaller *length of the glaciers.* Ice pyramid formation requires a glacier tongue of more than c. 5 km *below* the snow line (ELA). A second factor is the necessity of a *steep* catchment area with avalanche feeding or over-thrust of a tributary glacier, so as to provide an overlying body of ice or a hanging glacier. Thirdly, glacier fractures (ice falls, séracs) preparing ice decomposition are favourable.

3.3 Further Features of the Mass Balance of Present Glaciers in the Area under Investigation

The *ablation* rate of the K2 glacier amounts to c. 1200–1300 mm/year, of the Skamri glacier c. 1300–1400 m/year and of the Sarpo Laggo glacier at least about 1500 m/year (Ding Yongjian 1987), whilst values of around 600–700 m/year are indicated by Ding (1987, p. 15, Tab 5) for the NE Karakorum glaciers. Evidence of 5 cm-thick *stalky water ice* among seasonal superimposed ice at 0.4–0.8 m below the firn surface ("infiltration congelation zone") at the level of the snow line (somewhat below a cold "recrystalline infiltration zone") also argues for the view that the classification of glaciers as presented above does not do justice to the *hygric change* in all its features when considering the altitude and the great *temperature amplitude* towards the snow line level. Compared with the glaciers of the Himalaya N-side and the Qilian Shan the more extreme division of the Karakorum glaciers into a *semi-arid, warm-in-summer zone* of glacier ablation next to a *cold-humid feeding area* is striking. These sub- *continental* characteristics apply to the glacier systems in question on the Karakorum N-side which terminate at about 4000 m asl. They are reflected in the measurements taken on the K2 glacier in the period 1.9.–18.10.1986: 7 precipitation events at 4120m asl (glacier termination) produced a total of 1.0 mm; at 4660m asl in the period 11.9.–8.10.1986: 15 events - a total of 33.5 mm; at 5150 m asl over the period 12.9.–8.10.1986, 15 events - a total of c. 100 mm; snow profiles show *exponential* precipitation increases up to altitudes of 5500 m. In the almost 5 decades since 1937 (cf. Spender map 1:250 000) the K2 glacier (92 km^2) has receded by 1.8 km (36.7 m/y; Fig 23; 30a) (ice margin position: Fig 138 No. 1.; 36°03'N/76°27'E). During the same period the Skamri glacier (380 km^2) has receded by 0.2 km (Fig 9; 47; 49) and persists in this trend as does the Sarpo Laggo glacier (Fig 44, 46 left); whereas the K2 glacier has been advancing again since about 1983. The glacier continued its advance even in 1986, as shown by the *fully convex* front of the glacier tongue (Fig 23, 30a). The advancing tongues and submargins of the 50 *smaller* hanging glaciers, with surface areas of a few km^2 only, are also evidence of a continuously *positive mass balance* on the K2 north slope in 1986. In 1986 consequently the product of temperatures, precipitation and radiation favoured the glaciation (concerning the Alps cf. Kuhn 1983, p. 90). Below the altitude of 4600m asl, the *surface moraine* resulting from avalanche processes, influences the ablation process. At this altitude the K2 surface moraine exceeds 20–30cm (Fig 28, 10 x), and *reduces* the ablation rate to c. 40

mm/ summer month. These observations were carried out between September and October 10 th, 1986. With a superimposed moraine layer of only 3–8 cm (Fig 13 ■; 7 ○) the *most significant* ablation rate of 250–330 mm in the K2 glacier is achieved in this same period.

In the snow line profile short-term calculations of velocity showed K2 glacier movements (Fig 1a near □ on the right; 6 foreground) of at most 10 cm/day. Below the major confluence of tributaries on the orographic left-hand, at about 4750 m (Fig 10, tributary below No. 4) the daily yield in the late summer of 1986 rose to 20–35 cm/ day. Fig 29 records the *meltwater run-off* of the K2 glacier from the beginning of September to the middle of October 1986, and establishes its relationship to the *atmospheric conditions* by measuring the climatic parameter, the interplay of which governs the run-off. The run-off of the melt-water stream analysed (Fig 23 ◇), which emerges from the glacier cave (○) not only contains water from the K2 glacier with its tributary ice streams, but also that from the 8.6 km-long Skyang Kangri glacier (Fig 2; 12) which fails to reach the main valley glacier (Fig 11; 30), so that it drains a total glacier area of c. 143 km^2. After flowing *sub-aerially* for more than 1 km (Fig 30 □-6) down-valley from its glacier outlet in the area of the tributary valley mouth, the meltwaters of the Skyan Kangri glacier enter a cave-like and evidently permanent glacier ice ponor and flow away *under* the main valley glacier (K2 glacier) (Fig 14 ↓). The meltwater discharge of the K2 glacier stream is *representative* of medium-length Karakorum glaciers on the N-slope as functions of air temperature, relative humidity, wind direction, wind velocity, cloud cover and air pressure. The parameters were recorded at the glacier outlet, at 4100 m asl, and again 40m lower down (4060 m asl) in a distance of 1.24 km from the glacier outlet. The late *summer run-off/graph* (measurements were taken – as far as the weather was concerned – on representative days, 4.–5.9.1986) represents *air temperatures* and the curve of *global radiation* with a *minimum of delay.* The more pronounced "run-off peak" between 12 am and 2 pm is explained by the fact that around midday the *insolation ablation* extends furthest up the glacier, whereas *air temperatures* reach their maximum one or two hours later in the afternoon. Though increasing with the flow velocity, the rate of discharge is unlikely to be greater at the height of summer (July and August) than during the prolonged period of fair weather recorded by the expedition in the early part of September, 1986. In October, the *high-continental winter* of the Karakorum N-side has already set in. The almost identical "run-offs" from 28./29.9 and 15./ 16.10.1986 are caused by *differing* weather conditions which *cancel out* the seasonal difference. For reasons of expedition logistics (the return journey over the pass had to be completed before the onset of wintry snowfalls at the end of October 1986) the discharge in winter could not be observed. It is likely to be almost nil in December and January (probably from November to February), considering the marked frosts of this season at altitudes above 4000 m. The exemplary K2 glacier can

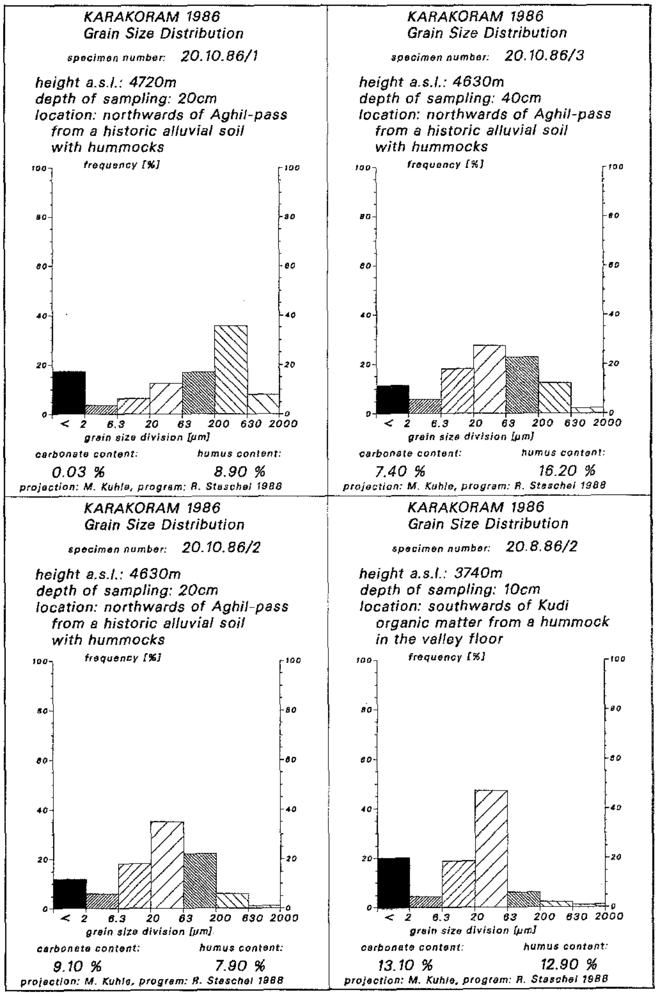


Fig 57 /a (20.10.86/1) Locality: 36°12'10"N/76°36'30"E; /b (20.10.86/2) and /c (20.10.86/3) Locality: 36°13'05"N/ 76°36'E (Fig 138, Nos. 25 and 26) /d (20.8.86/2) Locality: 36°40'25"N/77°04'05"E (Fig 138, No. 17).

therefore be classified as a *temperate* glacier with seasonal run-off.

4. Selected Observations Concerning the Sequence of Historical, Neo-Glacial and Late Glacial Glacier Positions

In the context of investigations concerning Main Ice Age cover, this section is mainly of methodological importance. The most profitable approach in matters of glacier reconstruction is the *reverse chronological order,* starting with the present state and tracing them back to their *maximum* prehistoric glaciation by way of their historical, Holocene and Late Glacial stages, in other words from fresh, well-preserved forms to the older more severely weathered ones. The intervening stages therefore serve as *bridges for the understanding* of the present mountains and valley forms, which have undergone partial transformation through the substantial effect of glaciers of

sample nr.	sample material	sampling	sampling depth	sample location	sample discovery circumstance	konv. ^{14}C-age (YB 1950)	^{14}C content (in % modern)
25.10.86/1	soil in alluvial terrace	exposure	0,30 m	36°27'20"N/76°57'45"E, Yarkand tributary valley, 4 km westward Mazar, Kuen Lun 3800 m asl	lower terrace below fescue of a spring niche root zone depth 0,6 m; granite gravel body, 1,3 m above the receiving stream	(40+/–80) indirect gravel field, glacier-stadium X	99,5+/–1,0
25.10.86/3	soil	exposure in terrace wall	0,30 m	36°27'20"N/76°57'45"E, Yarkand tributary valley, 4 km westward Mazar, Kuen Lun 3800 m asl	lower terrace below fescue of a spring niche s. 1/3 root zone depth 0,5 m; granite gravel body, above the receiving stream	155+/–65 indirect gravel field, glacier-stadium IX	98,1+/–0,8
20.8.86/2	organic material of earth hum-mocks	exposure	0,10 m	36°40'25"N/77°04'05"E, south-ward Kudi-valley up to Mazar-pass; Kuen Lun 3740 m asl	earth hummock in flood area of the mountain river in valley bottom; granitic sand; receiving stream about 2 m deeper; root zone depth 0,15 m	1610+/–90 indirect outwash, middle Dhaulagiri-stadium 'VII	81,1+/–0,9
24.10.86/4	peat horizon	exposure	0,62 m	36°24'N/76°52'E, Yarkand valley orogr. right	alluvial fan orogr. right of Yarkand river, high water bed with sand from metamorphic rock, root zone depth 0,3 m; reed and grass	110+/–60 indirect gravel field, glacier-stadium IX	98,6+/–0,7
20.10.86/1	organi-cally enri-ched soil horizon, peat from alpine grass	exposure at erosion edge, thermo-erosion in permafrost	0,20 m	36°12'10"N/76°36'30"E, Surukwat-valley, north-wards Aghil-pass, Aghil-range, 4720 m asl	erosion edge at spring grass in pre-recent alluvial fan material on morainic diamictites; granite-limestone-debris mixture; root zone depth 0,25 m	1655+/–180 indirect out-wash cone, middle-Dhaulagiri-stadium VI	81,8+/–0,8
20.10.86/2	organi-cally enri-ched soil horizon, peat from alpine grass	exposure at erosion edge, thermo-erosion in permafrost	0,20 m	36°13'05"N/76°36'E, Surukwat-valley, north-wards Aghil-pass, Aghil-range, 4630 m asl	erosion edge in pre-recent allu-vial fan material with earth hum-mocks on surface; granite-lime-stone-debris mixture; root zone depth 0,2 m	355+/–80 indirect out-wash cone, jounger Dhaulagiri-stadium VII	95,7+/–1,0
20.10.86/3	organi-cally enri-ched soil horizon, peat from alpine grass	exposure at erosion edge,	0,40 m	36°13'05"N/76°36'E, Surukwat-valley, north-wards Aghil-pass, Aghil-range, 4630 m asl	erosion edge in pre-recent allu-vial fan material with earth hum-mocks on surface; granite-lime-stone mixture; root zone depth 0,2 m	6205+/–145 indirect out-wash cone, Sirkung-stadium IV	46,2+/–0,8
15.10.86/1	lower moor peat	drilling core	0,20 m	36°03'N/76°25'20"E, Muztagh-valley, orogr. right, Karakoram 3950 m asl	spring fan, central position homo-geneous spring meadow peat; root zone depth max. 0,15 m; granite and quarzite debris, receiving stream about 12 m deeper, vegetation with earth hummock and hollow formation and alternative stagnating moisture	730+/–100	91,3+/–1,1
15.10.86/2	peat	exposure	0,80 m	36°03'N/76°25'20"E, Muztagh-valley, orogr. right, Karakoram 3990 m asl	riparian exposure below moor homo-geneous spring fen peat; root zone max 0,30 m deep; granite and quar-zite debris receiving stream 2 m deeper	2575+/–170	72,5+/–1,5
15.10.86/4	mud	exposure	1,00 m	36°03'N/76°25'20"E, Muztagh-valley, orogr. right, Karakoram 3990 m asl	moor, spring grass; pelites from granite and quarzite; receiving stream about 2 m deeper; root zone max. up to 30 cm deep; riparian exposure, 1 m below surface	12870+/–180 ground moraine late glacial period, Dhampu- or Sirkung-stadium IV	20,1+/–0,4
15.10.86/5	peat	exposure	1,20 m	36°03'N/76°25'20"E, Muztagh-valley, orogr. right, Karakoram 3964 m asl	riparian exposure lower terrace a more fluvial influenced area of sedimentation; gneis and phyllite gravel body with accumulated peat layer; root zone depth 0,2 m	3450+/–135 indirect out-wash, Nauri-stadium V	65,1+/–1,1

sample nr.	sample material	sampling	sampling depth	sample location	sample discovery circumstance	konv.^{14}C-age (YB 1950)	^{14}C content (in % modern)
24.10.86/1b	peat samples	exposure undercut by river	1,00 m	36°24'N/76°52'E, Yarkand-valley, orogr. right; Kuen Lun, 3760 m asl	alluvial flood soil with alpine meadow peat; erosion edge in the alluvial fan region; reed cover, sampling depth of the peat clay resp. the roots 100 cm receiving stream c. 60 cm lower; depth of root zone c. 0,3 m	4580+/–65	56,6+/–0,5
24.10.86/c	s. 1b					5935+/–85 indirect gravel field, Sirkung-stadium IV	47,7+/0,5
24.10.86/d	s. 1b/1c					1925+/–120	78,7+/–1,2

Tab 2 Samples for radiometric dating (C14) with their localities and thus detailed description in the area under investigation by the 1986 expedition. Laboratory analysis: M. A. Geyh in the Lower Saxony State Office for Soil Research, Hannover, Germany.

less than Main Ice Age size, although only exemplary localities will be mentioned.

The *reverse chronological* transition from the present glaciation of the transverse valleys (tributary valleys) in the Karakorum to the prehistoric (Late to Main Glacial) glacier infilling of the longitudinal valleys (main valleys) is best recorded within the *inter-connected* piedmont plains of the K2, Sarpo Laggo and the Skamri glaciers in the study area, as this is the place where the *former* confluence of these three medium to large-sized valley glaciers can be reconstructed in detail, such as to form a continuous dendritic glacier system. At the time of the confluence also the Shaksgam valley, as the N-Karakorum longitudinal valley, was linked to and partly in-filled by this glacier system.

4.1 The Moraines in the Forefield of the K2 Glacier

The historical glacier retreat from an ice margin position at a distance of 1.8 km from the present glacier end since the year 1937 has already been mentioned above (cf. Ch. 3.3). The ice margin is marked by converging *block ramparts* running conically to the talweg (Fig 138, No. 1).

An even more distinctive moraine locality occurs at 4060 m asl, the level which the K2 stream has cut down to into the very thick moraines. Here, at a distance of about 2.2 km from the present glacier tongue, the *lateral moraines* which have been preserved along both sides of the valley meet to form a *several* hundred-metre-high arc of end moraines (36°03'30"N/76°28'E; Fig 138 No. 2; 30 a ▸ top). The moraine outcrop walls uncovered by the stream cutting into them show the essential *characteristics* of glacier diamictites (Fig 31 ●). The outcrop front is divided into *diamictites* in the underlying bed (●) and *sorted* outwash sediments in the overlying bed (X). The diamictites show *glacio-tectonic* disturbances (minor faulting of materials of varying grain sizes and consistencies along upthrust slickensides and wedges thrown against one another ◂), flexures and readily distinguishable morainic strata with a typical salinebanking structure (◇). The overlying layers of gravel have been deposited in a small lateral valley, a lateral glacial trough between the valley slope and the right-hand glacier margin. The *compressions,* in particular, point to this moraine complex as *end moraine* rather than as lateral moraine - the latter being joined further up valley (on the right). The granites and metamorphites of the crystalline schists in the catchment area are completely preserved. Fig. 32 shows the lateral moraine terraces (V, VI) on the valley flanks, which provide the upstream link with the glacier surface of which this ice margin had been a part. These *impermeable* boulder clays disintegrate in *landslides* and *mudflows* during thaws and rainfalls and, following the retreat of the glacier and thus the loss of its resistance, have slipped down to the valley floor in recent times (decades) (Fig 23 ↙). There they are washed away by the valley stream (◇), so that none but the very coarse boulders remain on the valley floor (□). Fig 32 shows a *whole series* of lateral moraine edges (V) on the orographic right-hand, which are part of the *end moraine complex* of the outcrop described above (Fig 31). United in a *single* body of accumulations, these 5-7 generations of lateral moraine are younger than the 12 870±180 YBP (Tab 2 sample 15. 10. 86/4.) This C-14 date represents the *oldest* one in the sediments among those of the valley floor in the Muztagh valley (Fig 36 X). This is the locality of the confluence of the K2, Skamri and Sarpo Laggo glaciers which must have been ice-free even at that time.

This indication, this necessary classification in the *post*-Late Glacial period, suggests the neo-Glacial period between c. 4500 and 2000 YBP (cf. Kuhle 1986e, pp. 439-454; 1987c, p. 205, Tab 2; Shiraiwa and Watanabe 1991, p. 404) as the time of the formation of this moraine sequence.

No longer reached by ice, the valley floor level of the confluence area at 3920 m asl is evidence of the possibility that this *sequence of ice margin positions* reflects glacier positions in the ELA depressions of at most 100 m (present glacier termination: 4120 m; pre-historic glacier termination: no less than 3920 m asl; difference in elevation = 200 m : 2 = 100 m). It follows that these *ice margin positions* belong to a *neo-Glacial* to *historical (Little Ice Age?)* orographical snow line level at about 5200 m asl. In view of this ELA depression, the question arises of how old the last junction of the Skyang Kangri glacier with the K2 glacier is (Fig 11; 30; 138 No. 3; 30 a ▸ bottom). In *contrast* to the K2 glacier (main glacier) the Skyang Kangri glacier was *retreating* in 1986. With a debris cover measuring only a few decimetres in thickness, the tongue has *flat* longitudinal and cross-profiles at its end, thus indicating that back-melting is in progress. Squeezed against the southerly valley flank, its *asymmetric* position (Fig 11 ○; 30 xx on the right) corresponds to the shadow cast by the peaks to the S, which shield the ice from the markedly intensive midday radiation of this almost *subtropical* latitude. The remnants of *dead ice* on the orographic right-hand (Fig 11 ◇; 30 ◇) are indicators of the width of the tongue end *some years,* or a few decades, ago. At that time - and the *geometry of the ground-plan* of the former glacier tongue is evidence of this - the Skyang Kangri glacier reached the confluence with K2 main ice stream (Fig 30 a ▸ bottom). The ELA which was part of it ran just a few decametres below the present one. The *last confluence* of the two glaciers therefore belongs to the 1937 glacier edge of the K2 (Fig 138, No. 1) (see above), or to an even later advance, as suggested by the air photo (Fig 30 a). During the *preceding* historical to Holocene glacier positions (from the "Little Ice Age" back to the neo-Glacial period) there was a much heavier influx of ice from the Skyang Kangri glacier. It is most easily associated with the end moraines observed 2.2 km outside the present K2 glacier end (Fig 138, No. 2). Evidence of this *somewhat older* confluence is available in well preserved, orographic right-hand *flank abrasions and polishings* with a marked glacial polishing line (Fig 30 ▲, bottom right, 11 ◥ left). At that time the tongue of this tributary glacier *not only* reached the K2 glacier, but also turned entirely into the main valley, where it *settled down* on the right of the K2 glacier. The height of an end moraine gusset (Fig 30 X) provides evidence of the decametre-thick, historical to neo-Glacial glacier confluence. Thanks to *glacial flank abrasion and polishing* up to 200 m above the valley floor (Fig 30 ⋓, bottom right), largely without traces of weathering, and not even showing dark water lines (which only set in above), this confluence is attributed to the "Little Ice Age" (most recent Dhaulagiri Stage VIII or IX according to Kuhle 1982, p. 165 et seq.). In the central Himalaya the Dhaulagiri Stage VIII or IX is credited with an ELA depression of 40 m (Dhaulagiri-Annapurna-Himal; Kuhle 1982, p. 166) or 80–100 m (Khumbu-Himal; Kuhle 1986e, p. 454; 1987c, p. 205). The pertinent glacier level of the most recent Dhaulagiri Stage VIII or IX is preserved by a c. 150–200 m high lateral moraine ridge upstream on the orographic right-hand of the Skyang Kangri glacier (Fig 12 IX, right).

4.1.1. Some aspects of the preservation of prehistoric glacier levels: the case of historic glacier advances

Along the edges of the K2 glacier and its tributary ice streams only, and apparently *inevitably,* a very *sporadic* chain of indications of even the most recent historic glacier levels can be gained. The majority of the edge sections of the valley flanks have meanwhile been undercut by the lowered glacier edge, so that gullies, minor wall gorges and talus cones spilling out from them have become established on the new glacier edge within the short time of a few decades (Fig 34 X ↘ ▲). Frost weathering as well as rock falls due to the steepness of slopes, and *denudation* through avalanche abrasion and polishing which also grinds out gullies and wall gorges, all combine to destroy the historical polishing and abrasion limits and the lateral moraine ledges, which are limited to the area below the snow line. The destruction of the latter is accelerated by *undercutting* (Fig 10, right hand quarter; 28 ▽▽; 47 ↑↑; 49; 23). These conditions *contrast* with the abrasion and polishing that is simultaneously taking place below; they apply particularly to the *more steeply-draining* tributary glaciers, the polished or abraded edges of which are topped by deeply gullied, strikingly precipitous rock walls; they have disintegrated as a result of frost weathering, but contain little loose material (Fig 15 ⇦ ⇨; 10 below - - - -; 7 below - - - -). Nonetheless remnants of lateral moraines have ben preserved in a *few* places (Fig 12 IX and X, centre), though at times not a genuine, morphologically-formed ledge, but merely a *ground moraine* or *lateral moraine material* that clings to the valley flank - like the only remains of the inner slope of a lateral moraine (Fig 9 ↓↓; 47 ↑↑; 23 ■). In the lower third of the valley glacier courses there are *ablation valleys* near the S- and W- facing valley sides, the increasing width of which require intermediate space between the glacier edge and valley slope (Fig 30 □-6 centre top), so that a direct glacial denudation process is no longer taking place, nor has it done so in historical times (Fig 14 ○○ -6; 16 ○ -6). In the area of these glacial bank valleys various manifestations of an increasingly *melting* ice margin occur in the form of stages of a valley glacier with a *negative* mass balance. At the K2 glacier (below the junction of the Skyang Kangri valley) *mudflow fans* (Fig 16 ◆; 14 X) from the orographic right-hand valley flank are being deposited in the embankment valley downstream below 4650 m. The floor of the embankment valley consists of glacio-fluvial gravels (-6), partly *covering* (○○) the ice of the K2 underlying glacier (□□). The K2 overlying glacier recedes for a few more decametres from the valley flank than the underlying glacier, thus forming a *hard shoulder* for some of the mudflow and gravel deposits (Fig 16 □). In the valley glacier sections where those para-glacial *kames* and *outwash-like* sediments accumulate now, present flank polishing and abrasion are *suspended,* and glacigenic undercutting has *lapsed*. This development of the K2 glacier set in after the Skyang Kangri glacier ceased joining it, and constitutes the *last stage* in the recent glacier development with *negative* mass balance. The Fig 1 a (IX), 5 (IX) and 10 (X) show *another variant of preservation* of a glacier level which existed a few decades ago, but cannot develop unless it occurs *below* the ELA: the relative height of *the lateral moraine on the glacier.* Underneath this kind of *lateral moraine,* the several metres-high thickness of which has frequently been built up by the addition of local debris at the foot of the cliff of the valley flank, older, at times even *dead* (since no longer part of the glacier movements) glacier ice is preserved for decades, ie protected from ablation, thus indicating older, metre-to decametre-*higher, former* glacier surface positions.

In analyses of this kind, concerning indicators of prehistoric glacier levels, it is necessary to take into consideration the *basic fact* that the *level fluctuations* are greatest in the lower glacier sections, near the glacier tongue ends, whilst at the same time the surface height in the feeding area varies only *minimally,* even if the glacier tongue advances or retreats many kilometres. This *up-valley surface convergence* of prehistoric glacier levels *prevents* the initially seemingly obvious synchronocity of individual glacier levels on the basis of absolute differences in the altitudes of the upper edges of lateral moraines in the historic and Holocene glacier tongue basins. At best the respective *altitudinal relationship* of the lateral moraine ledges to one another - staggered upon one another on the valley slopes - would allow a stage to be recognized within the general order (cf. eg Fig 32 V). The *low,* prehistoric glacier levels just above the present glacier surface of the *feeding area* can consequently be synchronized with several tens to hundreds of metres-high *end moraines* at the *glacier end,* or several kilometres further down the valley, as in the case of the historical or even neo-Glacial moraines, in the forefield of the K2 glacier (cf. Fig 31 V). The stages under discussion here are the Sirkung Stage IV (late Late Glacial), the Nauri Stage V and the Dhaulagiri Stages VI to IX; according to the author's nomenclature (Kuhle 1982), they were first introduced for the Dhaulagiri and Annapurna parts of the Himalayas, and subsequently extended to the whole of High Asia (1986 e; 1987 c).

A detailed survey of the *sample valley flanks, selected here* from the K2 glacier valley in view of prehistoric *glacier level indicators* (Fig 1 a; 5; 6), and the glacier sections between the upper framing walls of the surrounding ridges above the snow line, and further up to 4600 m asl, ie to c. 700 m below the snow line in particular, reveals that the preservation of prehistoric glacier horizons is *more than scarce.* In this place nothing but an *integral smoothing* of the valley flank on the orographic left (especially on the E-wall of the 7315 m high satellite peak on the E side) can be diagnosed (Fig 1 a below No. 4 ▲; 6 below No. 1 ▲, left half of the photo), which is *less* pronounced higher up, where some of it disappears under flank ice and hanging glaciers with some ice balconies attached (◇◇).

