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# Reconstruction of an approximately complete Quaternary Tibetan inland glaciation between the Mt. Everest- and Cho Oyu Massifs and the Aksai Chin. A new glaciogeomorphological SE–NW diagonal profile through Tibet and its consequences for the glacial isostasy and Ice Age cycle

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**Abstract**

Studies were done on new geomorphological and quaternary-geological profiles through representative reliefs of Tibet from the Central Himalaya as far as the Kuenlun. Thus, further detailed investigations on the prehistoric glaciation could be carried out. Youngest historical to neoglacial ice margin positions could be recorded. Their mapping took place in a downward direction from the modern glacier margins. They confirm snow line (ELA) depressions from decametres up to ca. 100–250 m. At distances of several kilometres to many decakilometres (depending on the relief) from the modern glaciers, névé shields and perennial snow fields, end moraines and later just remnants of lateral moraines and kame complexes of the Late Glacial (ca. Stadia IV-II) have been localized in an increasing disrupted succession and samples have been taken. The recorded, inter- and extrapolated lowest ice margin positions allowed the reconstruction of accompanying depressions of the snow line which, due to the altitude of the Tibetan plateau plains, attained a maximum of 400–700 m. Accordingly, the early Late Glacial (Stadia I to II) and High Glacial glacier traces (Riss or pre-LGM and Würm or LGM = Stadia −I and/or 0) occurred over a horizontal distance of 1620 km across the plateau with an average height of 4700 m asl without showing the key forms of ice margin positions. From the profiles introduced here, running from Mt. Everest/Cho Oyu (Central Himalaya) in the SE via Gertse (Kaitse; Central Tibet) as far as the Lingzi Thang and Aksai Chin and from there into the Kuenlun, as well as from a parallel section of the Gurla Mandhata (central S Tibet) to the currently very arid Nako Tso, located centrally in the W, sediment samples have been analysed which provide evidence for a ground moraine genesis. Thus, the macroscopic field observations are confirmed. Only the relatively small basin of Shiquanha (Ali) – like the Indus valley chamber of Leh – may have been free of ice during the High Glacial (LGM). Forms of glacial horns, as well as roches moutonnées and large, several metres-high round-polished mountain ridges with slight debris covers, flank polishings, abraded mountain spurs at intermediate valley ridges and high-lying erratics document the widespread ice cover. Important ice thicknesses of at least 1300–1400 m have been recognized by means of transfluences. Especially by and in the Nako Tso (lake) the limnic undercutting of roches moutonnées provides evidence only of a postglacial filling into a primary glacial relief. The glacial ice cover (with the LGM at the end) testified here for a further area of Tibet, is the foundation of the relief-specific hypothesis on the development of the Ice Ages, based on the global radiation geometry: accordingly, the last great geological event, the early Pleistocene plate-tectonically induced uplift of Tibet above the snow line, has brought about a glaciation which, owing to its high albedo, reflected the subtropical radiation energy into space, so that it could not be exploited for the heating of the atmosphere. This may have triggered the Ice Ages. The repeated interglacial warming-up is to be reduced to the positive radiation anomalies by the variations of the parameters of the earth's orbit – which take place rhythmically – and the overlying glacio-isostatic lowering of Tibet and the other inland ice areas.

## 1. Introduction and method

The reconstruction of the Ice Age glacier cover has been pursued for more than 150 years and not yet brought to an end for High Asia. It is carried out with great success according to the glaciogeological and glaciogeomorphological method. Thus, our knowledge of an at least three times more extended terrestrial ice cover of the earth during the Ice Age is based on such investigations. The essential characteristic of this method is the positionally-specific arrangement of the geological and geomorphological indicators with regard to the process of their glacial genesis. Only the three-dimensional arrangement of the positions of the separate key forms of a glaciation to each other provides evidence of a former ice cover (Kuhle, 1990e). In the course of the author's geomorphological expeditions and fieldwork campaigns in many areas of Tibet and its surrounding mountains (Figure 1) since 1976, this method, which is considered to be the true and classic working technique of paleoglaciology, has led him step by step to the synthesis of a Tibetan inland glaciation during the High Glacials (Riß and Würm) (Figure 12). This study introduces new observations, obtained in 1996 by means of field- and laboratory analyses on the Tibetan plateau up to its marginal mountain chains (Figure 1, No. 20) with regard to the arrangement of their positions, including them in the context of the investigations already presented (Kuhle, 1980–1998).

In a spatially-connected chapter the findings of two partly parallel-running profiles of the Himalaya on the S margin