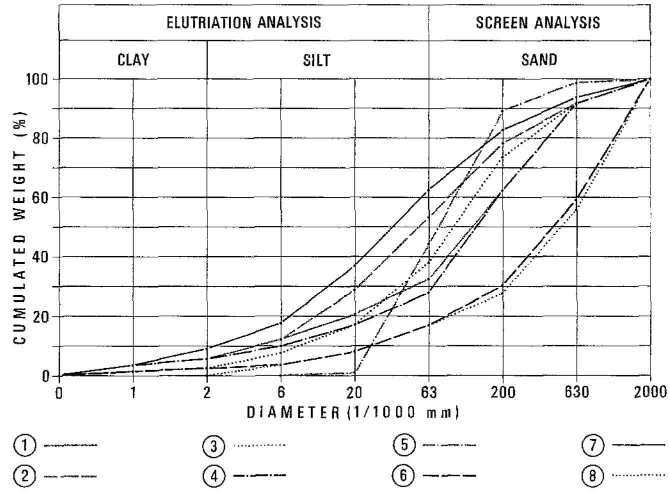


Fig 66 Cumulative frequency grain-size curves form different clastic materials from the Karakorum region. Grain-size curves of alluvial and glaciofluvial sediments. Samples 5 and 8 are from very large gently sloping (1°) glaciofluvial fans on the piedmont. The material is polymict. The distance transported amounts to more than 100 km (3850 m asl). Curves 1, 2, 4 and 7 show gravel deposits with differing admixtures of talus cone material on the bottom of a narrow Kuenlun valley. The granite and metamorphic detritus has been transported 10 km at the most. Curves 3 and 6 show also well-graded gravel deposits consisting of granitic and metamorphic detritus after transport of up to 100 km (middle Yarkand valley; 3800 m asl).

Glacigenic polishings or abrasions are also preserved further downstream. Thanks to the locally differing *interference* of valley wall and rock structure they vary considerably, though truly *significantly better* flank abrasions and polishings cannot be found anywhere (cf. Fig 7 ▲; 10 ▲; 11 ▲ below ----; 15 ☜ ; 28 ▲). Everywhere in this area, snow inserts and periodic meltwaters in *wall gorges and gullies,* and as a result, frost weathering, rock falls and avalanche processes, have *dissected* and *dissolved* the prehistorically intact rock slopes and areas, which could have shown glacier abrasions and polishings, down to the *present glacier surface.*

Only in places where the altitudes of the catchment area of the valley slopes are comparatively low and existing rock conditions favourable, can glacigenic flank polishings or abrasions be more *readily* reconstructed (Fig 32, ▲ right), albeit *without* actually preserved glacier striae anywhere above the present K2 glacier, Skyang Kangri glacier, Sarpo Laggo glacier and Skamri glacier (cf. Fig 44 and 9 below ----; 2 and 12 below ----). Though glacigenically rounded slope sections do occur in many places on the orographic right-hand valley flank of the K2 valley, large sections of them are cloaked by metre-thick debris covers (Fig 1 a ◁; 5 ▽ left hand third of the photo; 6 ▷ right half of the photo;

11 ◁ left third; 10 △ true left; △ true right). Besides the detritus developed in situ, part of these *debris mantles* consists of in places very thick ground and lateral moraine (Fig 10 ⋃; 11 IV, V) deposited on glacigenic slip-off slope sections. Such preserved moraines from a time when the snow line occurred at least 100 m (at about 5200 m asl) below the present one (Fig 5 VI, V; 35 ▷) almost reach up to the snow line (up to 5100–5200 m asl). All these formations of debris and moraines on the orographic right-hand benefit from their W-exposition. Daily increase in temperature coinciding with afternoon radiation both favour *weathering* in the permafrost zone as well as *moraine production* by a process of forced melting.

These observations on glacigenic abrasion and polishing and their *preservation* on the valley flanks *above the present* glacier levels are essential for the assessment of glacial forms in the main valleys of the area under investigation which are a *long* way outwards and down-valley from the present glaciers. In many places of the main valleys glacial rock smoothing and glacier abrasions and polishings are much *better preserved* (cf. Fig 27 ▲; 37 and 38 ▲; 39 ▲; 40; 41; 42) *although* the hardness of rocks is the same. This *contradiction* is regarded as the main reason for the fact that some Chinese authors like Zheng Benxing & Li Jijun (1981), Shi Yafeng & Wang Jing-Tai (1979) and the "Quaternary Glacial Distribution Map of Qinghai-Xizang (Tibet) Plateau" (1991) by the same authors have argued for an only *marginally* more extensive valley glaciation in large parts of High Asia than there is today as the *maximal extent* of *glaciation* during the *Ice Age;* this view has been held for decades, and continues even to these days. The reasoning leading to this error runs as follows: 1. "since the valley flanks do not – or scarcely – show smoothing above the *present* glacier levels, glacier ice during the historic, neo-Glacial or Holocene times cannot have been significantly higher up on the valley flanks"; 2. "what ever was *sporadically* preserved in the way of minor flank abrasions and polishings, and always only a *few* decametres above the glacier levels (cf. above) has been so much transformed that it must be regarded as belonging to the Ice Age at the latest, otherwise the polishing forms ought to be much better preserved". On the other hand the author, who does *not* proceed from such a *linear extrapolation* of present conditions, but rather from *very well preserved,* old and almost completely reworked *young* forms of glacier erosion, takes the view of *qualitative leap-like discontinuities* in the prehistoric process; this view is founded upon very comprehensive findings in the field and the *comparative method.* The authors mentioned above completely reject the glacio-geomorphological key forms determining the entire main valley relief, simply ignoring glacier abrasions, polishings and striae, or vaguely enlisting periglacial "forms of convergence", which have *no empirical* basis on earth. According to the *alpine* example, which the author considers representative in this case, frost weathering has transformed glacigenic smoothings on the mountain flanks above recent glaciers and in their immediate forelands *past all recognition,* within a period of a few decades to centuries. In the Alps, the *purest* forms of U-shaped valleys set in tens of kilometres away from the present glaciers, and the *best* preserved ground abrasions and polishings and landscapes of glaciated knobs are related to transfluence passes which have been free from ice since Late Glacial times. Already beyond the actual glacier tongues in the confluence area of the Muztagh valley (Fig 138 No. 10) the glacial forms of the valley flanks are not only much better preserved in the same bedrock than those up-valley above the present Skamri glacier, which have been completely obliterated by the development of gullies (Fig 9 ▽), but possibly generally only there preserved as *unambiguous* forms (Fig 8 ▲; 36 ▲ ▲ ▲). Looking still further down-valley to the lowest main valley down into the longitudinal valley of the Shaksgam, the quality of preserved, glacigenic abrasion and polishing forms *continues to improve* even up to very high transfluence passes (Fig 138 No 12; 51 ▲; 37 ▲ right; 52 ▲▲; 38 ▲). At a *great* vertical and horizontal distance from present glaciation, glacier *striae* and *polished* surfaces of glaciated knobs in the Yarkand valley, the great valley system further north, are *perfectly preserved* as far down as 3700–3400 m asl (Fig 138 Nos. 46 & 33, 40, 41; Fig 93; 42; 128). This juxtaposition of a *bad* glaciogeomorphological state of preservation in areas of *ongoing* active formation through glacier ice run-off, and clearly well preserved forms from a greater spatial *distance* and therefore also *temporal* interval relative to present glaciation, leaves no alternative but to draw the conclusion that *glacial* transformation leads to a *faster* destruction of forms than fluvial and periglacial processes operating at lower altitudes. There is *no* way for the older and much more extensive forms to be in a fresher condition than the recent ones in the vicinity of ongoing glaciation. However, since in the course of deglaciation, those lower-lying areas must *also* have been *undercut* and *transformed* by smaller (narrower and less thick) valley glaciers and valley glacier tongues, especially on the valley flanks, the active time for those processes can only have been *very brief.* In any case, it must have been significantly shorter than the period of transformation activity meanwhile available to the *Holocene* and *inter-glacial* glaciers. It follows that the more than 1000 m thick Ice Age valley glacier – and ice stream network systems which filled the main valleys during the Ice Age (cf. Ch. 5; cf. for example Fig 37; 39 and 116 - - - -) must have thawed out completely within a short time, ie approximately down to the *present state* of the Karakorum glaciation. This fact is confirmed by the oldest C14 date of 12870 ± 180YBP of the valley floor of the Muztagh Valley (Tab 2 samples No. 15. 10.86/4) since Sarpo Laggo and Skamri glaciers *must* already have retreated from this valley cross-section at about 3900 m asl and terminated in the vicinity of the present ice margins *before* these sediments were deposited. It might even be the case that, in the course of post-Glacial climatic warming, the ELA rose *so rapidly* out of the completely glaciated valley relief, that glacial processes of under-cutting and transformation were not able to take place after a few isolated Late Glacial glacier advances. This is all the more likely, as deglaciation of *large volumes* of ice (which must be assumed for the Main Ice Age, according to the glacier reconstruction described in the following - see Ch. 5) must have taken place comparatively *slowly*, thereby allowing quite a long time for the raising of the snow line, without - considering the relatively minor periods of climatic cooling in between - the occurrence of significant glacier advances, causing glacial *undercutting*. This *fundamental* difference in the glacio-geomorphological course of the glaciated areas close to or at a greater distance from the present glacier has not only a *temporal*, but also an additional *thermal* component: the *altitude* of the glacier tongue ends depends on the snow line in its absolute, as well as its *relative*, altitude in respect of the mountain relief. When the snow line *descends* further into the relief, the glacier ends flow *progressively* - a factor of 1.5 to approximately 2 - further down into the valleys (Kuhle 1987, pp. 208-10; 1987b, pp. 415-19; 1988, pp. 564-66). It follows that the glacier-free valley areas in the area surrounding the present terminations of relatively small glaciers near the ELA present a colder climate, with many more freeze-thaw cycles than those in the area surrounding Late Glacial ice-streams which have descended *far* into lower altitudes. Highly effective frost weathering in the vicinity of present glacier margins accordingly has a much more *transforming* effect than weathering in the area surrounding pre-Holocene glacier margins.

Summing up, one may generalize as follows: extreme increases in frost weathering near the snow line, which are even more severe in the vicinity of snow margins and on the *black-white* line of smaller glaciers, *transform* prehistoric glacial formation so *much faster* than in the lower regions of glacial advances that, in many places, *Main Ice Age* erosions are *better* preserved than the *Holocene to historic* forms of glacier abrasion and polishing. In this case the influence of the "weathering intensity" factor overtakes the "time" factor (cf. "Höhenstufe besserer glaziärer Formenerhaltung", Kuhle 1983, p. 161).

4.2 Moraines and Glacier Traces in the Muztagh Valley up to its Junction with the Shaksgam Valley (in the Confluence Area of the K2 Glacier, N-Skyang Lungpa Glacier, Sarpo Laggo Glacier and Skamri Glacier)

The confluence with the N-Skyang Lungpa glacier (Fig 138 No. 2; Fig 43 ▸▸) took place at a greater distance from the present K2 glacier tongue, down-valley from the striking end moraine, which can, at most, be classified as *neo-Glacial* (Nauri Stage V, c. 4000 YBP, or older Dhaulagiri Stage VI, c. 2000-2400 YBP) though its base may be of an even *more recent* date, belonging to the period of the middle to younger Dhaulagiri Stage 'VII-X (younger than 2000 to older than 30-80 YBP, cf. Kuhle 1982, pp. 162-66; 1986 e, p. 454; 1987 c, p. 205 Tab 2) (Fig 31, 32). A good 15 km long, this parallel glacier of the K2 ice stream now ends about 6 km from here. Fig 32 shows two *lateral moraine* levels on the orographic right, which developed at the time of the confluence of the two glaciers (IV, III; Fig 138 No. 3 a). At that time, their joint tongue terminated in the Muztagh valley, at about 3900 asl (Fig 43 X). It is probable that at the same time the joint area of confluence with the Muztagh valley was covered by the Skamri-Sarpo-Laggo glacier system, thus creating *another confluence* at this location. Though no direct end moraine has been preserved there, *lateral moraines* (Fig 30 a left hand top; 36) provide evidence of this fact. For chronological reasons the two lateral moraine terraces, which are located up valley at 400-500 m above the K2 valley floor (Fig 32, IV and III) are to be classified as Sirkung Stage IV and Dhampu Stage III (both older than 12 870 YBP), ie the *Late Glacial* period. Their extreme continuations outside the valley are the moraine ledges (Fig. 43, IV, III), a few decametres above the gravel floor of the K2 valley, which is set into the gravel floor of the Muztagh valley (Fig 36, -6). This chronological classification is *obligatory* in the sense that it follows from the fact that from 13 000 YBP at the latest (before 12870 YBP, Tab 2) the ice must have melted from the valley floor area of the Muztagh valley for the development of the *dated* peat clay in the bog with a spring meadow, which is 1 m below the present surface of the valley ground.

About 32 km long, in as far as its main branch is concerned, the Sarpo Laggo glacier has been in continuing, intensive retreat since 1986 (Fig 44; 46 left). Over a distance of c. 4 km its tongue is completely *covered* with superficial moraine, and split up into numerous large *dead ice complexes* below the glacier outlet that follows the live ice stream (Fig 44 ■). Still "live" in 1986, the glacier tongue end lies at 4200 m in the junction area of the last tributary valley on the orographic left-hand side of the Sarpo Laggo valley; a comparison with the Chinese map on the scale 1:50 000 (sheet 9-43 -ζ; air photograph base) shows that during the past 10-15 years it has *retreated* about 2 km, and 100 m upwards, ie over this distance the glacier tongue has *split up* into the blocks of dead ice mentioned above (Fig 138 No. 4). In its forefield the 1.5 km-wide glacier tongue left behind a complex meltdown landscape, or landscape of glacial accumulation forms, with meltwater capable of transporting sizeable loads meandering and *tunnelling* the dead ice complexes. This landscape of end moraine and thawing consists of three staggered very recent prehistoric fronts of ice margin positions (dumped terminal moraines) (Fig 44 X ■ ■), the oldest of which must been in contact with the glacier terminal as late as 1937 (cf. below 36°N/76°22'E). There is no trace at all of comparable outlines of fresh tongue basins down-valley, thus indicating substantial glacio-fluvial transformation of the valley floor. The dark metamorphite (phyllite) debris is mixed with massive crystalline components (granite, Falchan gneiss und K2 gneiss), which have come down from the Karakorum main ridge; removal and sorting of morainic material released from the ice takes place at many locations. In their area, and 3 km down valley of the disintegrated Sarpo Laggo glacier tongue, two tributary valleys filled with smaller glaciers join on the orographic right (Fig 45; 8). They are linked by confluence steps – one of which has meanwhile been dissected by a steep, V-shaped gorge (Fig 8 ▼) – and release substantial, though only a few decades old *mudflow fans* on to the main valley floor.

According to the Spender map of 1937 the Sarpo Laggo glacier was still close to reaching the lower of the two valleys (Fig 8), ie at that time its active glacier outlet was located 2.8 km further down-valley than at the time of collecting data for the topographical map (1:50 000), and in a 4.8 to 5 km lower position than the active glacier end in 1986 (Fig 44 & 46 X). It follows that the mud flow fan on the orographic right farthest up the valley can in fact not be more than at most 40-50 years old, ie it has been built up since 1937 (Fig. 45 ▽). Tributary alluvial fan deposits of this kind, as well as glaciofluvial transformation by glacier meltwaters in the forefield, prevented the preservation of an even older (ie than 1937) unequivocal end moraine (if there ever was one).

The previous (older than 1937) positions of the Sarpo Laggo glacier formed 100-300 m high *terraces of lateral moraines* on both sides (Fig 36 IV left; 46 IV). Their upper edges lie between 4100 m and 4400 m asl. On the intact inner slopes of the lateral moraines a total of at least 10–13 lateral moraine edges can be identified, thus giving an impression of the very *frequent* oscillations and variations of level which must have taken place at this glacier tongue. The moraine terraces are classified as belonging to the period of the "Little Ice Age", or younger Dhaulagiri Stages IX to VII, middle Dhaulagiri Stage 'VII, older Dhaulagiri Stage VI, back to the oldest neo-Glacial stage, the Nauri Stage V (Holocene, approximately 4000 YBP). Thus they belong entirely to the post-Glacial period. Up to the older Dhaulaigiri Stage VI, the Sarpo Laggo glacier always reached a confluence with the Skamri glacier, as demonstrated by the interlocking of lateral moraines in the triangular moraine inset of the confluence (Fig 36, IV, IV; Fig 138, No. 5). The only uncertainty of such a confluence concerns the final phase of the Sirkung Stage (IV) and the Nauri Stage (V). The Skamri glacier did indeed reach the Sarpo Laggo valley at that time and formed a *hammerhead* spit in its confluence, whilst the Sarpo Laggo glacier must still, or once again, have been in retreat in its valley embedment, as shown by the evidence of combinations of moraine configurations (cf. Fig 46 ▽ V; 36 ▽ V). Approximately nine lateral moraine dams of the Holocene Skamri glacier on the orographic right transform the left hand lateral moraines from the Holocene Sarpo Laggo glacier. A transformation of this kind has probably been caused by the *difference* in length, or size, of the two ice streams. Due to slower reaction to climatic cooling, the larger Skamri glacier can only have advanced with the end of its tongue when the Sarpo Laggo glacier tongue had already completed this advance, was in the process of retreat, and had thus vacated the mouth of the Sarpo Laggo valley. A corresponding difference in the glacier size-related behaviour of the tongues ends can currently be observed on the *advancing* K2 glacier in contrast to the *retreating* tongues of the Sarpo Laggo and Skamri glaciers (Fig 44 and 47).

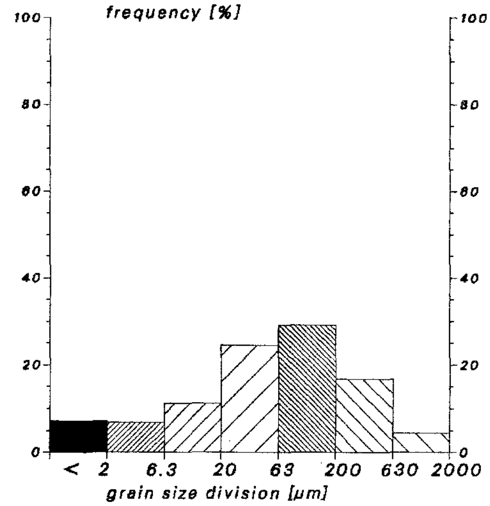
Essential facts to be recorded are 1. the approximate *contemporaneity* of the two semi-level moraine terraces in the forefields of the two, formerly joined and still major valley glaciers, and 2. the *youthful* age of these lateral moraines, evidence of which exists in the good state of preservation of those small moraine ledges in the permafrost zone where solifluction is intensive. Only the uppermost areas of these late Late Glacial and Holocene lateral moraine terraces show clearly *periglacial* transformation in the *rounding* of ledges and the formation of *solifluction* tongues (Fig 36, IV; 46, IV). Hitherto only minor incisions of gullies into the soft moraine material, even *beneath* larger *source basins,* now filled with firn shields and hanging glaciers (Fig 36 \\) point in this direction. In the valley cross-profile of its present (1986) glacier tongue end these equivalent lateral moraine terraces on the Skamri glacier (sometimes referred to as Crevasse or Yinsungaiti glacier) reach up to 4450 m asl (Fig 36 IV), thus attaining altitudes of 420–430 m above the outwash plain at the glacier outlet at 4030 m asl. Below the level of the Sirkung Stage (IV) (Fig 36) another three, particularly striking edges of lateral moraine terraces can be discerned from top to bottom along these lateral moraine deposits on the orographic right: The Nauri Stage (V), the older Dhaulagiri Stage (VI) and the middle Dhaulagiri Stage ('VII) to the younger Dhaulagiri Stage (VII–IX). Fig 47 shows the panoramic view from the second highest level of the lateral moraine terrace (Nauri Stage V) at 4330 m asl across the 2.2–2.3 km wide tongue of the Skamri glacier. The Skamri glacier tongue is composed of tongues of at least three tributaries, each *over-riding* glacier streams (cf. Fig 49 □■●; this air photo was taken in about 1975). The three *overthrust* glacier tongues, the lowest of which forms as an underlying glacier tongue the actual and lowest end of the Skamri glacier, have remained *separate* ice bodies (Fig 9 X●). Each overlying glacier has pushed a small *frontal moraine* upon its supporting or respective underlying glacier (Fig 47 □□□), and moreover retrained its original tongue shape (cf. satellite picture NASA ERTSE-2653-04441-701; 0 69 / 0 70; 5 Nov. 1976). The glacigenic *truncated spurs* and *cuspate slopes* are evidence of prehistoric flank abrasions and polishings on the orographic left (Fig 47 ▲▲; 138 No. 6). Like the orographic right-hand lateral moraines, their formation dates back to the *later Late Glacial* period. The abrasions and smoothings are *unusually well* preserved in regard to outcropping metamorphites. Though on the same level the rock flank on the orographic right-hand is far more strongly weathered and *dissected* by gullies (Fig 9 & 48 ▽▽; 138 No. 8). Corresponding glacial flank smoothings and cuspate areas, offering evidence of in these places even higher, and thus older *levels of glaciers, filling the entire valley,* are preserved in the middle section of the Sarpo Laggo valley, which continues to be glaciated. There they reach up to the mountain spurs (Fig 44 ◀ ▶; 138 No. 7) and *facetted* the entire mountain shapes in the confluence area with

Fig 67a (25.10.86/1) and b (25.10.86/3); Location: 36°27'20"N/ 76°57'45"E; Fig 138, No. 38 (cf. Tab 2).

KARAKORAM 1986
Grain Size Distribution

specimen number: 25.10.86/1

height a.s.l.: 3800m
location: orographical right tributary of the Yarkand valley, 4km westwards of Mazar



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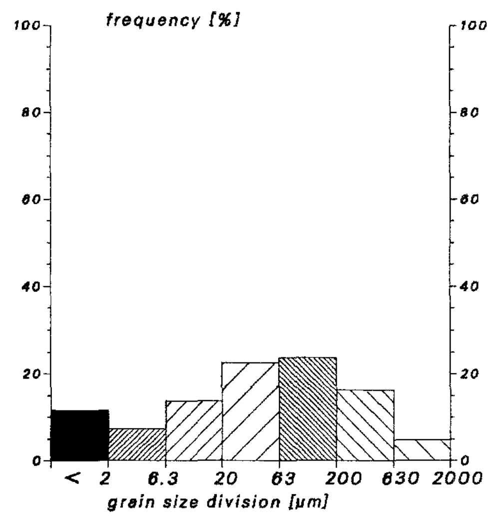
projection: M. Kuhle, program: R. Staschel 1988

KARAKORAM 1986
Grain Size Distribution

specimen number: 25.10.86/3

height a.s.l.: 3800m
location: orographical right tributary of the Yarkand valley, 4km westwards of Mazar



carbonate content: 0.40 % humus content: 9.90 %
projection: M. Kuhle, program: R. Staschel 1988

tributary glaciers to more or less complete *tetrahedrons* (Fig 46, bottom far left ----). On the orographic right of the Sarpo Laggo valley exist further truncated spurs with glacial cuspate areas and flank abrasions and polishings with rock smoothings are preserved (Fig 138 No. 8). The smoothings occur on vertical *outcrop bassets* of crystalline schist (Fig 8 ▲), and are interrupted by the acute incision of the *meltwater notch* (▼) of a hanging tributary valley glacier.

West of the Muztagh valley most of the peaks over 6000 m belong to the catchment area of the Skamri glacier. According to the Spender map (1937), their highest peak "The Crown" reaches 7295 m asl (Fig 46 and 47 No. 1). The present Skamri glacier terminates at 4000-4030 m asl (Fig 9) in ice covered by surface moraine. However, in common with most of the major tens of kilometres-long valley glaciers, the glacier *lacks* a frontal moraine, and the tip of the tongue, ie the body of ice, runs out on the rapidly growing *glacier outwash plain* (Fig 48 O). In 1986 the glacier tongue had been in *retreat*: evidence of this is available in the *flat*, longitudinal profile of the tongue end (cf. Fig 47 together with 49) and on the opening of the glacier outlet which set back some decametres into the tongue (Fig 9; 47 ∪; 48 O left). In the interval between the collection of data for the Spender map (1937) and the Chinese maps from the seventies (Fig 49) the Skamri tongue has receded by approximately 0.9 km. By 1986 the distance from the 1937 position was c. 1 km. Even those somewhat *earlier* ice margin positions (cf. above) cannot be established by any remnants from frontal moraines. They are missing because of the *far superior* morphodynamics of the meltwater discharge, as against the comparatively minor and short-term effects of the advancing and scraping glacier tongue margin. The retreat of the ice is indicated by the position of the tongue end in relation to striking slope gullies or slope gorges which the earlier maps were consequently able to include (Fig 36 \\). The next older stage of the Skamri glacier is marked by lateral moraines on the right which taper off at the gravel floor (Fig 36 'VII-IX). It was situated at a distance of about 1.5-1.7 km from the present glacier outlet position, and was reached 2000 YBP, or 440-80 YBP respectively (middle and younger Dhaulagiri Stage 'VII-IX). The next higher lateral moraine position on the orographic right is evidence of the previously maintained final confluence with the Sarpo Laggo glacier (Fig 36 IV; 46 IV). Although the tongue belonging to the Skamri glacier had presented an only slightly higher surface level, the volume of the glacier tongue had more than doubled, thanks to the *greater valley width* of 3 km (Fig 138, No. 9) in the area of the confluence with the Sarpo Laggo valley. Currently exposed ground moraine ramps higher up the valley, which stand out in Fig 9 as a result of a light cover of freshly fallen snow, show that, at the same time, the glacier level had been *raised* (Fig 9). The upper edge of the lateral

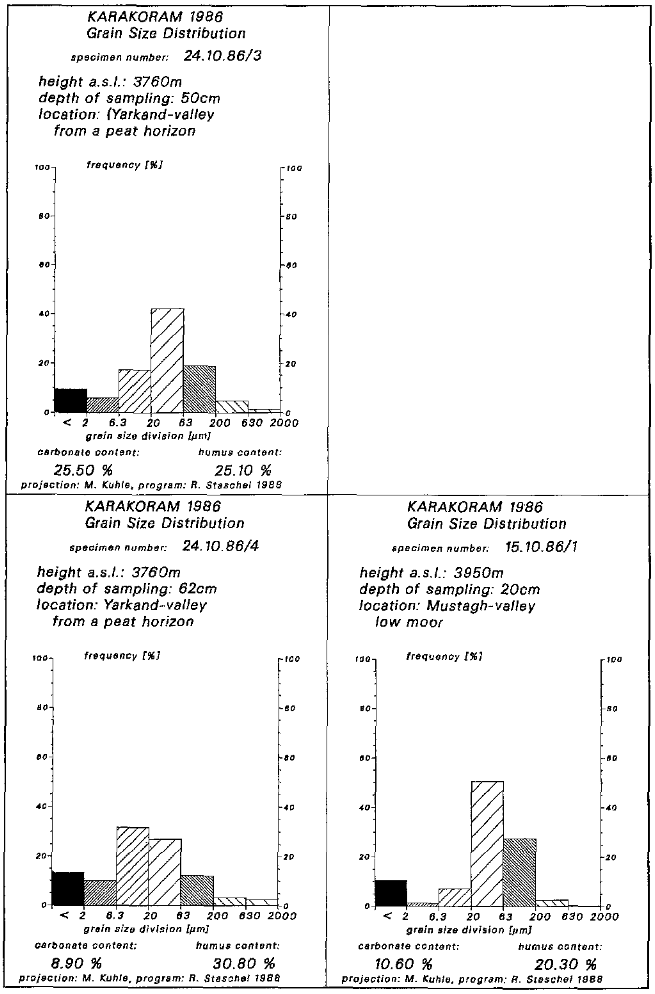


Fig 74 a (24.10.86/3) and b (24.10.86/4). Location: 36°24'N/ 76°52'E; Fig 138, No. 37; c (15. 10. 86/1). Location: 36°03'N/ 76°25'20"E. Fig 138, No. 10; Tab 2.

moraine of Nauri Stage V (Fig 36) lies at 4220 m asl, 190 m above the valley floor and can be classified as neoglacial (c. 4000 YBP). The level of the Sirkung Stage (IV) (Fig 36) will have been the *last* one to belong to the Muztagh glacier as a *joint* Skamri-Sarpo Laggo glacier, which *in turn* had joined the K2-N-Skyang Lungpa glacier system (cf. above). When the Muztagh valley was filled with ice, the locality of the samples (15.10.86 1-5; Tab 2; Fig 36 X; 138 No. 10⌑) must have been under ice as well. This means that the peaty-clay on the ground moraine, which has been dated to 12870 YBP, is *younger* than this glacier stage, and that Stage IV consequently forms part of the Middle Late Glacial period. In the confluence area of the Muztagh and K2 glaciers large-scaled deposits of ground moraine from the Sirkung Stage IV are preserved on the right-hand slope of the Muztagh valley (Fig 43 IV). Its surface shows *exaration grooves* and *furrows,* which continue beyond the mouth of the K2 valley (Fig 43 ↓↓↓). Their interlocking with moraine material from the former K2 glacier is evidence of concurrent lateral deposition or thrust by this minor tributary glacier. The ground moraines (basal till) in the Muztagh valley lie upon a glacially *abraded* and *polished floor* on the bedrock (Fig 43 ▷), which has now been undercut by lateral erosion, following probably metre- to decametre-deep *subglacial* erosion accompanied by warming up and an arising snow line as far back as the Late Glacial period (Fig 43 ▷). Some of this erosion could have been caused by the subglacial stream of the K2 glacier at the time of the Sirkung Stage (IV). But even during the preceding Stage III (Dhampu Stage, according to the nomenclature employed by Kuhle, 1982) the surface of the Muztagh glacier in its area of confluence with the K2 glacier system must have been *below* the snow line (ELA). Evidence of this occurs in another and still higher remnant of lateral moraine with a preserved crest point (Fig 20 ■ III) and a slight trough-like deepening towards the valley slope (Fig. 50 III; Fig 138 No. 10).

As an upper *sequel* to the ground moraine covering of the lower valley floor slope at 4330 m asl, about 400 m above the valley floor, the over 100 m-long dam of lateral moraine (Fig 50 IV) has remained intact, thanks to the "denudation shadow" of a spur. At the time of the Sirkung Stage IV in the *Late Glacial* period the snow line was consequently *at most* 900 m lower than now (the present ELA being at 5300 m asl in this area). When *marking the stage* mentioned in the figures, the author has followed the concept outlined above, and decided on the *moraine classification.* Attention must, however, be drawn to some doubt concerning the classification of Stages III and IV. The *lower* lateral moraine terrace in Fig 50 may possibly have to be replaced by III in Fig 36. The question concerns relatively unimportant details. Both the moraine generations are undoubtedly older than 12870 YBP, and consequently belonging to the *middle Late Glacial* period. The c. 12 km-long chamber of the Muztagh valley from the tongues of the Skamri- and the Sarpo Laggo glacier to the junction with the Shaksgam valley is filled by *gravel* from the *glacier outlet,* which is up to 3.8 km wide and still building up (Fig 36, -6; 46, -6; 51, -6). Glaciated hanging valleys and major slope gullies continue to join from the orographic left-hand valley flank by way of *confluence steps,* with V-shaped meltwater dissections and large alluvial fan outpourings ("indirect outwash cones" after Kuhle 1983, p. 334 et seq.) on the valley floor (Fig 38 □; 51 □). In the flank on the left side of the Muztagh valley *glacigenic abrasions and polishings* are only preserved up to low levels of prehistoric glacier levels, and not very clearly either (Fig 46 ○○). The flank was last reached by glacier ice during Stage IV (cf. above). On the other hand, attention must be drawn to the almost total *absence* of glacially-smoothed flanks, or their *far-reaching disintegration* by frost weathering and gully formation (Fig 38 ▽), and that in extreme contrast to - at some points - very well preserved forms of glacier abrasion and polishing at significantly greater altitudes above the valley floor. Fig 52 shows a *glacial horn,* in the outcropping limestone, which is sharpened up to its peak at

4730 m. It is situated in the confluence area of the Muztagh and Shaksgam valleys (Fig 138 No. 13). Such forms of much more substantial glacial infilling are part of the early Late Glacial to Main Glacial plethora of forms, and will be considered in Chapter 5. During Stages IV or III the Muztagh glacier just reached the Shaksgam valley. Fed from the catchment areas of the Skamri-, Sarpo Laggo- and K2 glacier, the tongue of the Muztagh glacier flowed over and abraded and polished the limestone bar hill at the centre of the confluence into a *glaciated knob* (Fig 52 a; 138 No. 11; 36°08'N/76°22'E). Covered in parts by a thin sprinkling of moraine and gravel, the *polished* bar was partly sedimented over from its base by material from more recent gravel-fields. There are *no* remnants from end moraines or frontal moraines. This is a *typical* feature of ice margin positions of major valley glacier systems (cf. Kuhle 1991 b, pp. 75/76). The glaciated knob lies at 3800 m asl, a *snow line depression* of merely 200 m would enable the Muztagh glacier tongue to reach, and flow over it (as the present glacier ends of this catchment area lie between 4000 m and 4200 m asl). The question of a *Shaksgam glacier tongue* extending into the area of the Muztagh valley during Stage IV and/or III, or of the continuing existence of a Shaksgam-Muztagh glacier confluence, cannot be affirmed. A *snow line depression* of 400-600 m, or more, however, makes it likely, if not necessary, in the cases of Stages IV and III. The present glaciers in the catchment area of the Shaksgam valley, which reach down furthest, including the tongues of the S-Skyang Lungpa glacier, the N-Gasherbrum glacier, Urdok glacier, Staghar glacier, Singhi glacier and Kyagar glacier, which were sending a *joint Shaksgam glacier tongue* downwards into the Muztagh valley at that time, terminate between c. 4200 m and 4300 m asl, ie only 400–500 m above the said *confluence* with the Muztagh valley of the Late Glacial Muztagh glacier.

4.3 Exemplary Observations Concerning Historical, Holocene (Neo-Glacial) to Late Late Glacial Ice Margin Positions and Glacier Traces in the Catchment Area of the Kudi Valley on the Kuenlun North Side

Fig 21 shows the upper valley chamber of the "NW-valley of the 6328 m massif" (36°32'N/77°17'E) closest to the valley head, and its catchment area with the present 3.4 km-long glacier (O). This glacier possesses a *steep* tongue-front (O) and after years of retreat it has been *advancing* again since 1986. From the present and lowest glacier tongue end and there at 4800 m asl down to 4450 m asl (aneroid measurement) at least four more recent ice margin positions can be identified (Fig 21, X, IX, VI, V, IV; 138 No. 14–15). This sequence of end moraines and their *fresh* state of preservation permit conclusions as to a chronological sequence during the past c. 4200 YBP since the Nauri Stage (V), the second oldest one here. It is the *Holocene* moraine sequence since the *neo-Glacial* period. The highest mountain of the catchment area (Fig 21 No. 1) is probably (according to the Chinese map 1:50 000) the 6328 m peak. During historical times a tributary glacier coming from the orographic right still achieved a *confluence* with the main glacier. Today, it is still preserved as a typical transition from a "rock glacier tongue" to a *dumped terminal moraine* (Fig 21 X). Covered with a metre-thick layer of block debris, its tongue ends at 4700 asl (aneroid measurement), 2 km down valley from the uncovered glacier tongue of the main glacier in the valley axis. Inter-locking moraines of the two glaciers in the confluence area are evidence of such a confluence (Fig 21 below O). Small hanging valleys join on the orographic right; their valley heads contain remnants of dumped terminal moraines from historical to neo-Glacial corrie (cirque) glaciers, which are the result of a 100-200 m snow line depression. The present snow line in this valley runs at about 5200 m asl. All the rock glacier-like phenomena in the talweg area of the tributary valleys and corries may be traced back to *thawed-out white glaciers* and the surface moraines they left behind as dumped terminal moraines (cf. v. Klebelsberg 1948, pp. 157, 192/193). One cannot rule out the possibility that a *pseudomorphotic* change of some bodies of glacial block debris into a subsequently periglacially moving block mass with a permafrost core has taken place. In any case this valley area above 4400 m asl is situated above the *permafrost line,* evidence of which is available in the several metre-thick *flows of coarse block*. The next older pre-neo-Glacial end moraines occur between 4200 and 4400 m basal height (Fig 53; 21 ■, foreground IV) where their valley floors offer secure locations away from rockfalls and floods for pastures and housing of a major mountain pasture settlement (Fig 53 IV, centre). There are two, or even three, Late Glacial positions of ice margins, which are classified as Stages IV and III (Fig 138, No. 15). The *end moraine arcs* enclose two glacier tongue basins, which are lined up on the valley floor. They consist of diamictite with a lot of coarse block material. The distance between the lowest of these end moraine dams (III) and the present glacier margin is 10.5 km (Fig 53, III). The lateral moraine ledges on the flanks of tributary valleys (■■) shown in Fig 53 indicate that at the time of the Late Ice Age glaciation in question tributary glaciers from altogether 8 tributary valleys on the orographic right reached the main glacier; today a mere two tributary glaciers do so (Fig 21 above O between No. 1 and 2). Both are linked to the 6328 m peak. The catchment areas of the Late Ice Age tributary glaciers reached maximum altidudes of 5780–6095 m asl. Below the valley flank on the orographic left two generations of end moraine have been deposited (Fig 53 V) in the exit further to the east of the two N-facing tributary valleys; (at present, both of them contain 2.2 to 2.3 km-long valley glacier tongues). The end moraines lie at 4480 and 4300 m asl, are 2.3 to 2.6 km away from the tributary valley glacier tongues, and 570–750 m below them (below 5050 m asl). For the time being, these two tributary glacier end moraines are classified as neo-Glacial (Nauri Stage V). This chronology is based on the fact that these moraines in the exit of the tributary valleys are adjusted to the Late Glacial lateral moraines of the main valley. All the neo-Glacial to Late Glacial positions of ice margin Stages V to III described here concern *ELA depressions* of 300 to 400 m. Further descriptions of details of the Late Ice Age in the valley of the "6328 m massif" are not relevant to the Main Ice Age glacier-filling of the Kuenlun relief. The important fact is that only the *late Late Glacial* glacier ends terminated within this valley, whereas the early Late Glacial period – the Taglung (II) and the Ghasa (I) stage – are not represented in this valley (no more than in the Muztagh valley on the Karakorum N-slope, cf. Chapt. 4.2). The ice from the stages of the early Late Glacial period flowed as far as the main valley, the "Vale of Kudi", and continued for *tens of kilometres* further down the valley. It has hitherto not been possible to give precise details of either ice margin positions II or I. The *confluence* of the "NW-valley of the 6328 m massif" with the "Vale of Kudi" (named after the Kudi settlement at 3100 m asl) lies at 3900 m asl (Fig 53 below - - - - in the background; 25). Fig 53 is evidence of a large glacier valley form glacial abrasion and polishing transformed into a U-shaped valley, a glacigenic trough; a *glacier valley form,* in fact, that was abraded and polished almost up to the crestline, *far beyond* the late Late Glacial end moraines at the valley bottom. In some sections evidence of abrasions and polishings occurs in the form of almost perfectly preserved truncated spurs and *glacial cuspate* areas (Fig 53 ▲ ▲). On the orographic right-hand of the valley these glacial cuspate areas in coarse crystalline Kuenlun granites (Y1/5 Geological Map 1:500 000, sheet 1) and the adjacent abraded and polished rock areas above them extend 600–800 m above the valley floor, possibly without yet having reached the maximal Main Ice Age glacier level (Fig 53 - - - -). Fig 25 (Fig 138, No. 15) also shows glacial flank smoothings in the confluence area with the "Vale of Kudi" (▲). There, another tributary valley with its upper 5380 to 5526 m-high catchment area joins in even more directly, ie shortly. This is a typical, *Late Glacial* glacier valley, too. At the time *after the Main Ice Age* its confluence step was dissected by *sub-glacial meltwater* (Fig 25 ▲ → ▲). This happened when the snow line in the SW-exposition had risen significantly above 4000 m asl. The rock floor remnants of the short Ice Age hanging trough valley are preserved as smooth glaciated *knob-like* denudation terraces (▲▲). The presence of firn shields at the crest of the catchment area (Fig 25 ○) are evidence of an *orographic snow line* at about 5000–5200 m (5100 m) asl. An ELA depression of at least 600 m was required here for the Late Glacial tributary glacier to reach the valley exit. The 4950 m-high Mazar pass (Fig 138 No. 16; 36°35'N/77°00'E) ought to be mentioned in the topographical context; surrounded by large-scale high hollows, it is the pass route across the main ridge of the Kuenlun; together they form part of the uppermost catchment area of the "Vale of Kudi" (Fig 54). It continues to be close to the ELA, as is evident from the *perennial* snow areas and firn shields between 5000 and 5806 m (No. 1). As late as the Late Glacial period these *high hollows* (Fig 54) were completely filled with glacier ice, though the preserved forms manifest this only in parts. The reason for this are the metamorphic sedimentary rocks like the vertically outcropping phyllites Fig 54 shows (S1, T1+2, T3, P1; Geological Map 1:500 000, sheet 1). These conditions are not unlike those observed in similar rocks in the Arctic, for instance in Spitsbergen at 200–240 m asl, at 78°–80°N. In spite of the presence of a superimposed ice layer, which was 1500–2000 m-thick during the last Main Glacial period (Grosswald 1983, Fig 25 p. 108 and Fig 42, p. 159) extensive *frost debris slopes* (Fig 54 ▽) are now emerging there as here. They developed on frost (drifts) compensation slopes below frost cliffs, creating the shallow valley forms and hollow profiles, which could also be explained from the purely periglacial point of view. Data could be gathered from the N-slope of the 5806 m massif, including its up to 3 km-long hanging glaciers which is representative of the Late Glacial moraine deposits in the area of the "Vale of Kudi". Fig 55 No. 6 shows the *grain-size graph of an end moraine* which has been extracted from the "main N-valley of the 5086 m massif" and deposited in the confluence area in the "Vale of Kudi" at 3740 m asl (Fig 138 No. 17). Fig 56 (20.8.86/1) shows the *morphometry* of the sand fraction within the moraine sample. It contains a 55% proportion of fluvially-polished grains and 20% proportion of re-deposited aeolian material, the remaining 26% being a substratum pounded and fractured by the glacier, which shows crescent-shaped, shell-like chattermarks on the grain surfaces and must have been taken up close to the bedrock. Such an *assemblage of materials* is typical for the *Late Glacial* moraines from the catchment areas in the *Kuenlun granite* (Y1/5, Geological Map 1:500 000, sheet 1) which mean *transport distances* of 10–30 km. The maximum transport distance of sample 20.8.86/1 is 10–15 km. The predominance of 93% silt, 52% of which is solely coarse silt, is due to the coarse crystalline parent material, and is thus typical for end moraines in granite areas. The proportion of clay and sand in the matrix between the coarse boulders is well balanced. Such "tributary valley exit moraines" frequently contain *mudflow sediments,* which in turn bear almost all the *moraine features.* This is quite likely in so far as younger, valley-upward glacigenic diamictites (moraines) are regularly *taken up* by mudflows (for instance, when glacier lakes burst their banks), needing nothing but an *additional* mud-flow transport. Fig 55 No. 9 (20.8.86/1a) shows such a mudflow deposit in the immediate environs of Fig 55 No. 6 (20.8.86/1). The cumulative graph of grain sizes within its 60% fine material proportion is *identical* with the one from the moraine material of the directly comparable catchment area. Its only *minor deviation* occurs within the 40% proportion of coarse silt and sand: the coarse grain in the *mudflow* sediment is only c. 2% greater than that of the *moraine,* a fact that is explained by the water in the mudflow, which is involved in the *erosion process.* For the sake of further comparisons the grain size composition of sample 20.8.86/2 (Fig 57/d) was also determined. It presents a purely fluvial gravel sediment from the floor of the main valley in the area of the episodic flood sedimentation located 2 m above the receiving stream (cf.

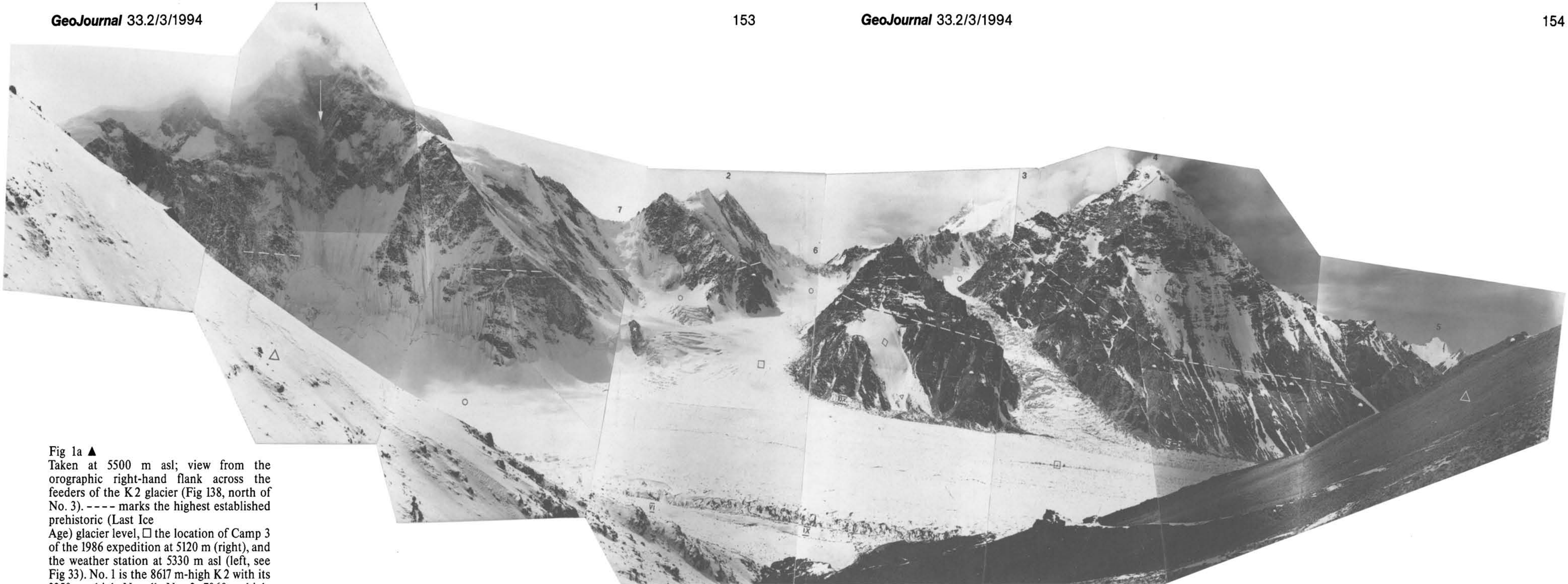


Fig 1a ▲
Taken at 5500 m asl; view from the orographic right-hand flank across the feeders of the K2 glacier (Fig 138, north of No. 3). ---- marks the highest established prehistoric (Last Ice Age) glacier level, □ the location of Camp 3 of the 1986 expedition at 5120 m (right), and the weather station at 5330 m asl (left, see Fig 33). No. 1 is the 8617 m-high K2 with its 3350 m- high N-wall; No. 2, 7060 m-high, unnamed; No. 3 = 7315 m (or 7330 m) Chongtar Peak, Chongtar Group; No. 4, c. 6800 m, unnamed; No. 5 = 6540 m summit; No. 6 = eastern Sarpo Laggo Pass. c. 5800 m high; No. 7 = Savoia Saddle, 6666 m. In the K2 glacier cross-section (through □, right) the 1986 expedition team measured a glacier movement speed of 0.2 m per day at 5120 m asl. Viewpoint: 35°55'30"N/76°30'E; panorama towards SSE via S, W to NNW. Photo: M. Kuhle 25.9.86.

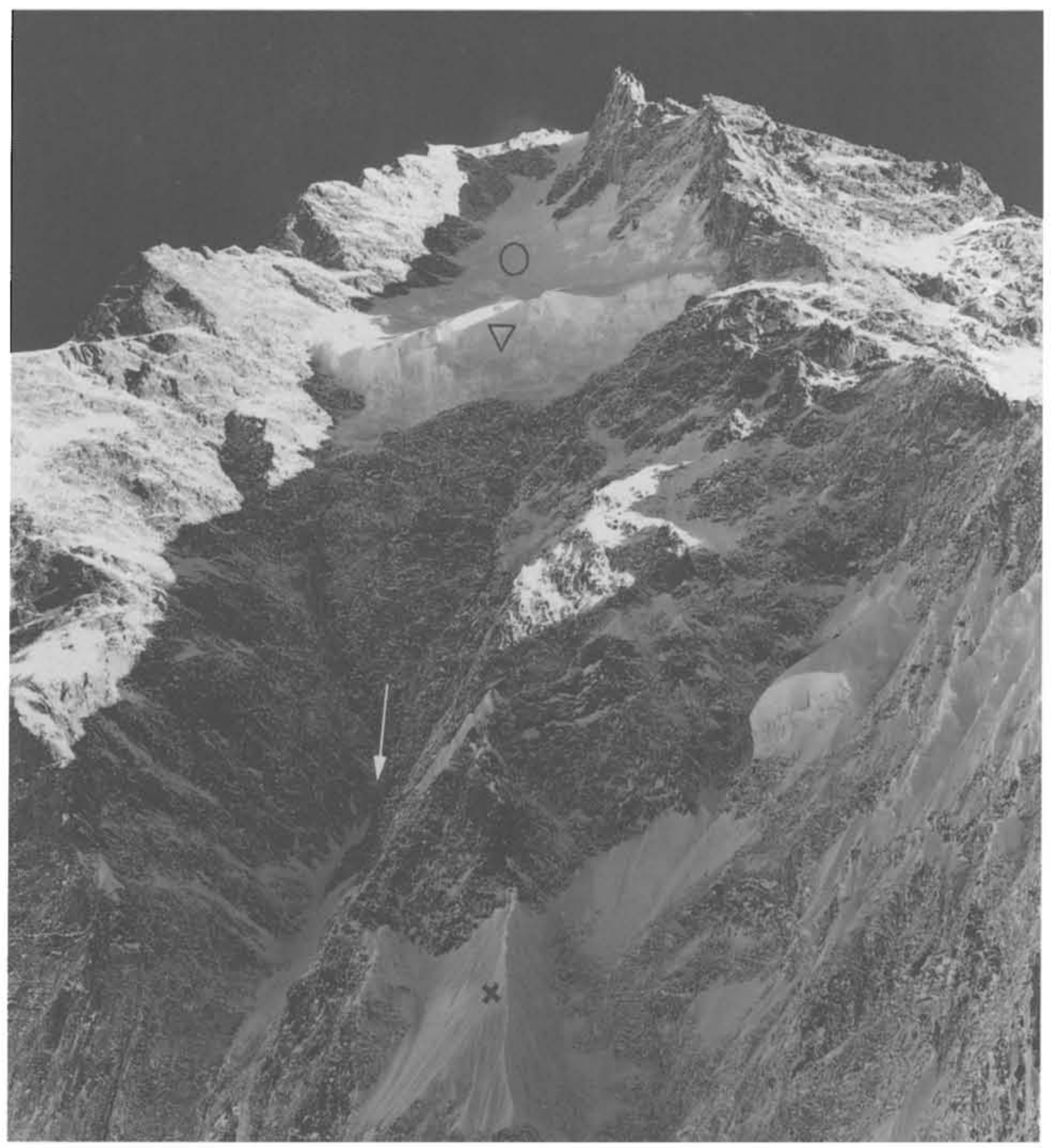
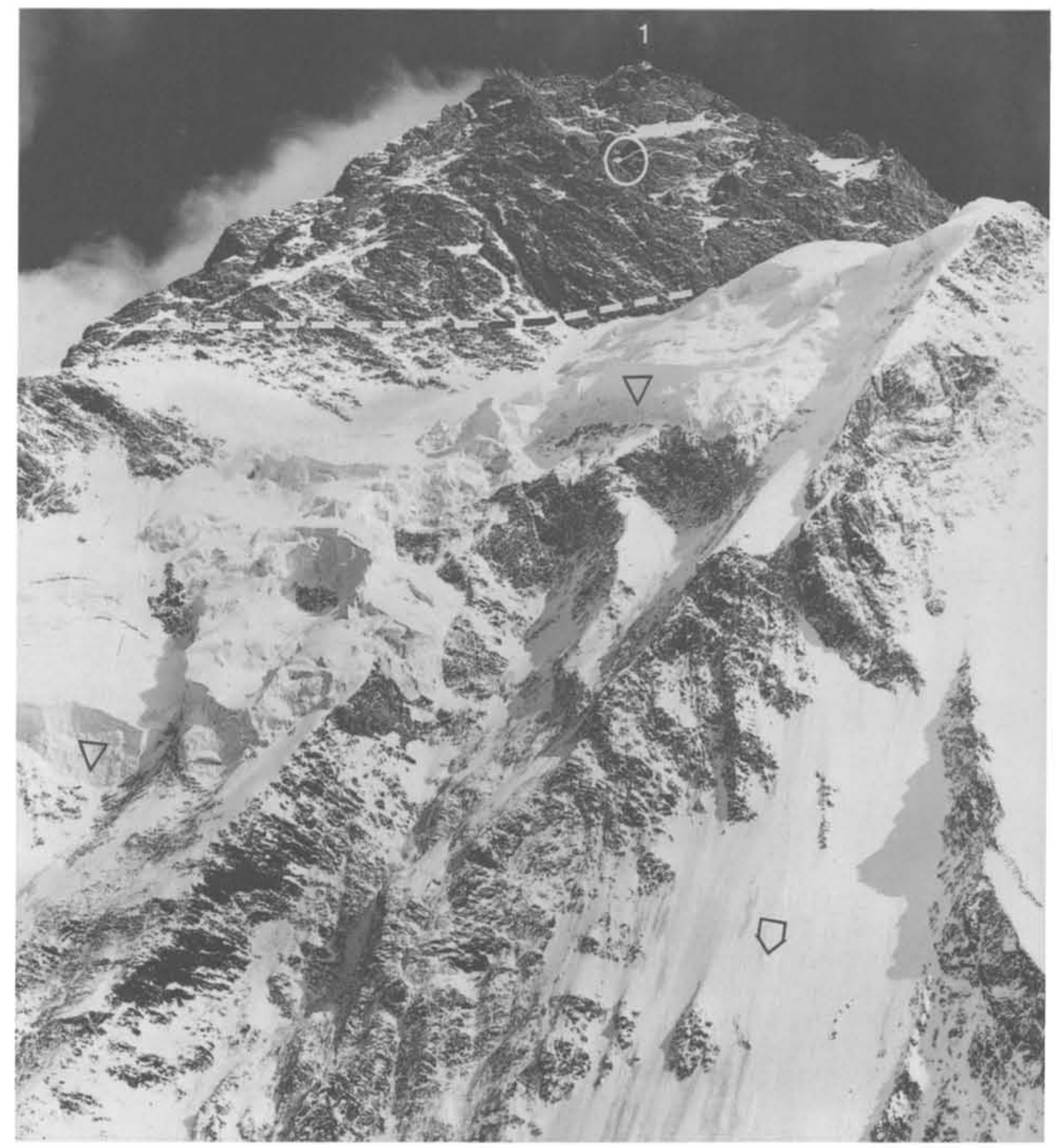


Fig 3 ▶
K2 (8617 m) with the hanging glacier (O) over the N-wall gorge (↓). The rocks of the peak's top section are largely free from glaciers and ice. Viewpoint: 35°55'N/76°30'E. Photo: M. Kuhle 22.9.86.

Fig 4 ▶
NW-wall of K2 (No. 1) between 8617 m and c. 6000 m asl, taken at 5450 m. Above c. 6900 m asl (----) glaciation and flank icing (O) stops. Viewpoint: 35°55'N/76°27'E. Photo: M. Kuhle 23.9.86.



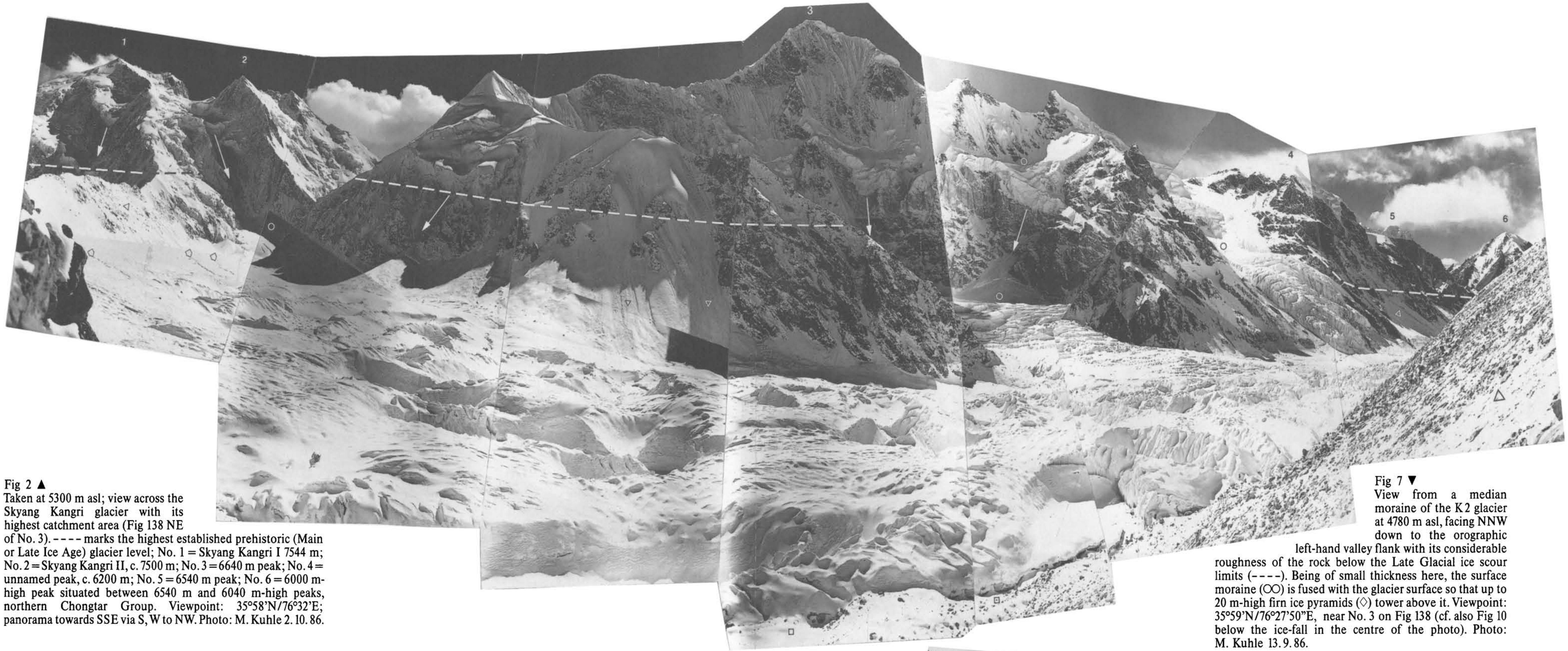
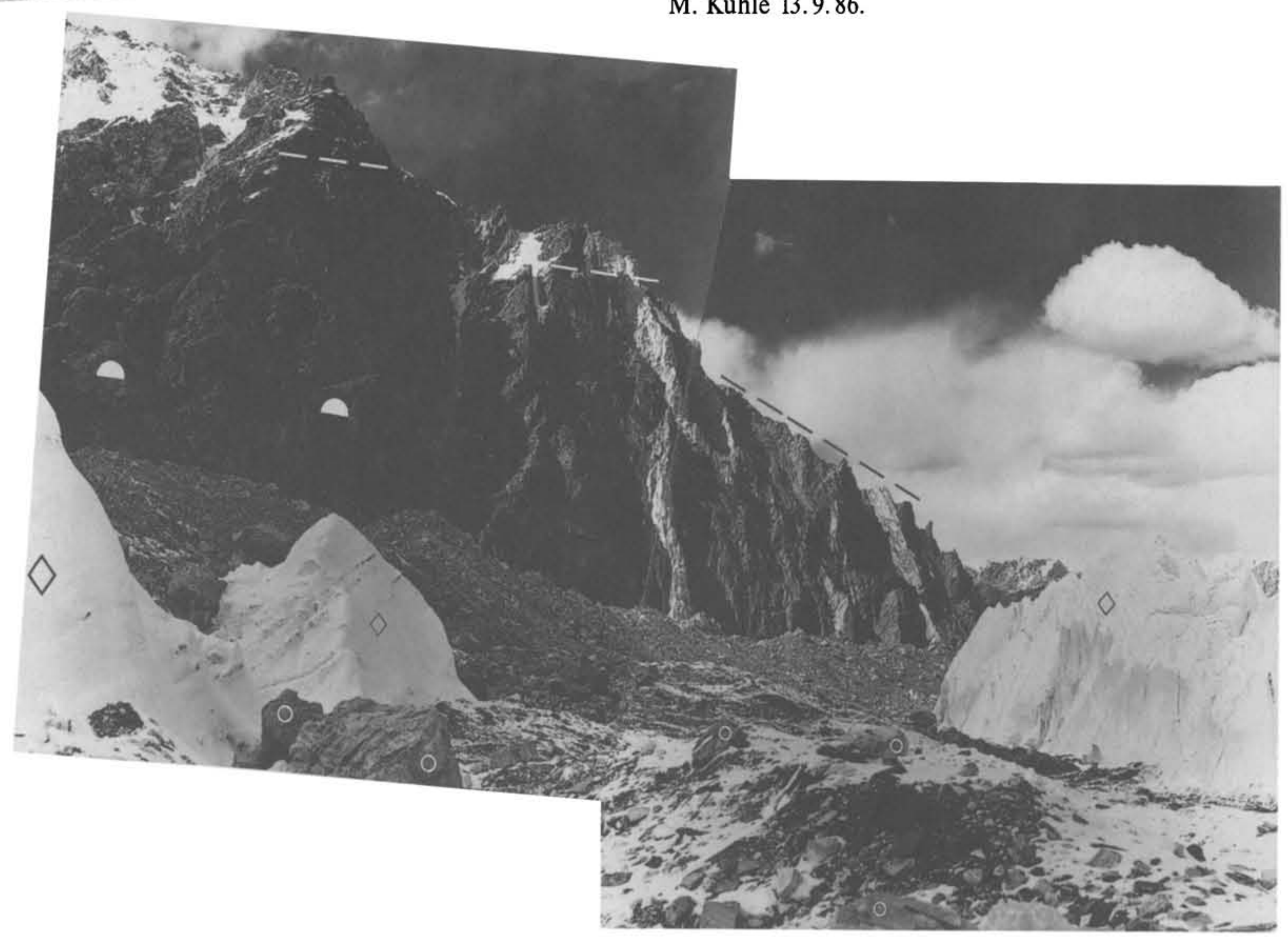


Fig 2 ▲
Taken at 5300 m asl; view across the Skyang Kangri glacier with its highest catchment area (Fig 138 NE of No. 3). - - - - marks the highest established prehistoric (Main or Late Ice Age) glacier level; No. 1 = Skyang Kangri I 7544 m; No. 2 = Skyang Kangri II, c. 7500 m; No. 3 = 6640 m peak; No. 4 = unnamed peak, c. 6200 m; No. 5 = 6540 m peak; No. 6 = 6000 m-high peak situated between 6540 m and 6040 m-high peaks, northern Chongtar Group. Viewpoint: 35°58'N/76°32'E; panorama towards SSE via S, W to NW. Photo: M. Kuhle 2.10.86.

Fig 7 ▼
View from a median moraine of the K2 glacier at 4780 m asl, facing NNW down to the orographic left-hand valley flank with its considerable roughness of the rock below the Late Glacial ice scour limits (- - - -). Being of small thickness here, the surface moraine (○○) is fused with the glacier surface so that up to 20 m-high firn ice pyramids (◇) tower above it. Viewpoint: 35°59'N/76°27'50"E, near No. 3 on Fig 138 (cf. also Fig 10 below the ice-fall in the centre of the photo). Photo: M. Kuhle 13.9.86.

Fig 8 ►
View of the orographic right-hand flank of the Muztagh valley (Fig 138 No. 10) with a hanging valley exit, seen from the main valley floor at 4100 m asl. There is a glacier tongue ending (↓) in the side valley exit, below which a prehistorically sub-glacially laid out cut dissects the confluence level (▼). Vertical quarzite and metamorphite strata show glacial abrasion and polishing (◓) beyond the outcropping edges up to a distinct ice scour limit (- - - -). Viewpoint: 36°01'N/76°53'E. Photo: M. Kuhle 17.10.86.



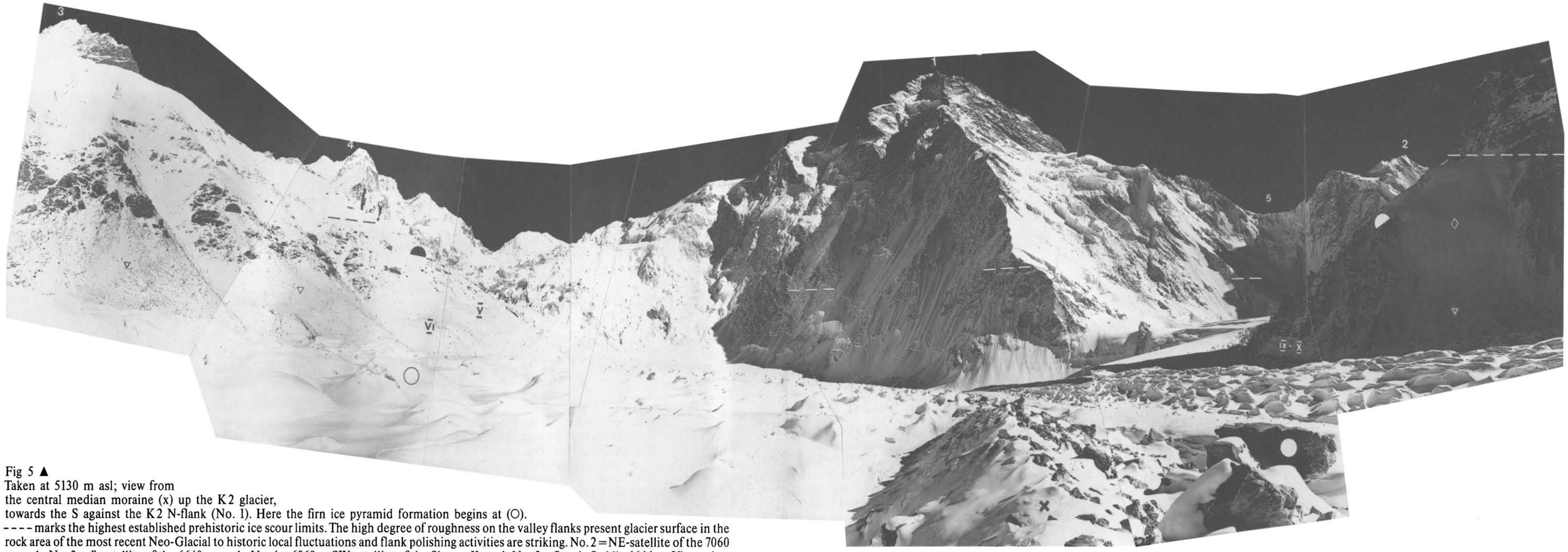
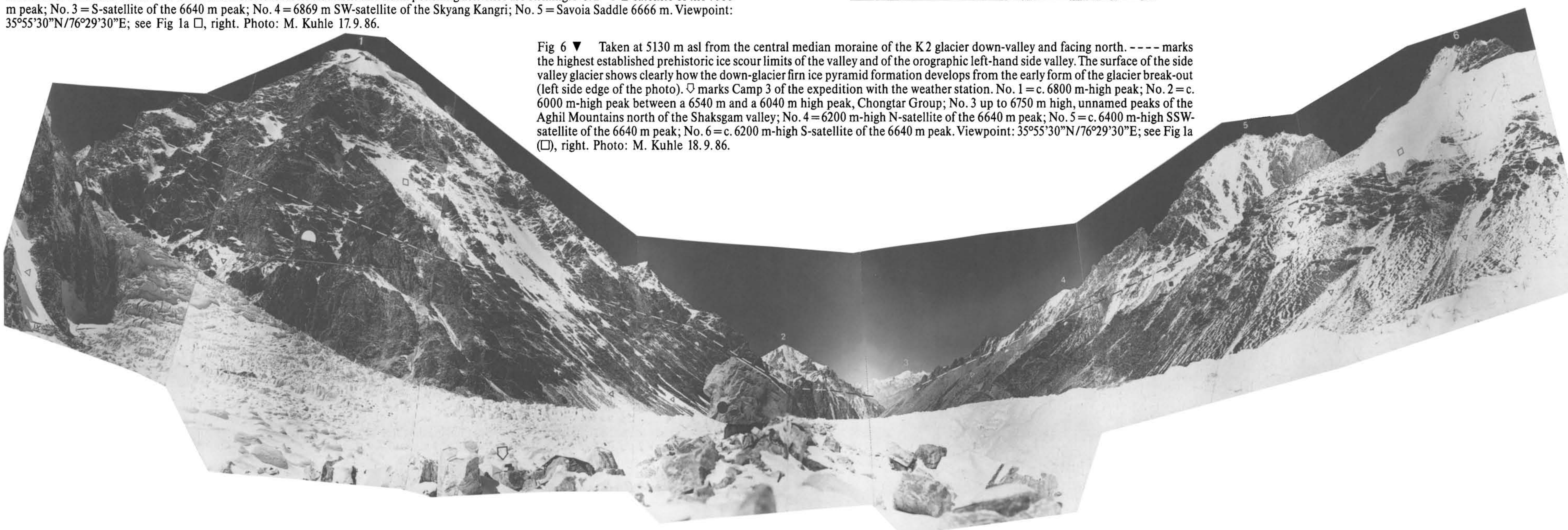
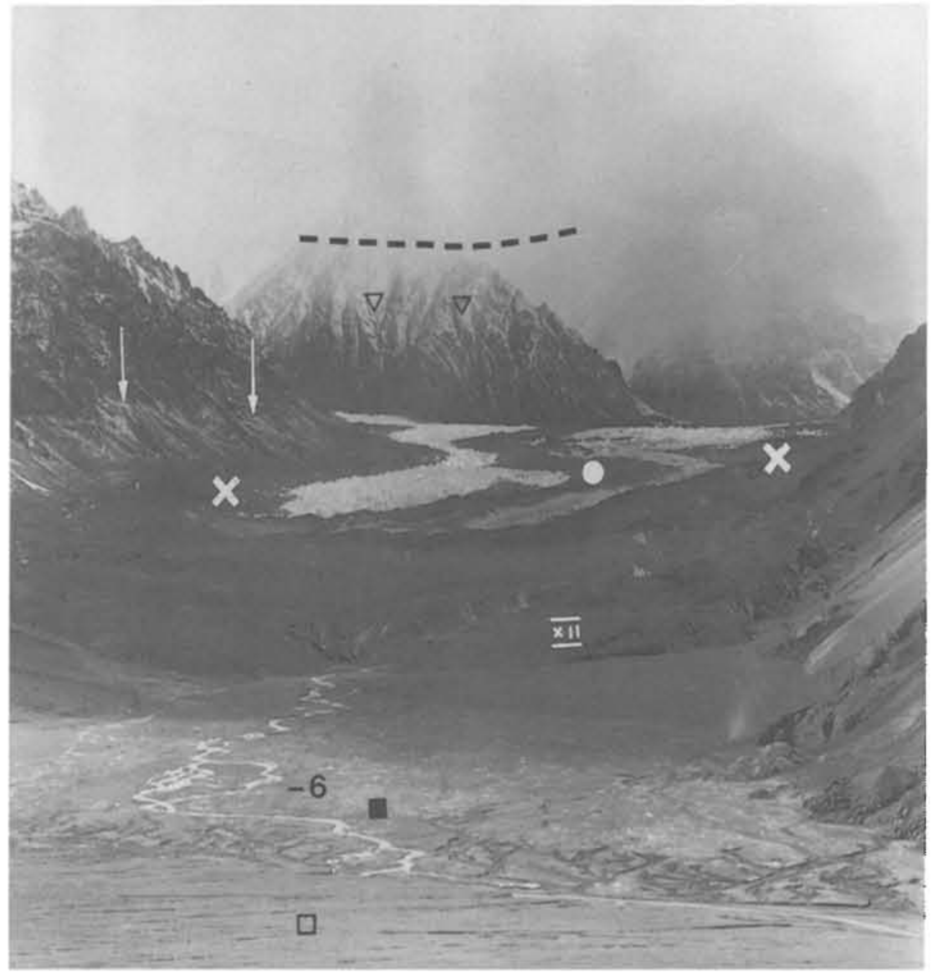


Fig 5 ▲
Taken at 5130 m asl; view from the central median moraine (x) up the K 2 glacier, towards the S against the K 2 N-flank (No. 1). Here the firn ice pyramid formation begins at (○). - - - - marks the highest established prehistoric ice scour limits. The high degree of roughness on the valley flanks present glacier surface in the rock area of the most recent Neo-Glacial to historic local fluctuations and flank polishing activities are striking. No. 2 = NE-satellite of the 7060 m peak; No. 3 = S-satellite of the 6640 m peak; No. 4 = 6869 m SW-satellite of the Skyang Kangri; No. 5 = Savoia Saddle 6666 m. Viewpoint: 35°55'30"N/76°29'30"E; see Fig 1a □, right. Photo: M. Kuhle 17. 9. 86.

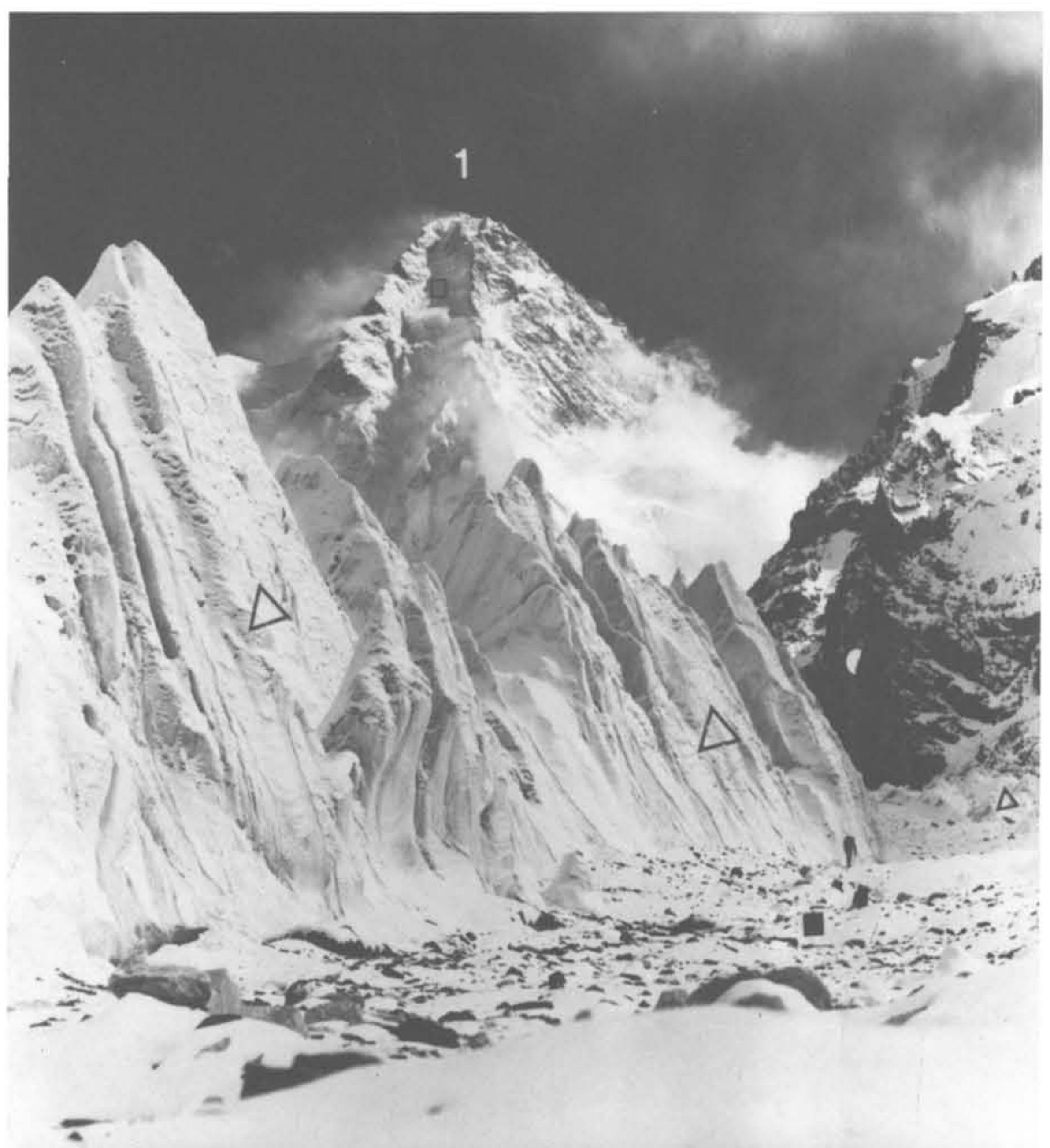
Fig 6 ▼ Taken at 5130 m asl from the central median moraine of the K 2 glacier down-valley and facing north. - - - - marks the highest established prehistoric ice scour limits of the valley and of the orographic left-hand side valley. The surface of the side valley glacier shows clearly how the down-glacier firn ice pyramid formation develops from the early form of the glacier break-out (left side edge of the photo). ⇩ marks Camp 3 of the expedition with the weather station. No. 1 = c. 6800 m-high peak; No. 2 = c. 6000 m-high peak between a 6540 m and a 6040 m high peak, Chongtar Group; No. 3 up to 6750 m high, unnamed peaks of the Aghil Mountains north of the Shaksgam valley; No. 4 = 6200 m-high N-satellite of the 6640 m peak; No. 5 = c. 6400 m-high SSW-satellite of the 6640 m peak; No. 6 = c. 6200 m-high S-satellite of the 6640 m peak. Viewpoint: 35°55'30"N/76°29'30"E; see Fig 1a (□), right. Photo: M. Kuhle 18. 9. 86.





◄ Fig 9
Taken at 4800 m asl, from the right-hand flank of the Muztagh valley towards the west, facing the tongue of the Skamri glacier and its glacier exit (Fig 138 Nos. 6 and 9). Composed of numerous tributary streams (x●), the over 40 km-long glacier shows a striped surface consisting - in accordance with the type of feeding these side glaciers receive - of drift-free ice pyramid areas (primary feeding) and a thick cover of surface moraine (secondary ie avalanche feeding). As is to be expected in the late autumn, the meltwater run-off is already reduced (-6). The flanks of the troughs are cloaked in Neo-Glacial to historic ground moraine (↓↓). Viewpoint: 36°02'30"N/76°50'E. Photo: M. Kuhle 18.10.86.

◄ Fig 10a
Exposure on the orographic left-hand end moraine curve of the Würm Period tongue basin west of the Pusseh (or Pusha) irrigation oasis in the northern Kuenlun foreland - that is to say, on the southern edge of the Tarim basin at 2000 m asl (Fig 138, right, above No. 43). The glacigenic character is established by the flexures (↘) with inserted, compressed limnites (X), as well as by the facetted, polymict erratic blocks of varying sizes, which are contained in it (■) and by the great density of this loose rock. Viewpoint: 37°19'N/77°08'30"E. Photo: M. Kuhle 30.10.86.



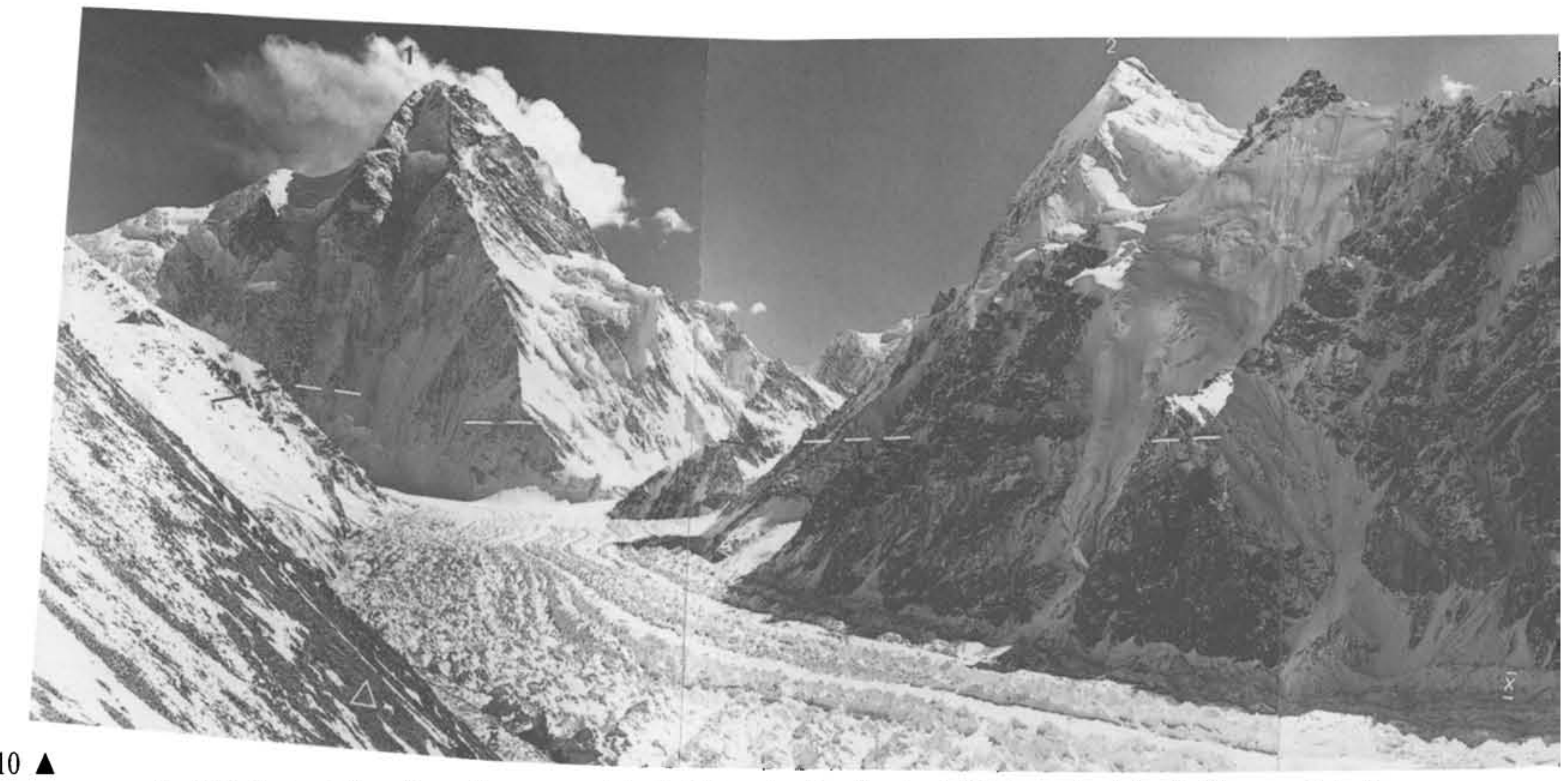
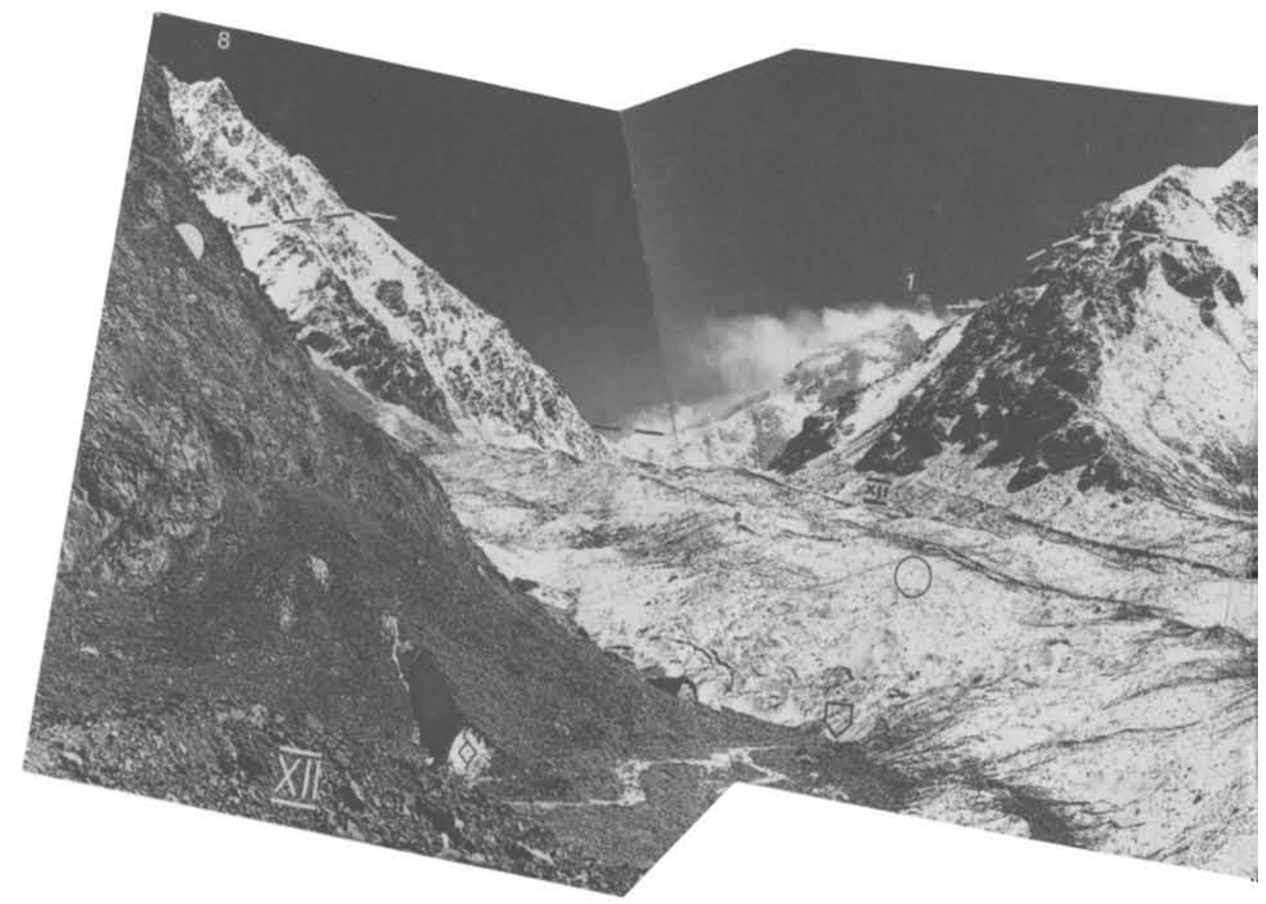
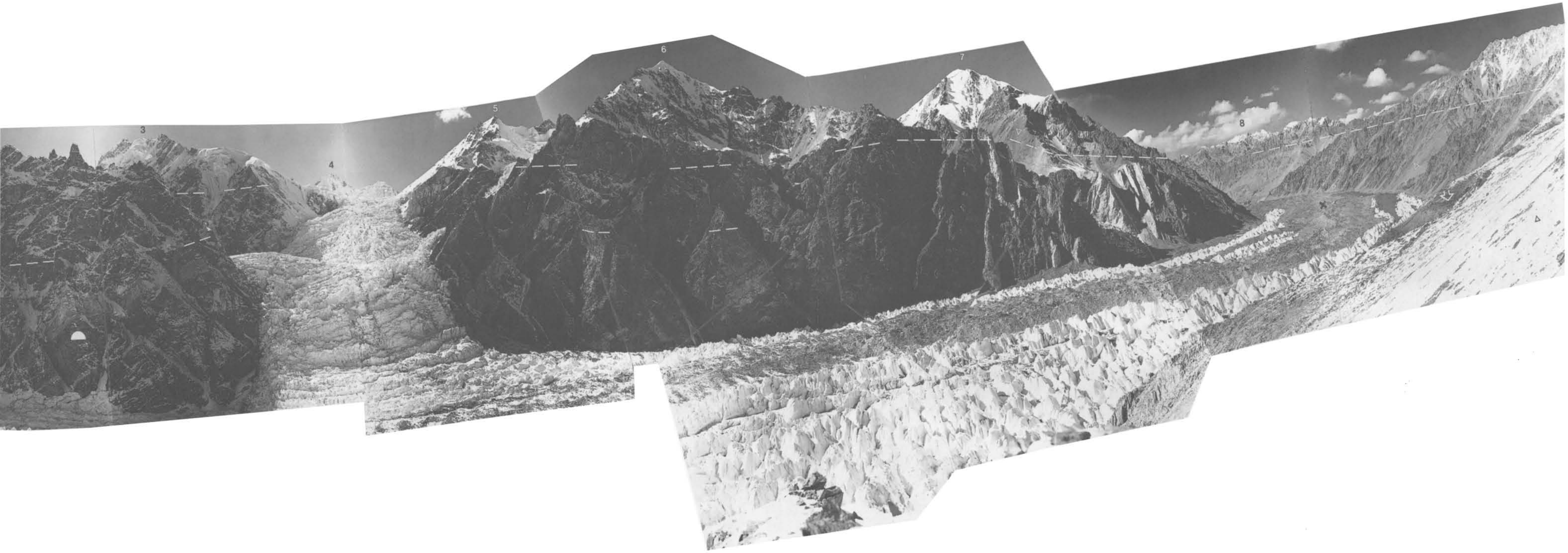


Fig 10 ▲
Panorama across the K2 glacier, taken from the orographic right-hand valley flank, at 5000 m asl, at the half-way point of the ice stream's length; from SSE (No. 1 = K2, 8617 m) via No. 2 (6800 m peak), No. 3 (c. 7000 m-high N-satellite of the Chongtar Peak), No. 4 (more than 7000 m-high N-satellite in Chongtar Group); No. 5 (c. 6000 m-high sub-summit in the northern Chongtar Group) via W with No. 6 (an ESE spur peak of the 6540 m summit), via No. 7 (c. 6000 m-high peak between 6540 m and 6040 m peak) towards NNW to the (No. 8) Aghil Mountains main ridge beyond the Shaksgam valley, which rises up to 6750 m there. On the mountain flanks above the still dendritic valley glacier system of the K2 glacier with its side glaciers (below No. 4) the highest established prehistoric glacier levels are marked (- - - -). Due to steepness, frost weathering and local denudational and erosive processes on the valley flanks the roughening of the walls down to the present glacier level is extremely severe, so that next to no rock abrasions and polishings are preserved (▲). The increasingly heavy cover of surface moraine is due to the horizontal and vertical distance of the ELA, which is now running at the foot of the wall of K2 at about 5200 m asl. Viewpoint: 35°58'N/76°29'E. Photo: M. Kuhle 3.10.86.



◄ Fig 13
View from the central gap of the surface and median moraine of the K2 glacier at 4740 m asl to the SSE and upwards to K2 (No. 1). No more than centimetres or few decimetres thick, the upper moraine with its fresh snow cover (■) has melted down for tens of metres into the body of sheer ice (▷), the surface of which has been dissected into firn ice pyramids (▽). A 188 cm-tall climber provides a comparison. Viewpoint: 35°58'N/76°27'30"E. Photo: M. Kuhle 13.9.86.



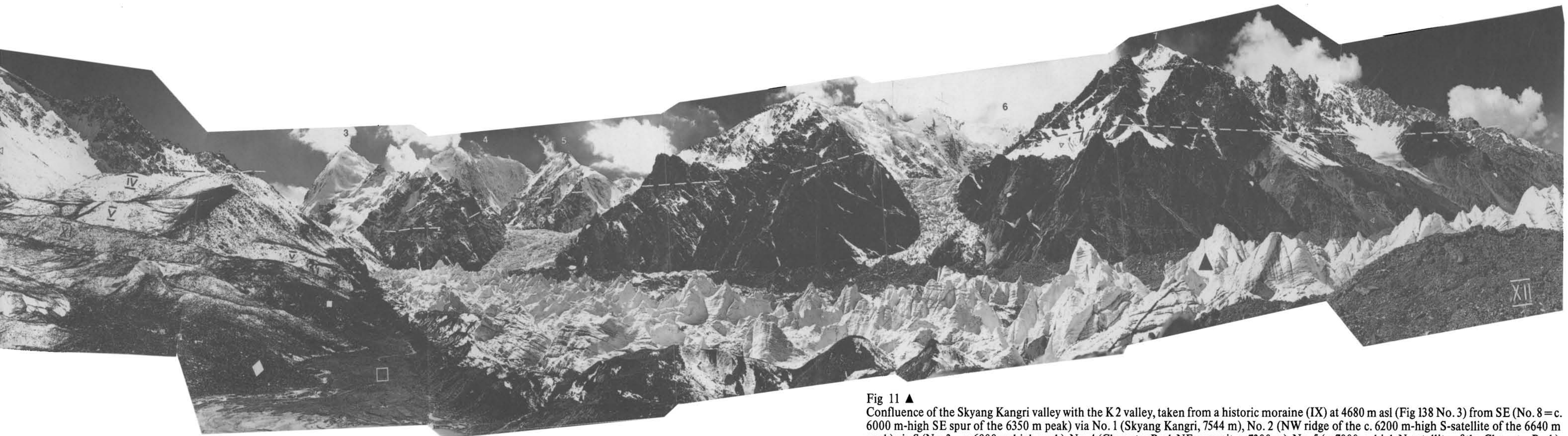


Fig 11 ▲
Confluence of the Skyang Kangri valley with the K 2 valley, taken from a historic moraine (IX) at 4680 m asl (Fig 138 No. 3) from SE (No. 8 = c. 6000 m-high SE spur of the 6350 m peak) via No. 1 (Skyang Kangri, 7544 m), No. 2 (NW ridge of the c. 6200 m-high S-satellite of the 6640 m peak) via S (No. 3 = c. 6800 m-high peak), No. 4 (Chongtar Peak NE summit, c. 7300 m), No. 5 (c. 7000 m-high N-satellite of the Chongtar Peak), No. 6 (6540 m peak), No. 7 (c. 6000 m-high peak S of the 6040 m summit in the northern Chongtar Group) to NW. The ice pyramids of the main glacier reach heights up to 20 to 30 m (▲). In 1986 the front of the Skyang Kangri glacier tongue (♦) no longer reached the K 2 glacier, though this had been so during recent historic stages (Stage IX). There has been infilling of glacifluvial drift material (□). Viewpoint: 35°59'40"N/ 76°29'E. Photo: M. Kuhle 16. 9. 86.

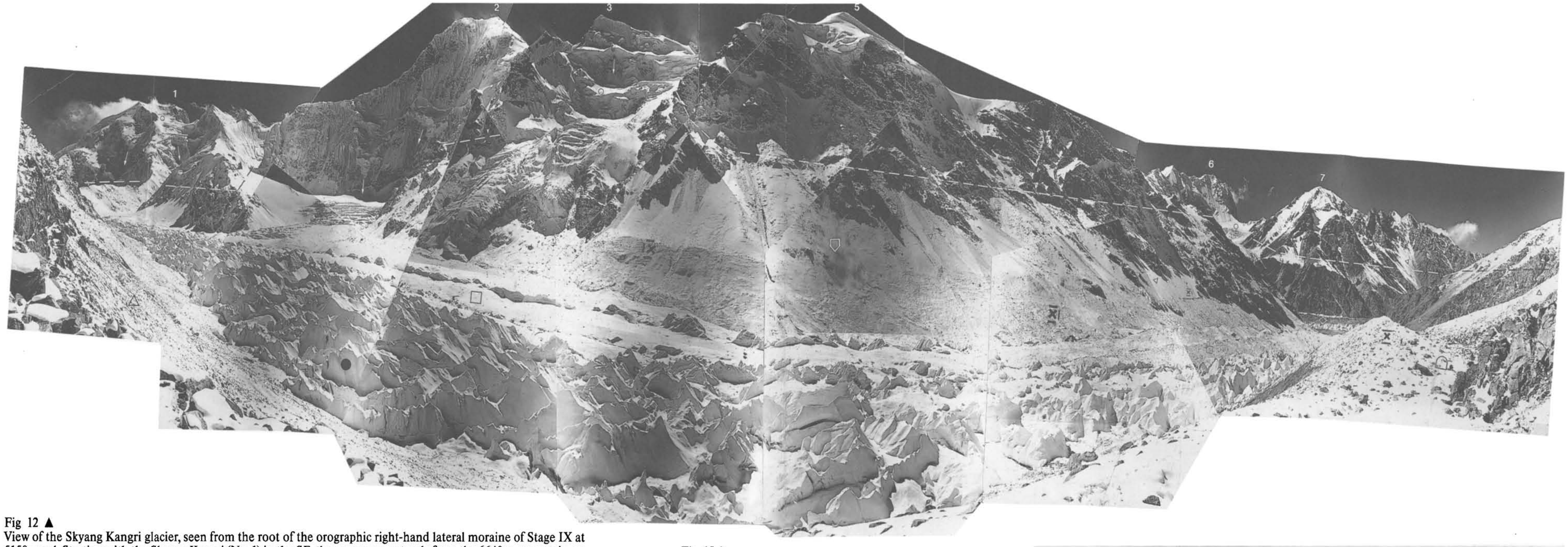


Fig 12 ▲
View of the Skyang Kangri glacier, seen from the root of the orographic right-hand lateral moraine of Stage IX at 5150 m asl. Starting with the Skyang Kangri (No. 1) in the SE, the panorama extends from the 6640 m mountain, or its ENE side peak (No. 2) to be precise, to its main peak (No. 3), to the c. 6200 m peak (No. 5) to the S, W and WNW with the 6540 m peak ((No. 6), the c. 6000 m peak (No. 7) and the main valley with the K 2 glacier (◇). The fresh snow cover is representative for the season at this altitudinal level. ⌂ indicates the position of the Skyang Kangri valley camp of the 1986 expedition, where systematic climatic measurements were made as well. Viewpoint: 35°59'N/76°30'30"E (Fig 138 right of No. 3). Photo: M. Kuhle 1.10.86.

◄ Fig 14
Valley on the orographic right-hand banks of the K 2 glacier outside the Skyang Kangri valley exit (Fig 138, No. 3). Here the Skyang Kangri stream (⇩) flows off beneath the K 2 glacier (□), having deposited glacifluvial drift sediments (○○) on its marginal ice (□) which have in the meantime formed terraces. Viewpoint: 4630 m asl; 36°00'N/76°29'E. Photo: M. Kuhle 27.9.86.

Fig 15 ►
View from the orographic right-hand valley flank across the K 2 glacier towards the WNW to the left side glacier furthest down the valley; taken at 5300 m asl. The exposure shows the extreme roughness of the rock, which can be seen even immediately above the surface of these fast-flowing and therefore heavily scouring branches of the glacier (⇦ ⇗). The scouring glacier exposes the sheer structural arrangement of the upright metamorphites without polishing rock at the same time. This is an example – in principle – of the improbability in the arid Karakorum of having prehistoric glacial polish preserved. Viewpoint: 35°59'N/76°28'E. Photo: M. Kuhle 11.9.86.

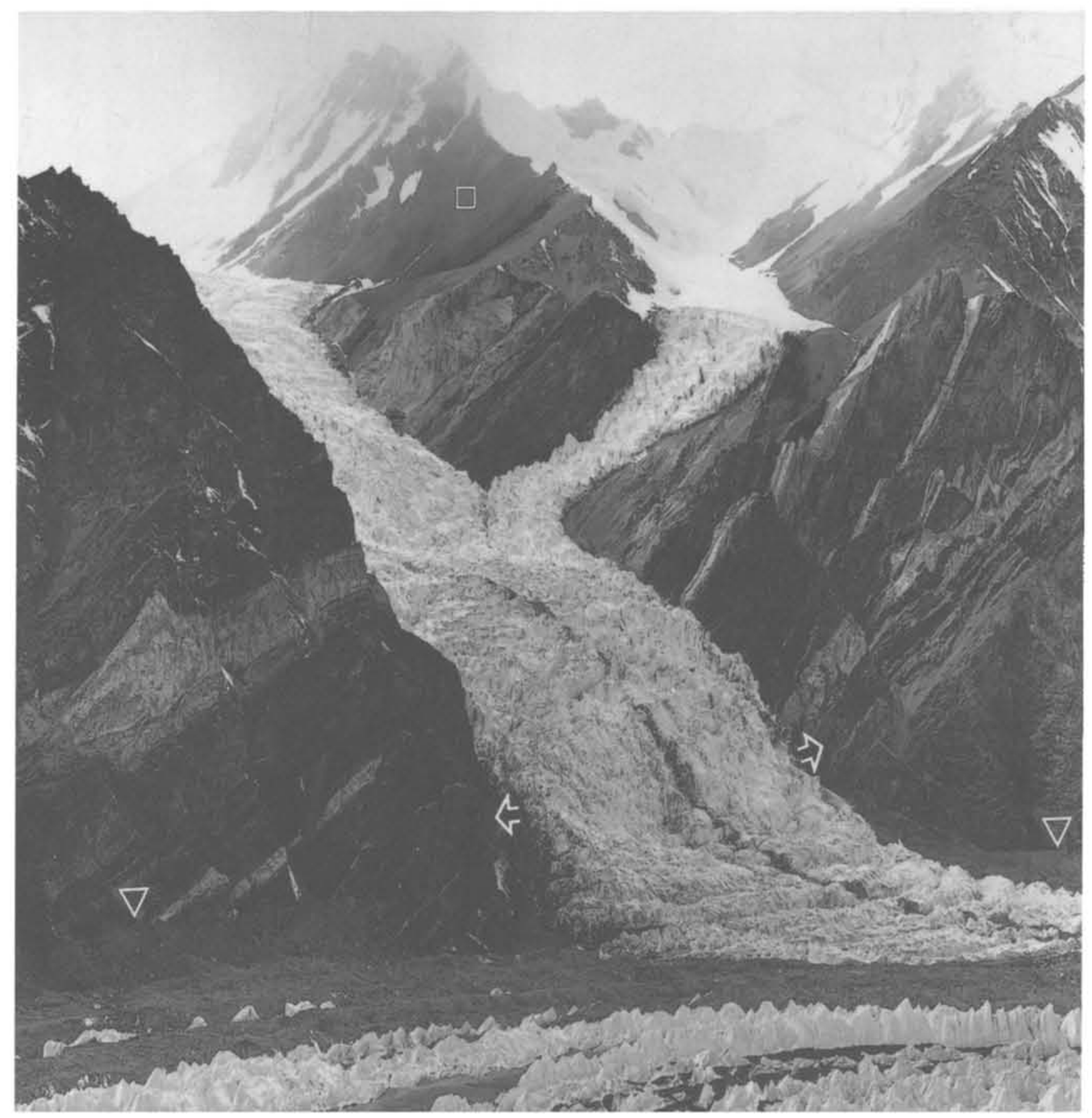
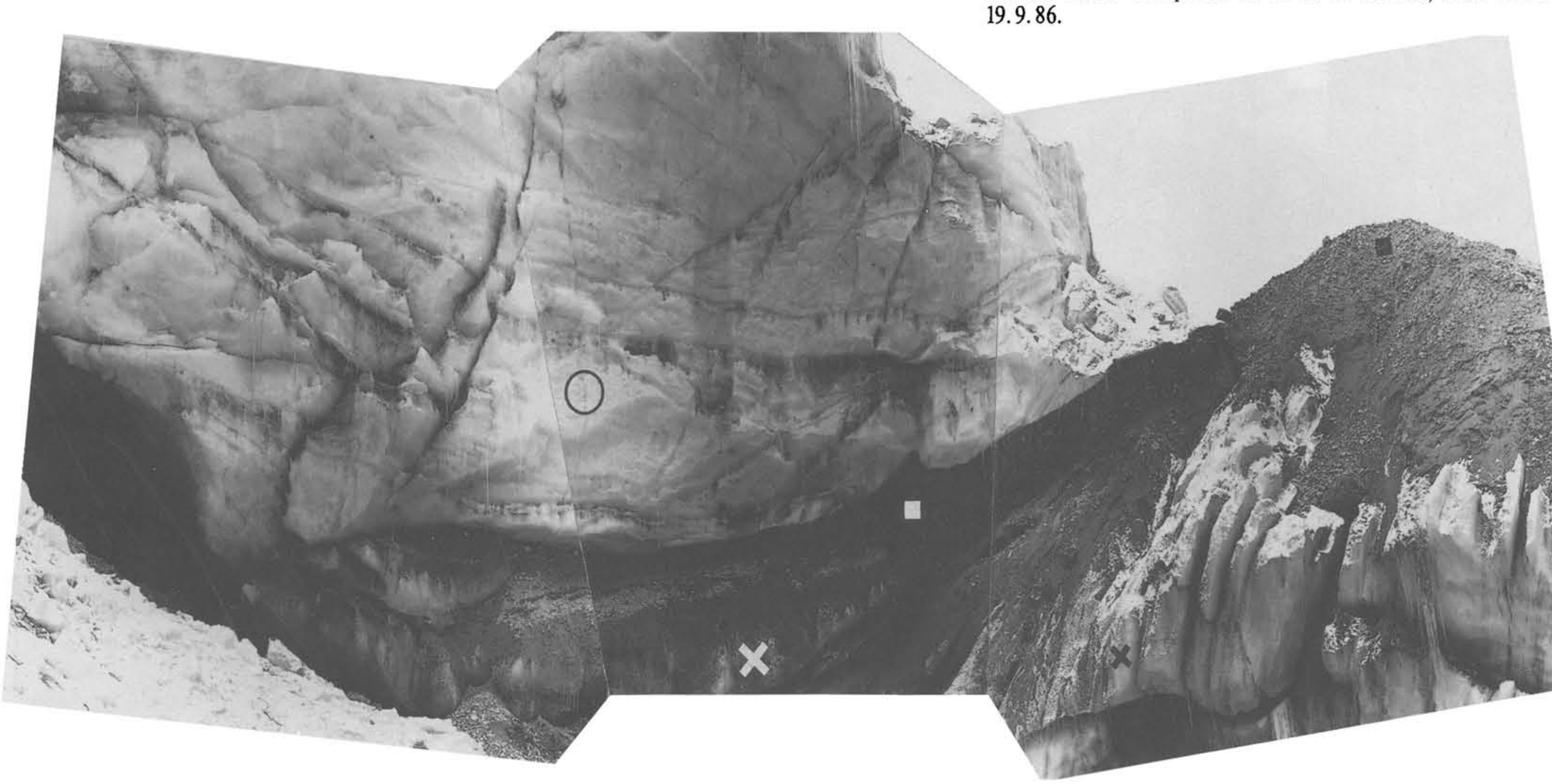


Fig 16 ▲
Orographic right-hand bank valley on the edge of the K 2 glacier seen from 4640 m asl, looking N. The visible ice margin (□) is not the actual edge of the glacier, which is submerged below the light-coloured outwash plain drift (-6). In prehistoric times the glacial filling of the K 2 valley was much thicker; polishings and abrasion are already preserved on some protruding rock ridges (⬟). Built on a much larger scale, the talus slopes occasionally produce talus cones, which are set on the floor of the little bank valley (◆) Viewpoint: 36°01'N/76°29'15"E. (Fig 138, above No. 3). Photo: M. Kuhle 27.9.86.



◄ Fig 17
Eastern edge of the K 2 glacier at 4630 m asl. The exposure in the ice shows separation of hanging (○) and lying glacier (X) by horizontally deposited internal moraine (■) which comes to the surface on the right towards the bank valley (■). The body of the hanging glacier is accordingly narrower than that of the recumbent glacier (X), which continues on the right as far as the valley slope (no longer visible here). Viewpoint: 36°00'N/76°29'10"E (Fig 138 No. 3). Photo: M. Kuhle 27.9.86.

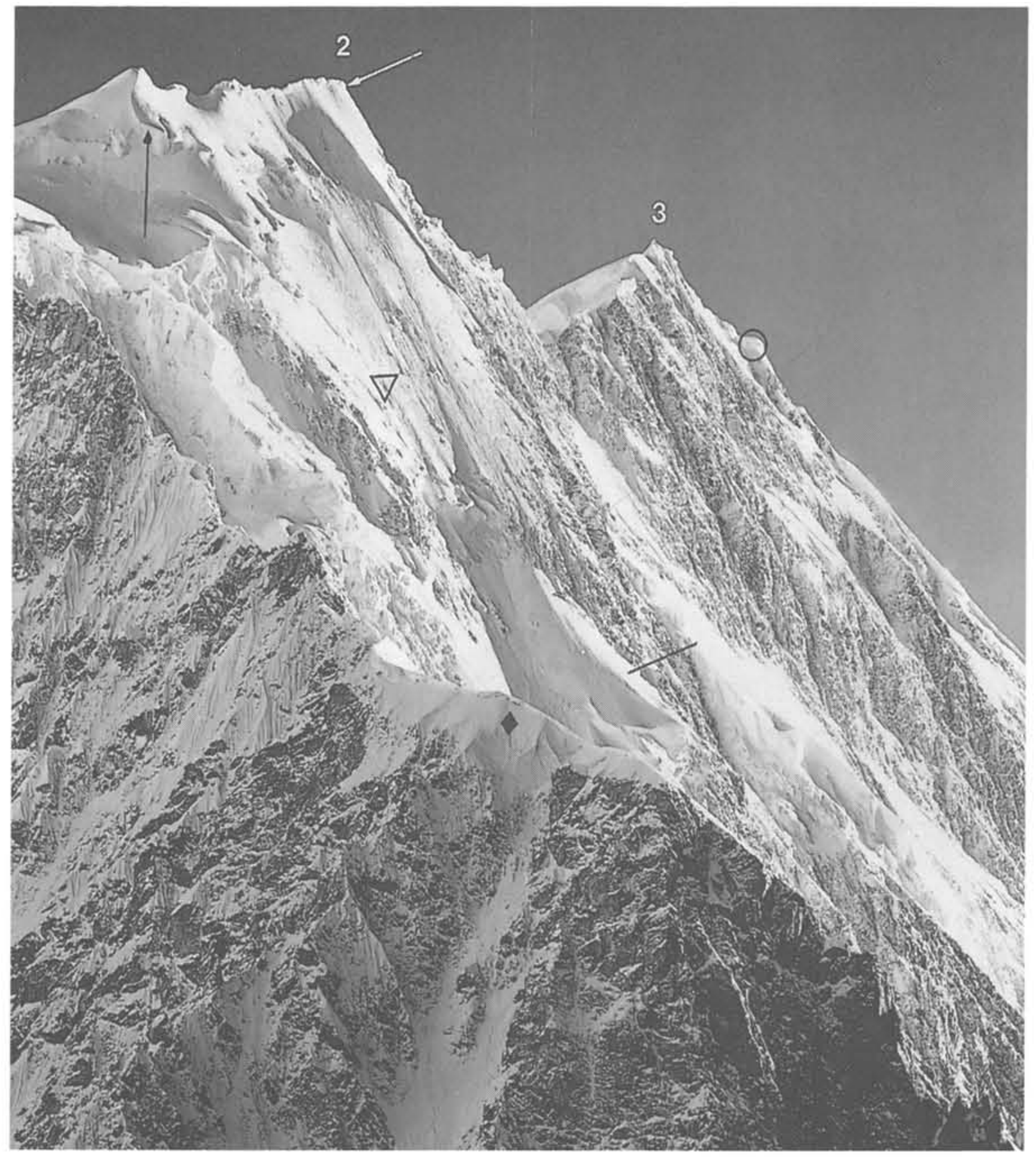


Fig 18a ▲
Two unnamed peaks SW of the Savoia Saddle, which, c. 7000 m (No. 2) and 7060 m-high (No. 3), build up the ridge which leads on to the 7263 m-high Summa-Ri. The north walls of both the peaks shown here are totally glaciated, ie equipped with a more or less thick ice (▽), ice balconies (⌐) and prominent cornices in the ridges (↙○◆). In spite of partly extreme steepness there are no exposed rocks near the peaks. This is the altitudinal interval of glacier feeding. These peaks consequently do not tower above the altitudinal level of glaciers like the K 2 Peak. Viewpoint: 35°53'30"N/76°28'E, seen from 5700 m asl. Photo: M. Kuhle 19.9.86.

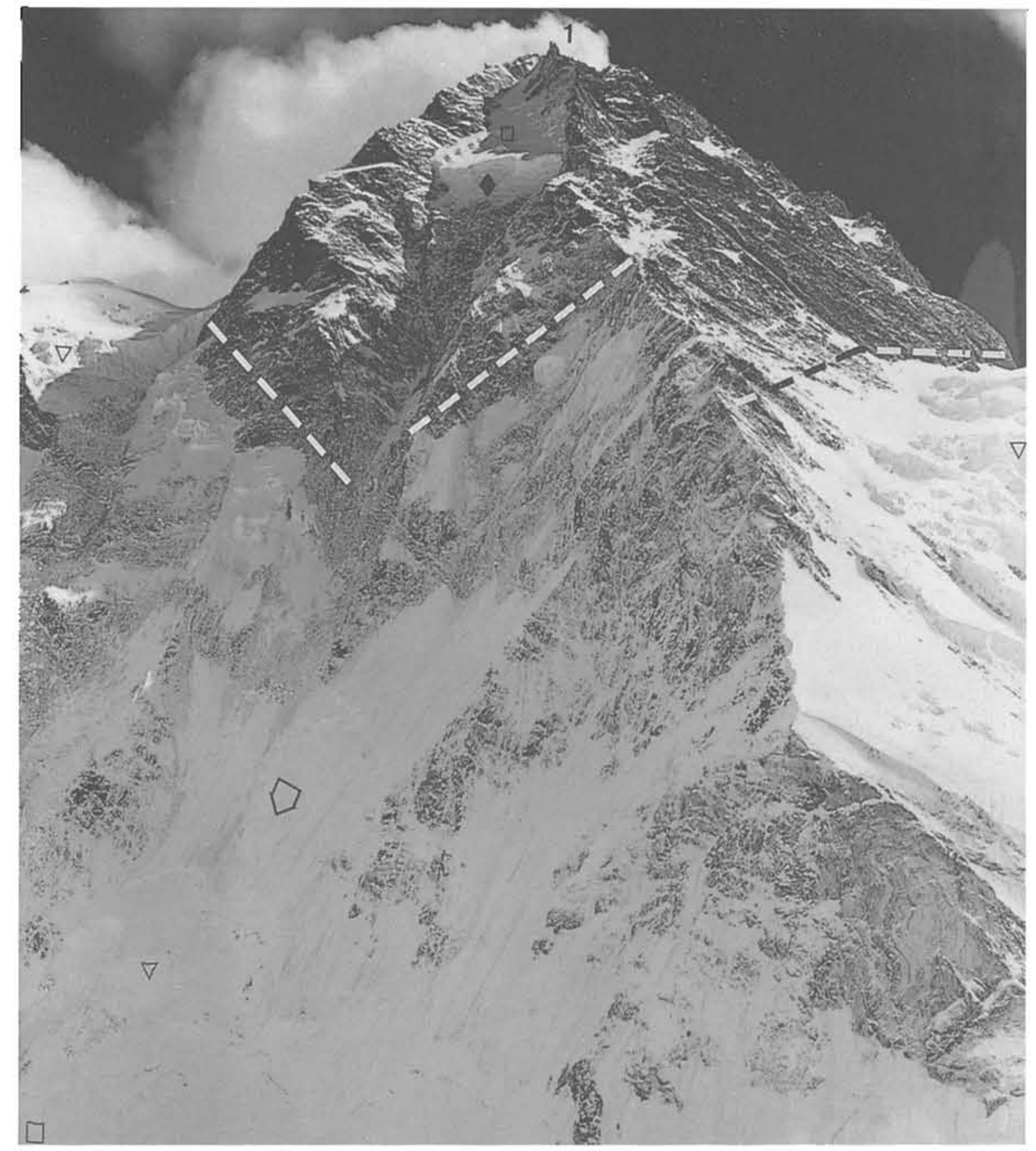


Fig 19 ▲
View of K 2, at 5200 m asl, facing S. Below (- - - -) the glacier or flank ice covering of the rocks is complete (⬠); above (- - - -), up to the peak, the gneisses are largely bare. Here, above the altitudinal level of glacier formation, only in the corrie-like gorge of the peak a glacier with ice balcony crumbling (◆) has formed. The reason for this is to be seen in the stable lee-side location within the sheltered niche of the gorge (□). Here drifting snow, followed by snow sedimentation and metamorphosis of the snow through pressure lead to glacier ice. Up there, at or above 8000 m asl, it is too cold for normal transformation of snow to ice by way of temperature metamorphosis, so that a permanent surplus of snow (due to the fact that more snow is blown in than out) is required to ensure the thickness needed to produce pressure. Viewpoint: 35°55'N/76°30'E. Photo: M. Kuhle 23.9.86.

Fig 20 ▲
The 6040 m (or 6050 m) peak (No. 1) seen from the N, from the Muztagh valley, at 4050 m asl. Like all "cold" steeply-ending glaciers, the hanging glacier breaks off almost vertically at its tongue end (↑). In the foreground the Late Glacial moraine landscape (■III) of the main valley (Muztagh valley) can be seen with its Holocene, solifluidal transformation (○) within the altitudinal interval from 5000 m to 4400 m asl. Viewpoint: 36°03'N/76°25'E (Fig 138 below No. 10). Photo: M. Kuhle 2. 9. 86.

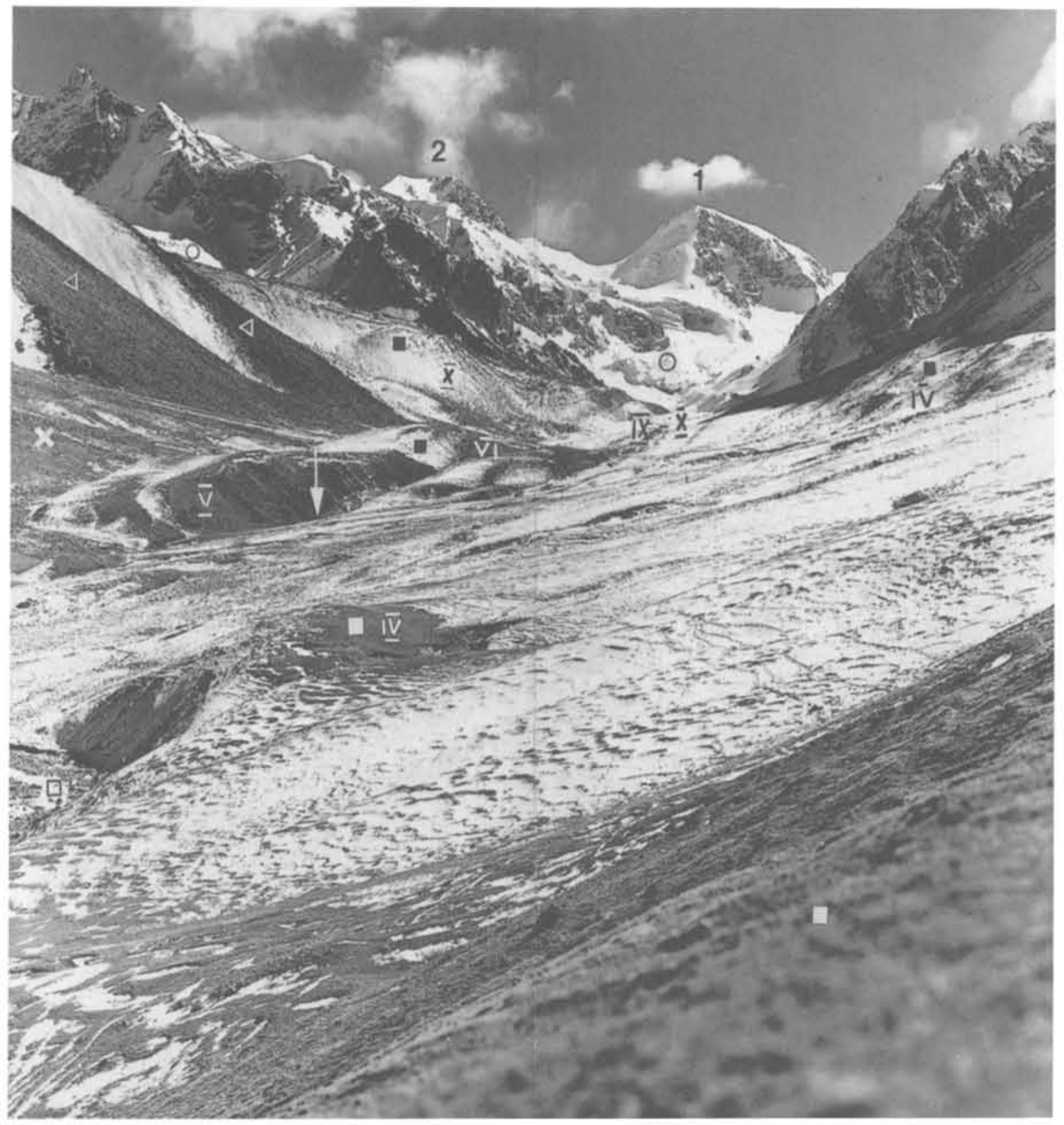


Fig 21 ▲
Representative valley with connection to the main ridge of the Kuenlun, sloping from the 6328 m peak (No. 2) towards the NW (Fig 138, Nos. 14 and 15). Taken at c. 4400 m asl up-valley (from Fig 138 No. 15) towards the SE across the most recent Late Glacial (■ IV), the Neo-Glacial (■ V, VI) and historic moraines (■ IX, X) and Recent glaciers (○○). Here, at the periglacial altitudinal level, these moraines are transformed and rounded by solifluction underneath the short grassland vegetation, which reveals itself in the terracettes of the slopes (foreground and middle ground). No. 1 = c. 6150 m peak of the Kuenlun main ridge. Viewpoint: 36°34'N/77°14'E. Photo: M. Kuhle 28. 10. 86.

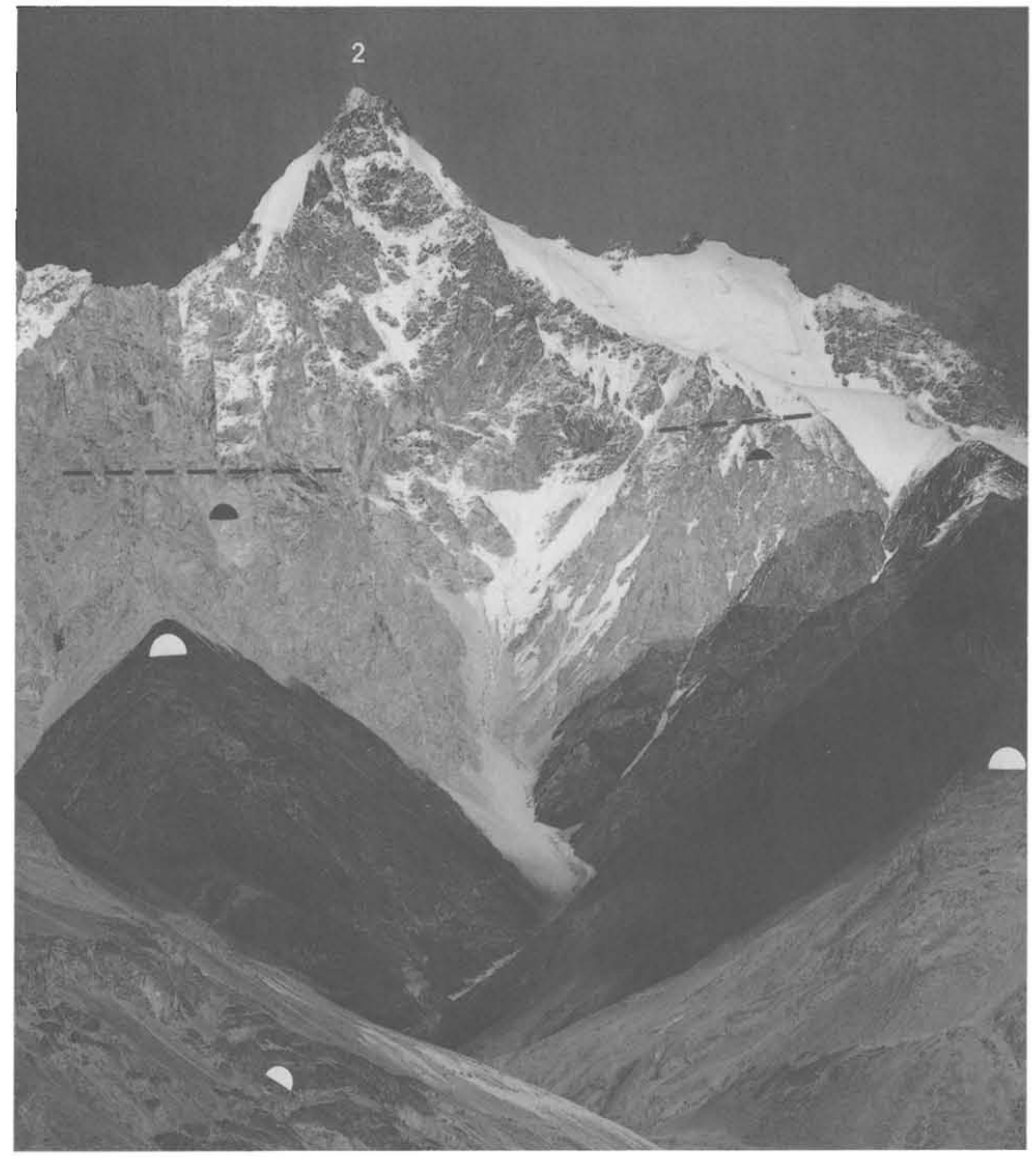
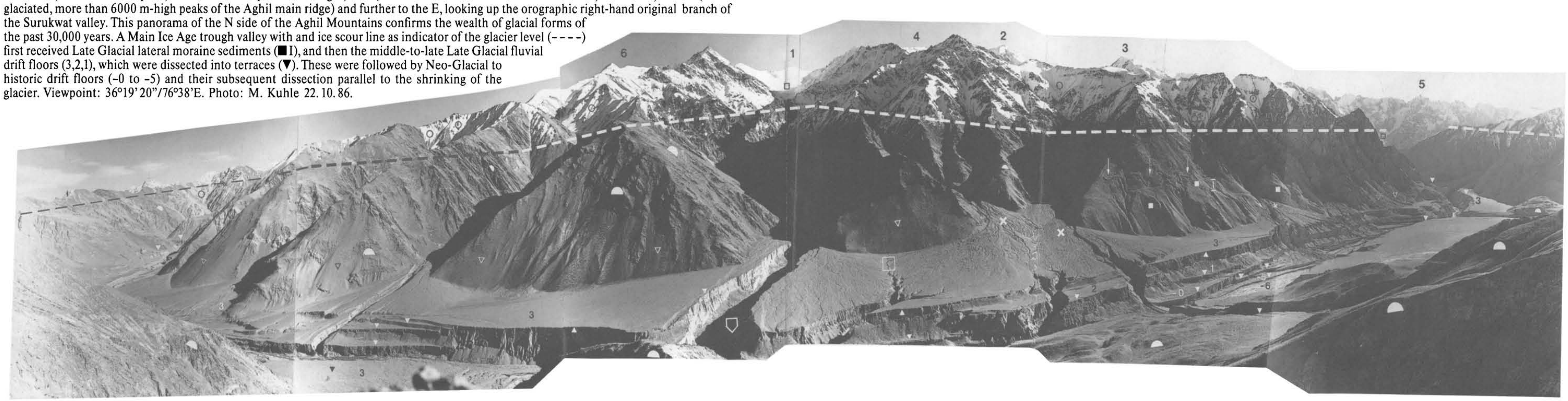


Fig 24 ▲
View from the bottom of the Shaksgam valley (Fig 138, No. 23) towards the NE to the SW flank of a high Aghil peak (No. 2 = c. 6500 m) of the 6755 m massif. The Ice Age ice scour limit (- - - -), or the then ice-stream level, ran below the present altitudinal level of glaciers. The rock regions further down show more or less well preserved remnants of abrasions and with polishings typical roundings (◗ ◥). Viewpoint: 36°08'N/76°36'E. Photo: M. Kuhle 31. 8. 86.

Fig 22 ▼
View taken at 4500 m asl, from the orographic left-hand flank of the middle section of the Surukwat valley (Fig 138 between Nos. 31 and 33) from SW (No. 5 = 6750 m peak, with the 6126 m peak to the right) to S (Nos. 3 and 2 = summits of 6300 m massif) via Nos. 4, 1 and 6 (other glaciated, more than 6000 m-high peaks of the Aghil main ridge) and further to the E, looking up the orographic right-hand original branch of the Surukwat valley. This panorama of the N side of the Aghil Mountains confirms the wealth of glacial forms of the past 30,000 years. A Main Ice Age trough valley with and ice scour line as indicator of the glacier level (- - - -) first received Late Glacial lateral moraine sediments (■ I), and then the middle-to-late Late Glacial fluvial drift floors (3,2,1), which were dissected into terraces (▼). These were followed by Neo-Glacial to historic drift floors (-0 to -5) and their subsequent dissection parallel to the shrinking of the glacier. Viewpoint: 36°19'20"/76°38'E. Photo: M. Kuhle 22. 10. 86.



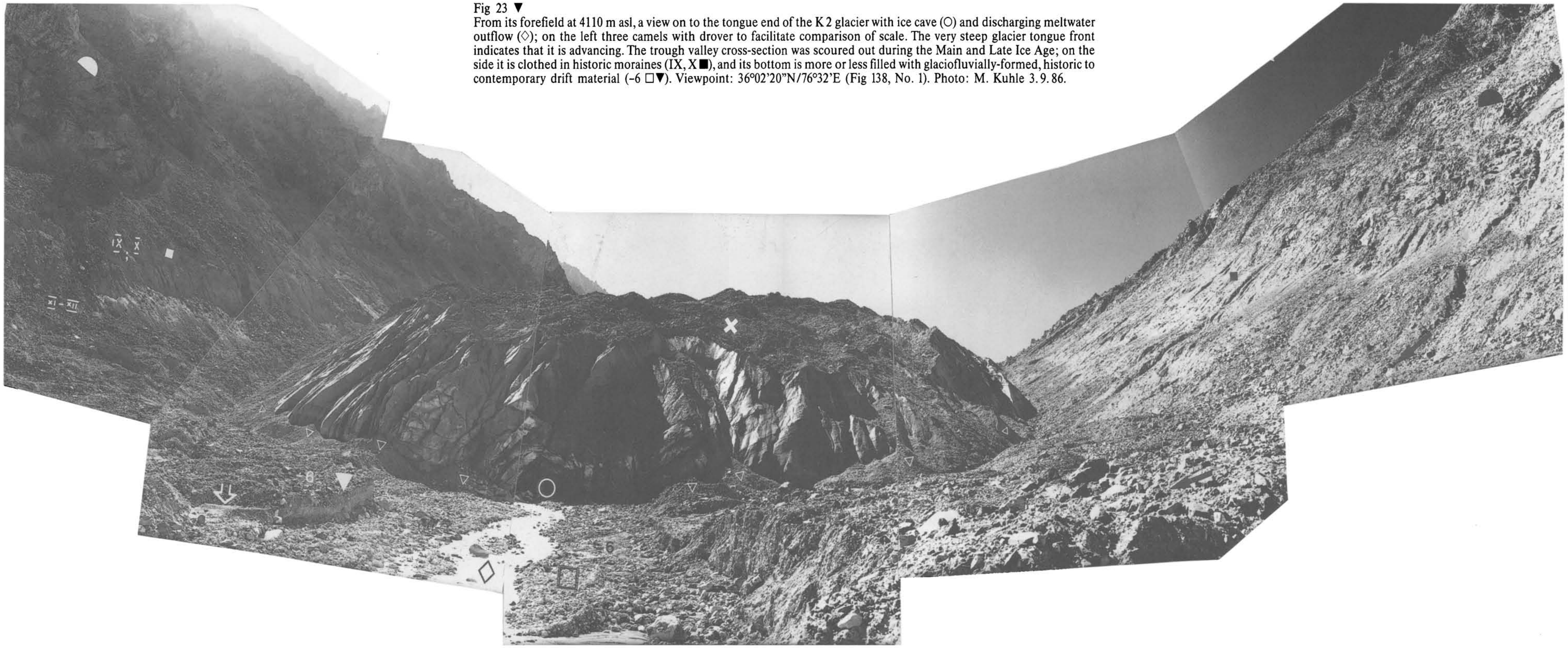


Fig 23 ▼
From its forefield at 4110 m asl, a view on to the tongue end of the K 2 glacier with ice cave (○) and discharging meltwater outflow (◇); on the left three camels with drover to facilitate comparison of scale. The very steep glacier tongue front indicates that it is advancing. The trough valley cross-section was scoured out during the Main and Late Ice Age; on the side it is clothed in historic moraines (IX, X ■), and its bottom is more or less filled with glaciofluvially-formed, historic to contemporary drift material (-6 □▼). Viewpoint: 36°02'20"N/76°32'E (Fig 138, No. 1). Photo: M. Kuhle 3. 9. 86.

◀ Fig 23a
View of the drift-covered tongue (○) of the K 2 glacier, taken at 4140 m asl from the base camp of the 1986 expedition facing SE (on the right the computer-controlled weather station where, during the period 3.9–13. 10. 86 the climatic parameters were recorded at 20-minute intervals through 12 different inputs). Compared with the situation given in Fig 23 – which is typical for autumn – the meltwater output has fallen to one third. Several metres thick, the surface moraine (○) preserves the recumbent glacier ice (x) from ablation. The very rough blocks of the upper moraine drift slips continuously down the steep glacier tongue front as melt-ablation makes it recede relatively fast. This is accompanied by a gully-like channelling of the ice slopes, at the exit of which moraine talus cones accumulate as a kind of terminal dump moraine (♦). Viewpoint: 36°02'33"N/76°31'58"E. Photo: M. Kuhle 12. 10. 86.

Fig 25 ▲
View from the bottom of the "Kudi valley" on the Kuenlun N-slope (Fig 138, left above No. 15), taken at 3900 m asl and facing a small side valley on the right with a 5704 m-high mountain at the valley head. Leading down from two still glaciated peaks (○), the hanging valley has two parts to its cross-section: in the remnants of a trough valley, evidence of which is provided in the abraded and polished, rounded valley shoulders (▲), a V-shaped valley profile has been inserted by the erosion of sub- and post-glacial meltwaters (→). During the Main Ice Age the entire valley had been filled high up with glacier ice. Viewpoint: 36°38'N/77°09'E. Photo: M. Kuhle 28. 10. 86.

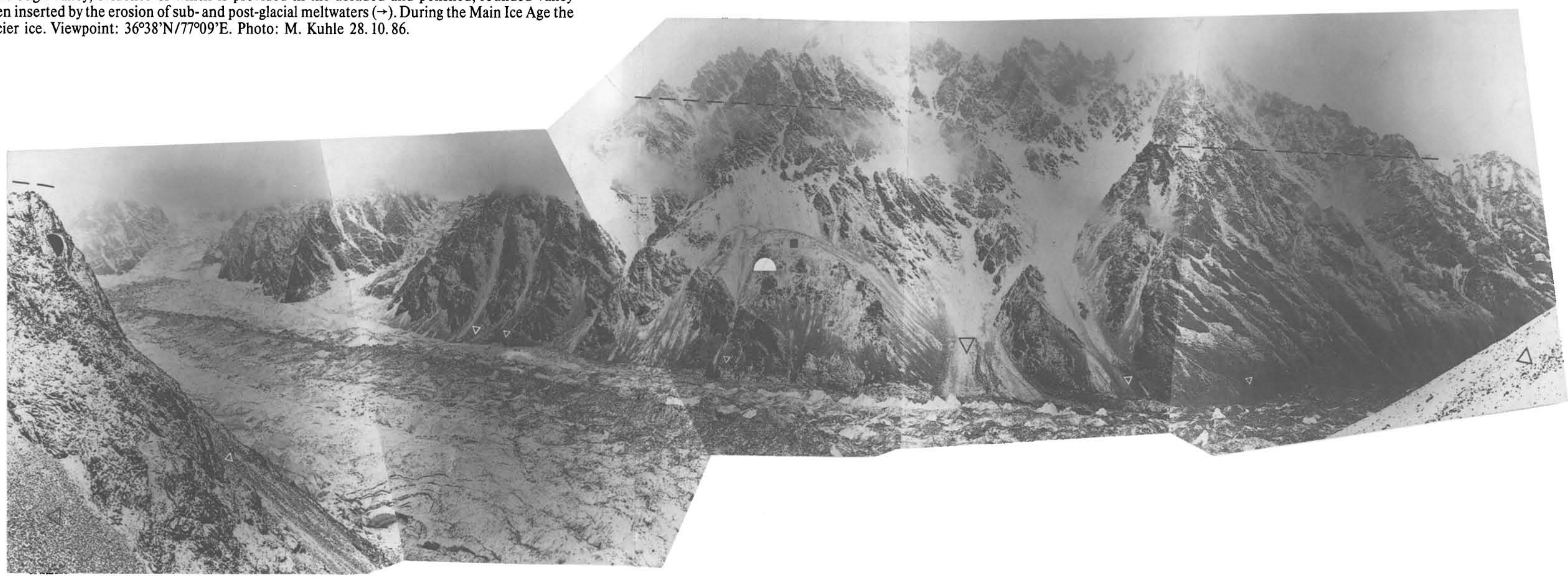


Fig 18 ▶
View from the orographic right-hand flank of the K2 valley across the lower reaches of the K2 glacier from an altitude of 4800 m asl. 5–6 cm freshley fallen snow covers part of its surface moraine. Apart from preserved glacial flank abrasions and polishings (◣ ▲), the substantial transformation of the slope by rock gullies and talus cones (◁▷) since deglaciation is clear. There are but few remnants of moraines (■). ---- marks remnants of ice scour limits. Viewpoint: 36°00'35"N/76°29'E (Fig 138 above No. 3) Photo: M. Kuhle 28. 9. 86.

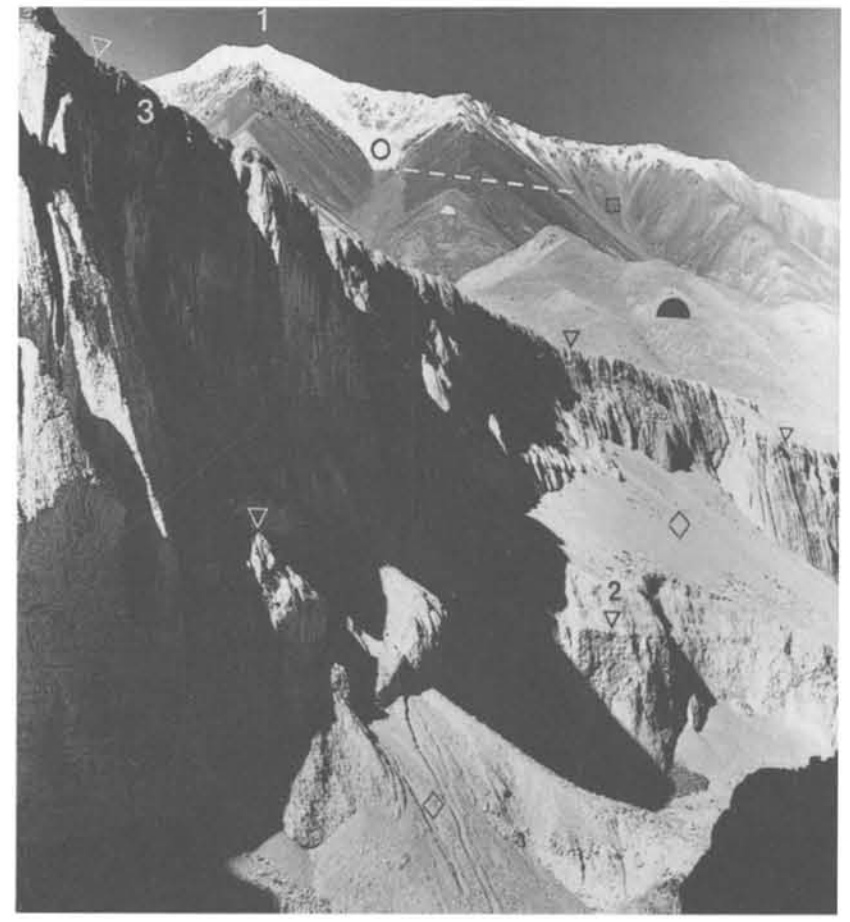


Fig 26 ▲
View from an altitude of 3800 m asl, facing N to the 6094 m-high peak (No. 1) of the Aghil Mountains across an approximately 300 m-high Late Ice Age ice cave drift floor terrace (▽ No. 3). The next recent sander terrace (▽ No. 2) has been deposited below. In the bottom foreground there is the talweg of the western Surukwat valley (Fig 138 below No. 31). On the orographic left-hand valley flank glacial rock abrasions and polishings have been preserved up to the main Ice Age ice scour limit (▲). ○ marks a small cold hanging glacier with a steep tongue front. Viewpoint: 38°18'N/76°34'25"E. Photo: M. Kuhle 22. 10. 86.

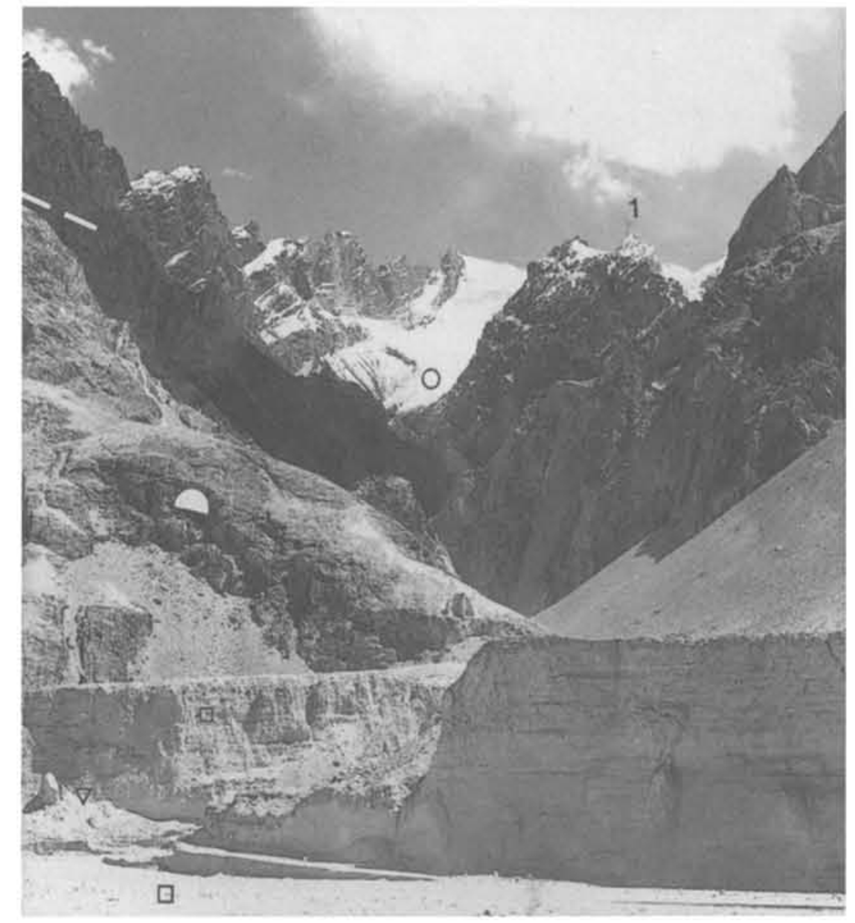
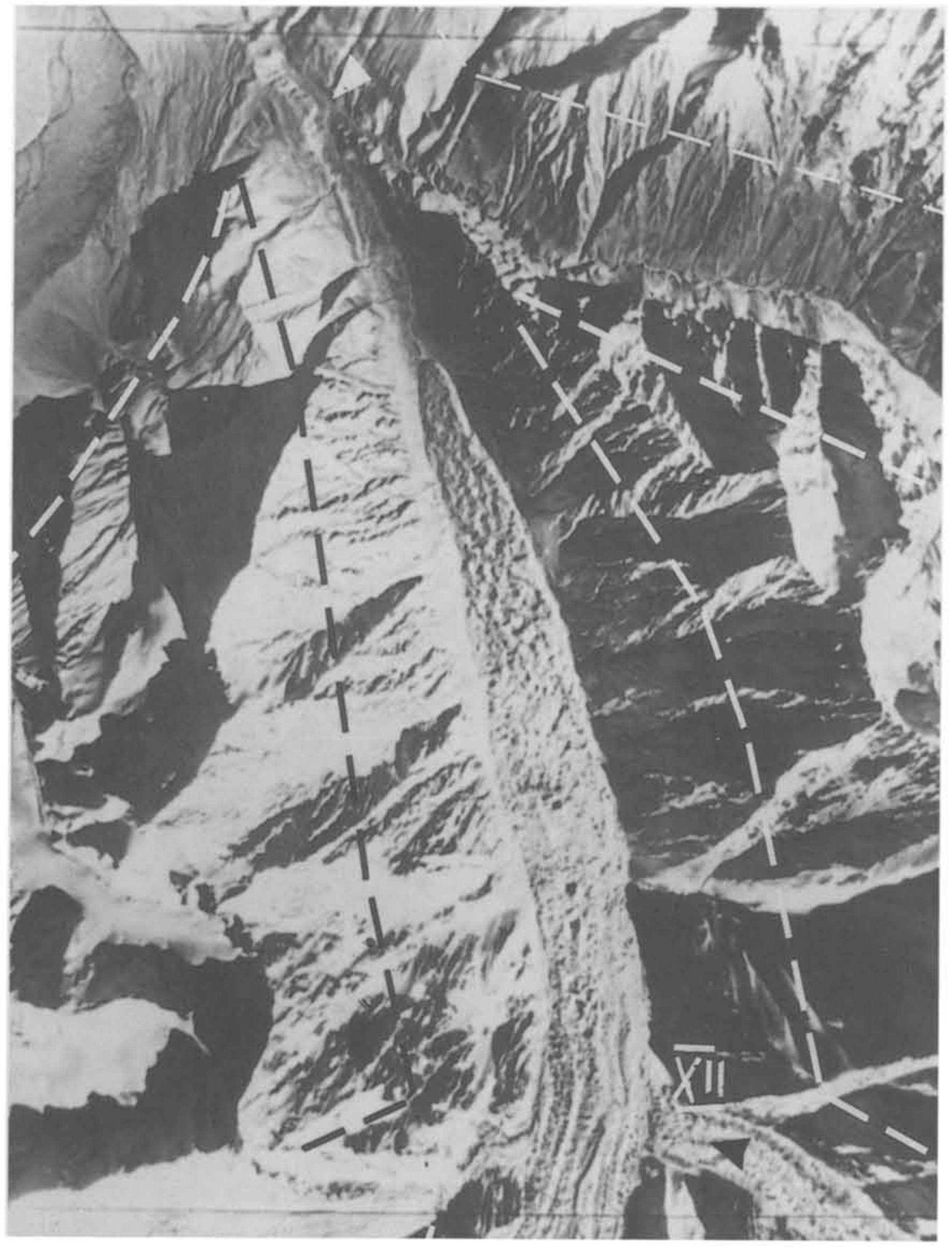
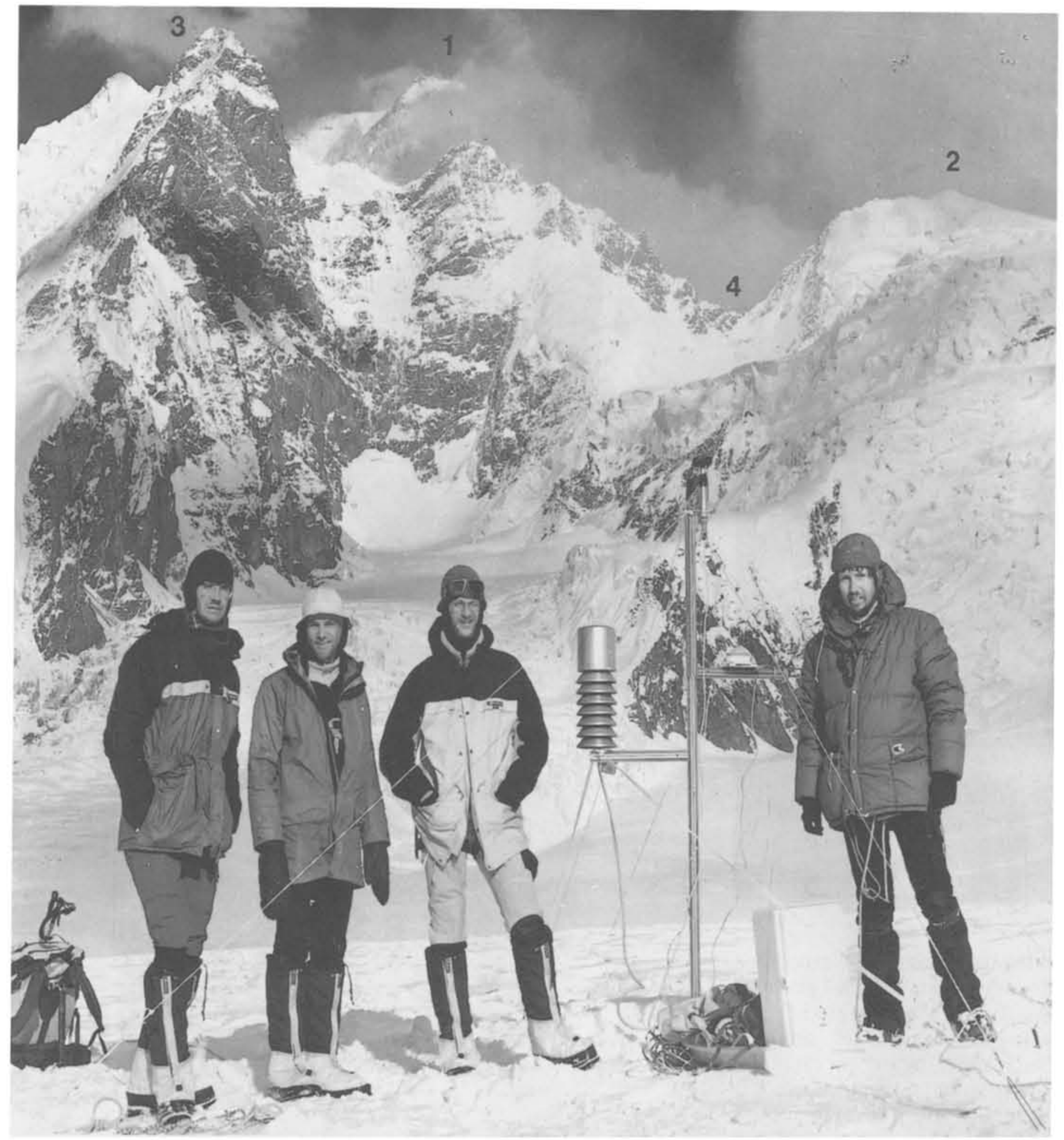


Fig 27 ▲
View from the drift floor of the Shaksgam valley (□ below) which continues to undergo annual working-through, facing SSE towards some satellites of the 6210 m-high peak (No. 1), a spur peak of the Karakorum system, and into an orographic left-hand side valley (Fig 138, beneath No. 21). At the valley head a glacier hangs down (○). Thanks to its extreme steepness as a glacial cut, or gorge-like trough, the side valley was partially buried by post-Late Glacial talus cones. In the area of the confluence with the main valley, perfectly preserved flank abrasions and polishings (▲) suddenly set in. They are evidence of an extremely thick prehistoric infilling of ice. The former glacier level (----) can be established with the aid of an ice scour limit. Viewpoint: 4020 m asl, 36°08'N/76°35'E. Photo: M. Kuhle 1. 9. 86.



◄ Fig 30a
Aerial photo, vertical exposure of the K2 glacier (Fig 138, seen from above Nos. 1, 2, 3 and 3a) showing the junction of the Skyang Kangri glacier with the K2 valley (bottom edge of the photo on the right side) as well on the right side as well as that of the northern Skyang Lungpa valley with the K2 valley and that of the K2 valley with the Muztagh valley (upper edge of the photo left side). At the time this photo was taken, ie 10 years before the 1986 expedition, the Skyang Kangri glacier reached the K2 glacier and turned somewhat off into the main valley (◄, bottom) (cf. Fig 30). At that time the outline of the K2 glacier corresponded to its present one. ---- marks the level of the reconstructed prehistoric ice stream network. Flying position: 36°01'N/76°27'30"E; Chinese air photo 1976.



◄ Fig 33
The fourth, and highest, of the expedition weather stations on the orographic left-hand tributary branch in the feeding area at 5330 m asl (cf. Fig 1a □, left), weighs 75 kg and was taken up on a sledge pulled by the German and Chinese scientists. It operated for 17 days, from 21.9 to 7.10.1986. Every 20 minutes the 12 different measurement data were averaged and stored together with the extreme values. Their batteries were charged by S-facing solar collectors and were thus maintained in working condition. No. 1 = Skyang Kangri 7544 m; No. 2 = 6869 m peak; No. 3 = c. 6400–6600 m high peaks in the ridge between Skyang Kangri glacier and K2 glacier as they are running between Skyang Kangri and the 6640 m peak; No. 4 = 6526 m saddle towards the Godwin-Austen glacier (Baltoro glacier system); beneath this high relief there is the firn cauldron of the orographic right-hand (eastern) tributary branch of the K2 glacier. Viewpoint: 35°54'45"N/76°28'30"E. Photo: M. Kuhle 21.9.86.

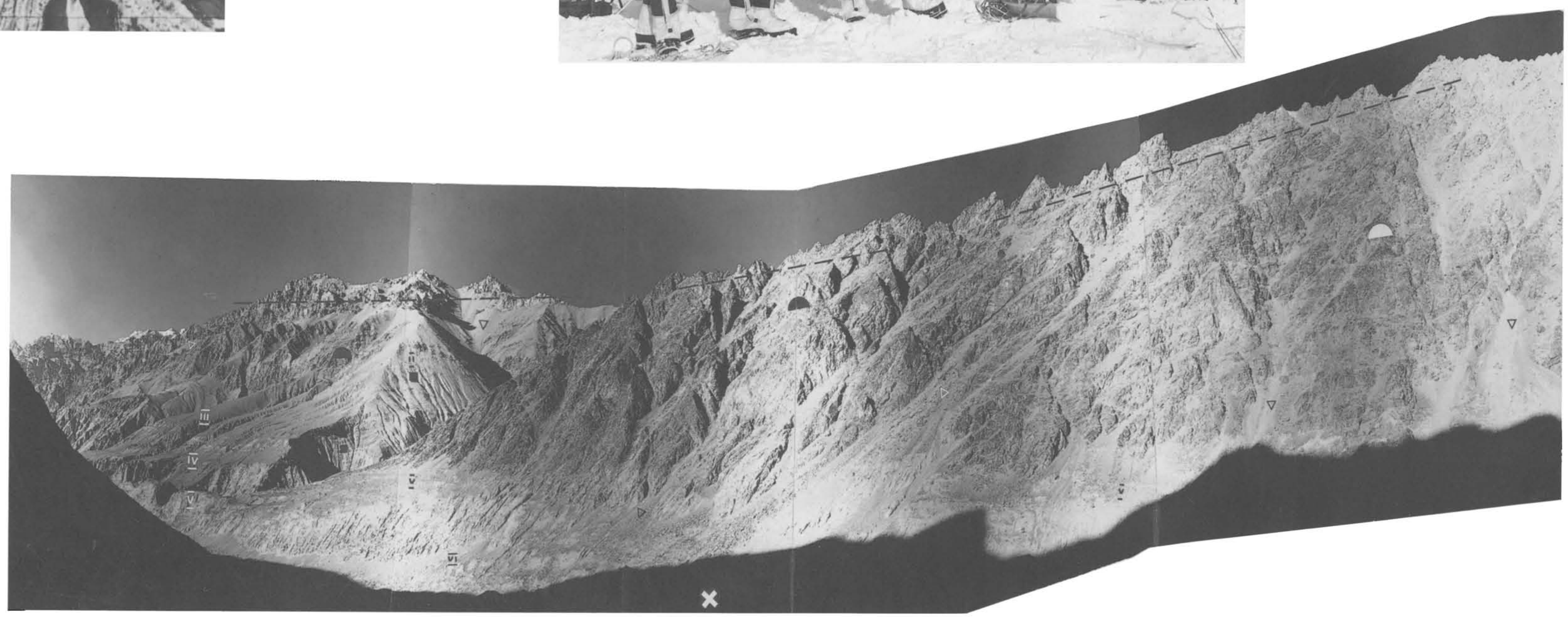


Fig 32 ►
View from the orographic left-hand bank valley of the K2 glacier at 4400 m asl, facing NE across the ice stream (X) to the right-hand, glacially abraded and polished valley flank (▲). When the Ice Age glaciation reached the glacier level (----), its surface was above the ELA, so that lateral moraines could not be separated out. Later, during the rise in temperature in the middle Late Ice Age (Stages ■ II and III, far left) moraines were accumulated, ie warming up had raised the ELA above the level of the valley glacier which had dropped in the meantime. The contribution of the late Late Glacial and the Neo-Glacial lateral moraine to the valley cross-section has accordingly been increasing (IV and V,. far left). Viewpoint: 36°01'40"N/76°27'E. Photo: M. Kuhle 3.9.86.

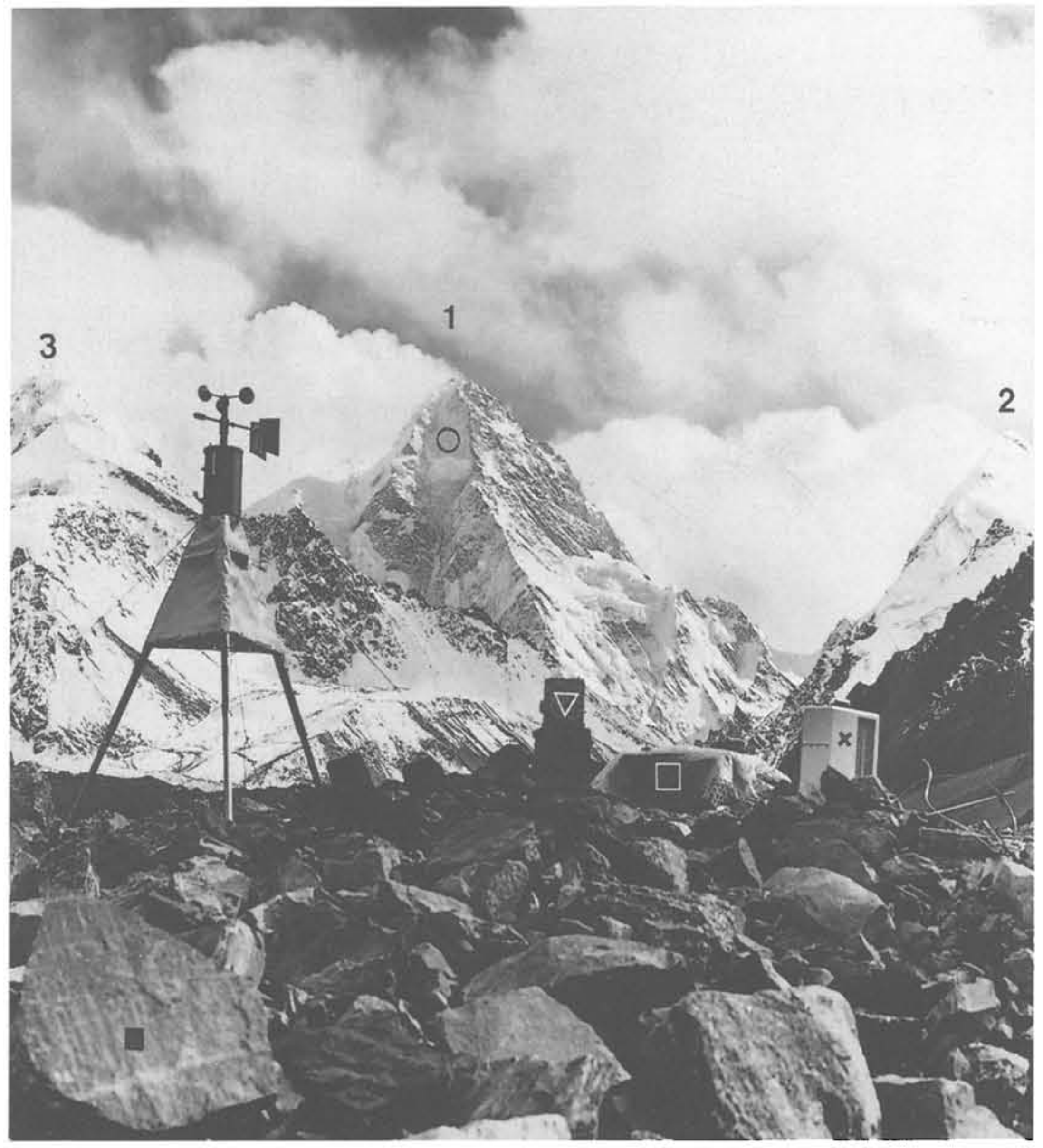


Fig 28 ▲
From 7. 9.–11. 10. 1986 the third weather station (from the base) of the 1986 expedition operated on the surface moraine drift (■) in the centre of the 2 km-wide K 2 glacier at 4620 m asl (cf. Fig 30 x left). Next to the 12 channels station of the "Lambrecht" type, complete with wind metre and shaded thermohydrograph (on the left side), an independent mechanical actinography (▽) was installed in order to carry out checks on the measurement of global radiation, together with a termograph (x) for the recording of the temperature of the surface moraine at the different drift levels. Data storage was effected with a data logger (□). No. 1 = K 2; No. 3 = 6640 m peak; No. 2 = c. 6800 m peak. Viewpoint: 36°00'30"N/76°33'15"E. Photo: M. Kuhle 11. 10. 86.

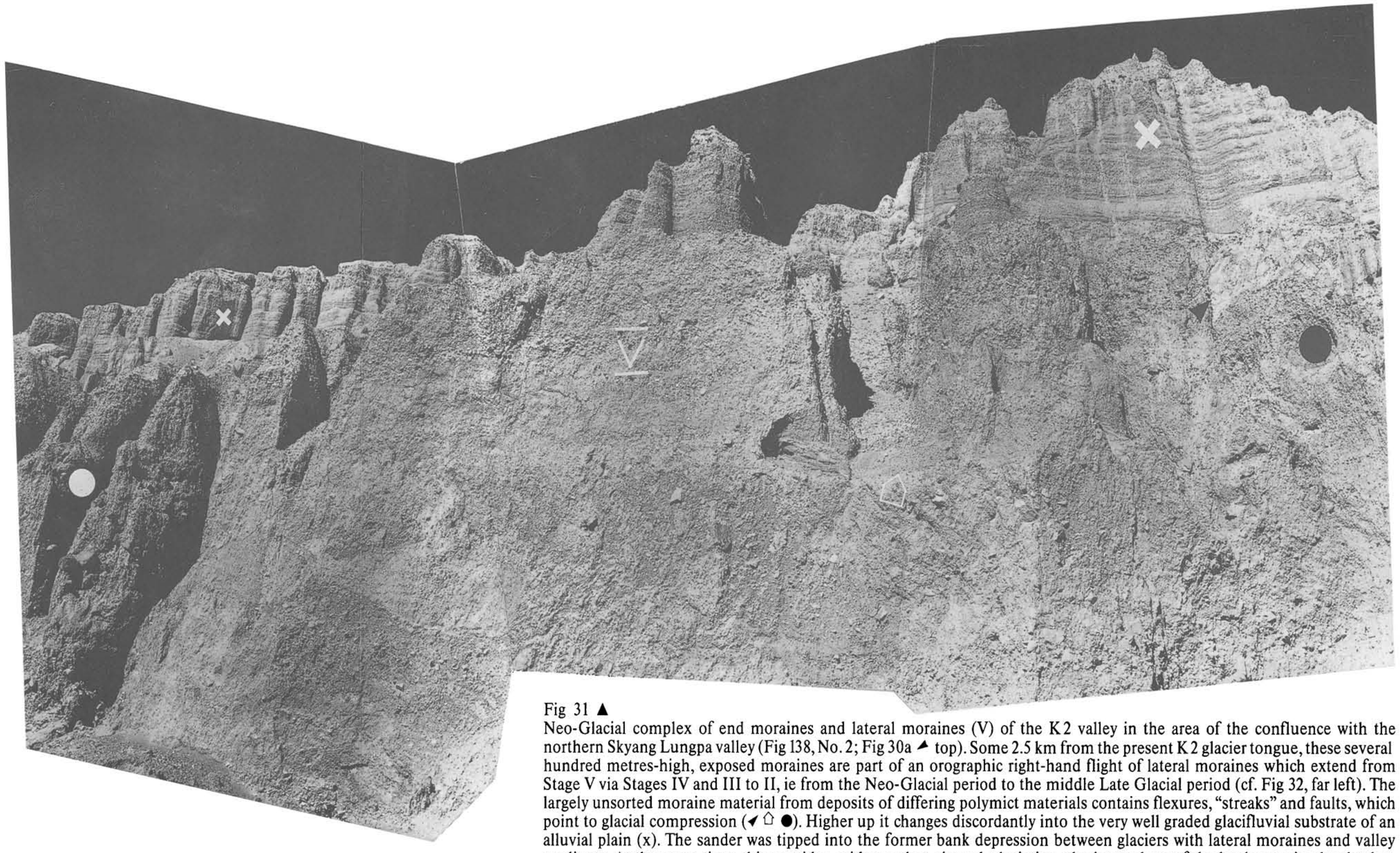


Fig 31 ▲
Neo-Glacial complex of end moraines and lateral moraines (V) of the K 2 valley in the area of the confluence with the northern Skyang Lungpa valley (Fig 138, No. 2; Fig 30a ▲ top). Some 2.5 km from the present K 2 glacier tongue, these several hundred metres-high, exposed moraines are part of an orographic right-hand flight of lateral moraines which extend from Stage V via Stages IV and III to II, ie from the Neo-Glacial period to the middle Late Glacial period (cf. Fig 32, far left). The largely unsorted moraine material from deposits of differing polymict materials contains flexures, "streaks" and faults, which point to glacial compression (✓ ⌂ ●). Higher up it changes discordantly into the very well graded glacifluvial substrate of an alluvial plain (x). The sander was tipped into the former bank depression between glaciers with lateral moraines and valley gradients. At the same time, this provides evidence that, since deglaciation, the inner slope of the bank moraine has broken back considerably. Viewpoint: 4000 m asl, 36°04'N/76°28'E. Photo: M. Kuhle 2. 9. 86.

◄ Fig 30
View from the altitude of c. 5030 m asl to the 4660 m-high confluence area of K 2 valley and Skyang-Kangri valley (Fig 138, No. 3). The Skyang Kangri glacier (◆) no longer reaches the K 2 glacier now (in the main valley on the left). In 1976 a glacier confluence still did take place (cf. Fig 30a). There is evidence in the Chinese Atlas 1 : 50,000, sheets 9–43–Ʒ, that it had existed since at least 1954. The accompanying moraines are consequently classified as Stage X (here c. 80–17Y BP) (X). The older, higher ice levels of this glacier confluence can be traced on the orographic left-hand lateral moraines of the Skyang Kangri glacier (IX to V) and followed back to the Neo-Glacial period (■ V). The orographic right-hand flank abrasions and polishings (∪▲) on the opposite side are of the same age. During the past 10 years drift floors of the "outwash plain" type (■ -6) have been accumulated between the banks of the K 2 glacier and the Skyang Kangri glacier tongue. Traces of glacial polish (∪) and the air photos (Fig 30a, left of ◄ , bottom) show that, on turning right, the Skyang Kangri glacier tongue lay down beside the K 2 glacier. - - - - marks the highest prehistoric polishing level, continuing right through the adjacent Muztagh valley and even further north into the Shaksgam valley (beneath No. 1). In the course of the reconstruction the thickness of the ice increases to far in excess of 1000 m. No. 1 = 6750 m massif of the Aghil Mountains. X on the left side marks the position of No. 3 weather station (cf. Fig 28). Viewpoint: 35°58'50"N/76°28'45"E. Photo: M. Kuhle 29. 9. 86.

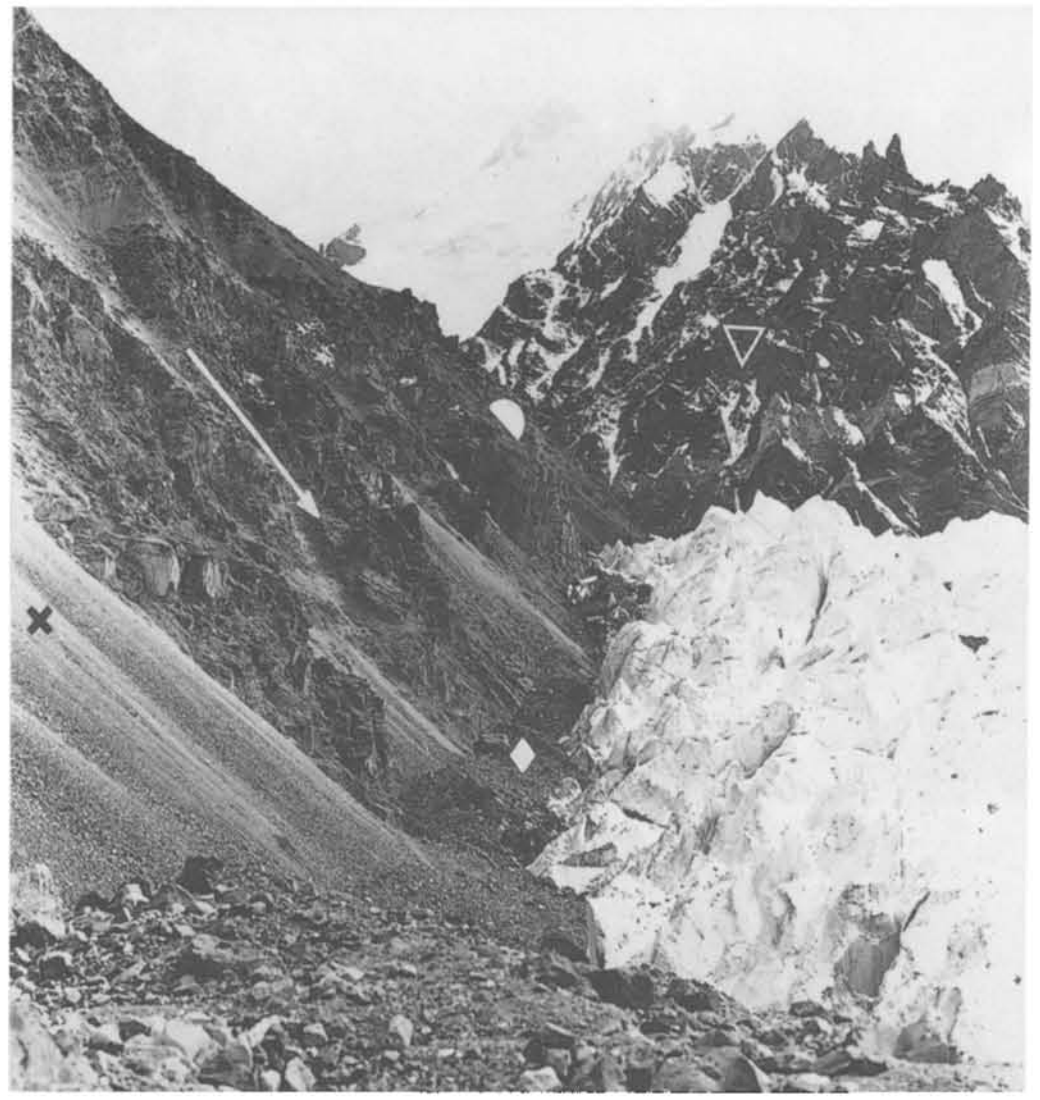
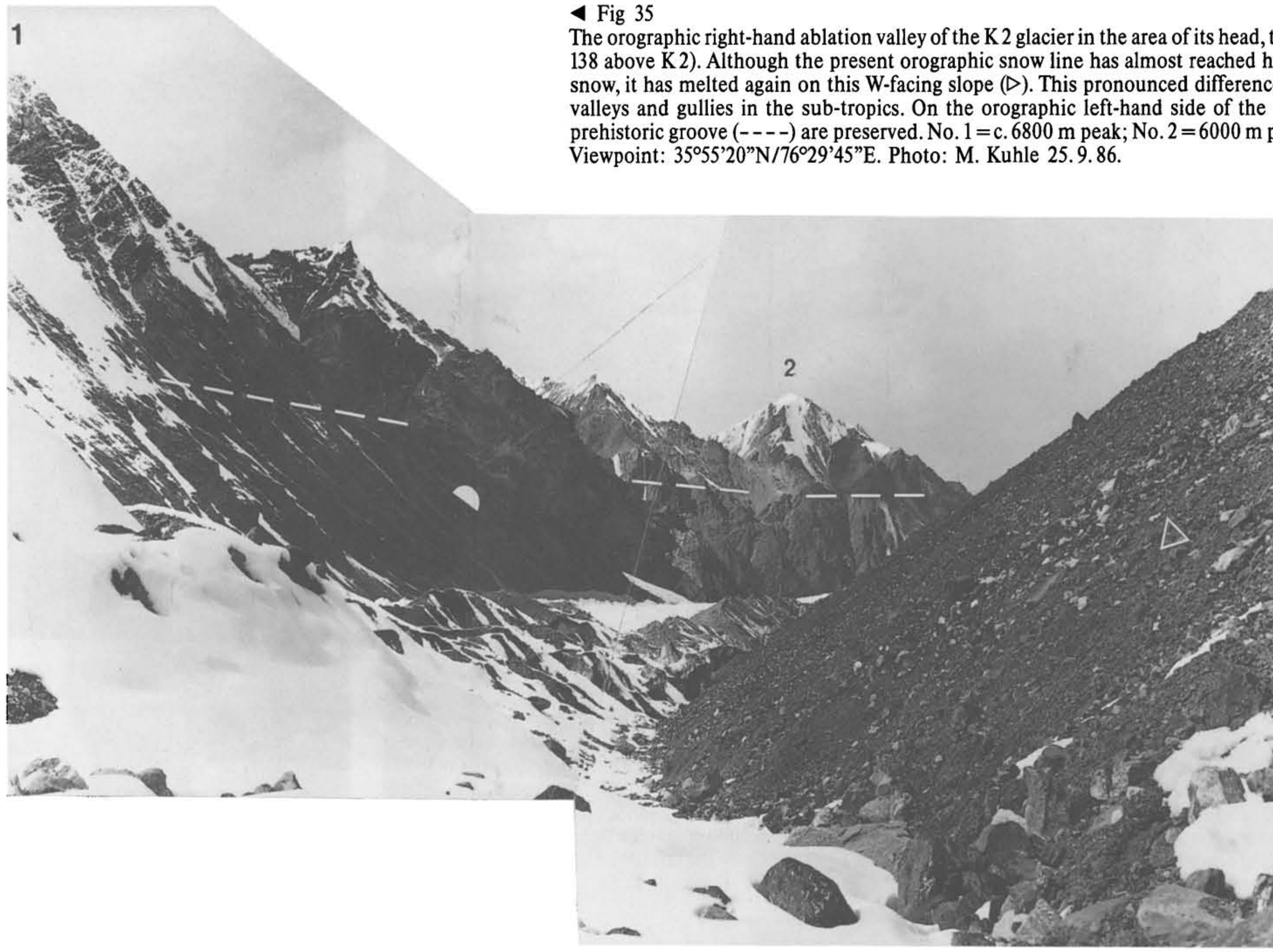


Fig 34 ▲
View from 4700 m asl, facing the orographic right-hand ablation gorge of the K2 glacier upwards and towards the S (♦) (Fig 138 beneath No. 3). In the background the heavily gullied rock wall (∇) of the orographic left-hand valley flank, which was polished by the valley glacier to a considerable height, even during the Late Ice Age. But even on this flank the K2 glacier has undercut this side of the valley along the ablation gorge and shows a very marked transformation. Its dynamics since deglaciation follows the fall-line, concerning the formation of rock-fall gorges (↘), which set back the slope, and talus cones have been piled up among the remaining ridges of rock (x). The displaced material of the former has built up the formation of the latter. Glacier abrasion and polishing has only been preserved at a very few points (◖). ♦ stands for the side moraine drift on ice which marks the edge of the glacier that underscours the valley flank. Viewpoint: 35°58'10"N/76°28'30"E. Photo: M. Kuhle 6.9.86.



◄ Fig 35
The orographic right-hand ablation valley of the K2 glacier in the area of its head, taken at 5150 m asl, facing downwards towards the NNW (Fig 138 above K2). Although the present orographic snow line has almost reached here, and the summer precipitation remains on the glacier as snow, it has melted again on this W-facing slope (▷). This pronounced difference in ablation is the cause of the formation of small ablation valleys and gullies in the sub-tropics. On the orographic left-hand side of the valley flank abrasions and polishings (◖) and traces of a prehistoric groove (----) are preserved. No. 1 = c. 6800 m peak; No. 2 = 6000 m peak NE of the 6540 m peak in the northern Chongtar Group. Viewpoint: 35°55'20"N/76°29'45"E. Photo: M. Kuhle 25.9.86.

Fig 36 ▼
View of the Muztagh valley (Fig 138, No. 10) from 3900 m asl looking SW, up to the junction of Sarpo Laggo valley and Skamri valley with their kilometre-wide drift floor (ice cave drift floor -6). Thanks to the glacier meltwaters going over the drift floor, myricariae bushes (X) grow in the manner of gallery vegetation. X (and upwards from it on the left) also marks the locality where the samples 15.10.86/1/2/4 and 5 were taken (Tab 2). The C-14 date of sample /4 indicates a minimum age of the ground moraine there of 12870 +/− 180YBP. Above the historic to Late Glacial (IV) lateral moraine terraces in the prehistoric confluence area of Sarpo Laggo glacier and Skamri glacier the Ice Age abraded and polished slopes (◖◗) form a link to the ice scour limits (----) and the north-eastern peaks of the Chiring Group, the highest being 7090 m: No. 2 = 6505 m peak; which - like a good 6000 m-high peak, No. 4 - is a satellite peak of the (not visible) 6900 m peak; No. 1 is the 6544 m peak, which rises south of the Sarpo Laggo pass (5685 m). Viewpoint: 36°03'45"N/76°25'20"E. Photo: M. Kuhle 2.9.86.

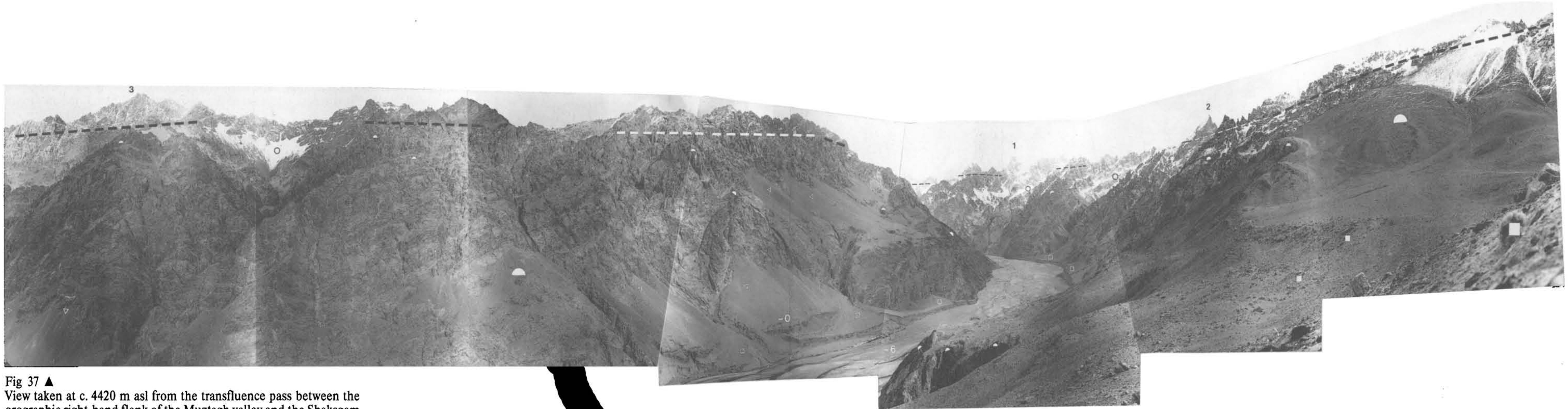


Fig 37 ▲
View taken at c. 4420 m asl from the transfluence pass between the orographic right-hand flank of the Muztagh valley and the Shaksgam valley (Fig 138, No. 12), showing a panorama ranging from N (No. 3 = dolomite satellite peak of the 5792 m mountain in the Aghil mountains) via E (No. 1 = 6190 m peak in the northern Muztagh Karakorum) via ESE (No. 2 = another more than 6000 m-high satellite peak NW of the 6210 m peak, no[redacted]K 2-Skyang Kangri Group) to SE (right-hand edge of the photo) up to the SE flank of the transfluence pass. The Shaksgam valley is the major longitu[redacted]ey between the two systems of the Karakorum and Aghil, draining the glaciers of the Karakorum N-slope. At most 1 km wide, its drift floor bottom (an in[redacted] cave drift floor, -6) runs at 3900–3960 m asl. The Shaksgam valley is a classic glacial trough with a wide base filled with loose rock and steeply ris[redacted]oidally abraded and polished flanks (▲◥). As a result of their steepness these flanks are subject to frequent crumbling, which produces scree and rough[redacted]ck up to the ice scour limits (----). On the calcite flanks of the transfluence pass glacial abrasion and polishing has been preserved up to more than[redacted]ight). In the Late Ice Age, when the level of the Shaksgam ice stream network had melted down below the ELA - which was then at about 4400 m [redacted]aine ledges with erratic blocks of dolomite and gneiss were deposited (■) on this transfluence pass. Viewpoint: 36°07'N/76°26'E. Photo: M[redacted]

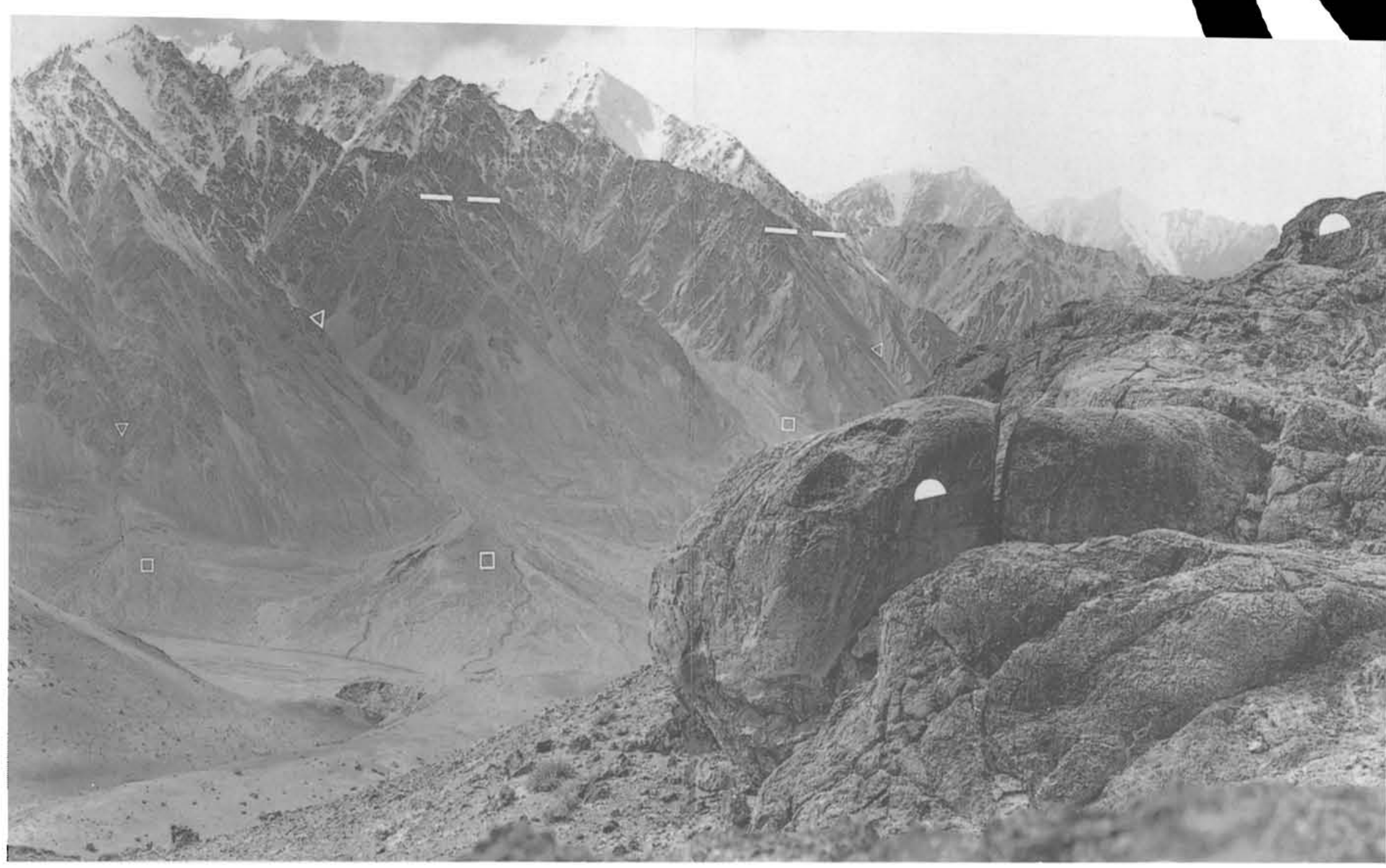


Fig 38 ▲
Glaciated knobs (▲) on the transfluence pass between the Muztagh valley and the Shaksgam valley, which have been formed in solid calcite rock at 4520 m asl (Fig 138, No. 12). The fine relief roundings on these basic polish forms (quite apart from traces of frost weathering and corrosion on the rock surface) are evidence that the polishing process of the ice took place when the pressure melting point had been reached. This points to a very substantial hanging glacier thickness of the transfluence. Following deglaciation talus fans and cones (□) have been deposited on the 3900 m-high floor of the Muztagh valley. Viewpoint: 36°05'N/76°29'E, facing W. Photo: M. Kuhle 19. 10. 86.

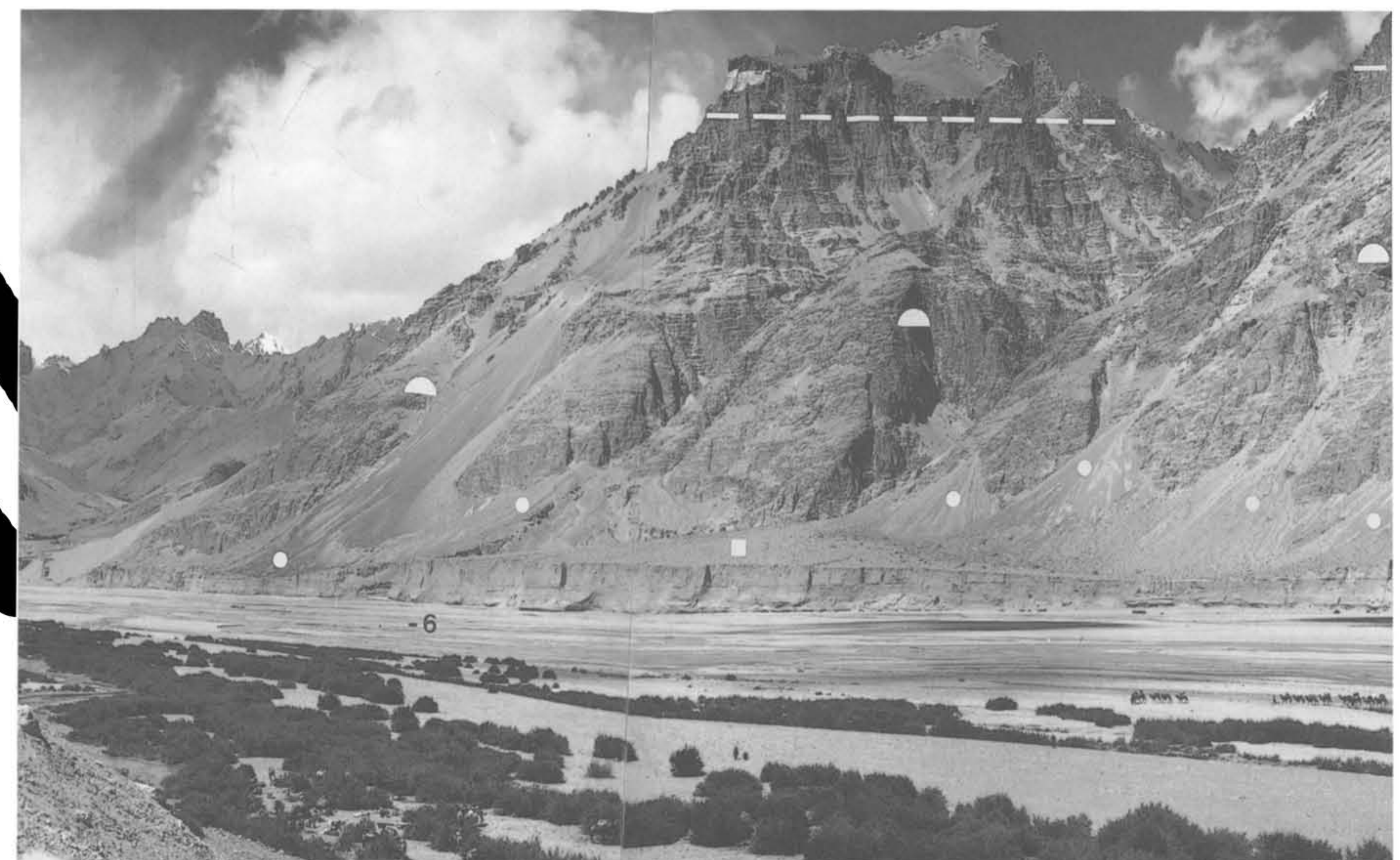


Fig 39 ▲
Taken at 4120 m asl; view from the or[redacted]ft-hand flank of the Shaksgam valley towards the NW to the opposite valley flank; being part of the Aghil mountains it is constructed fr[redacted]ontal dolomite strata (Fig 138, No. 23). It is a trough flank which is characterized by glacial band abrasion and polishing (▲); the ice[redacted]mits (----) extend to c. 1200 m beyond the edge of the trough. Talus cones and fans (● ■) were built up within a few thousand y[redacted]fter glaciation, and simultaneously undercut by the bed of washed drift (-6). Viewpoint: 36°08'50"N/76°36'E. Photo: M. Kuhle 30. 8. 86.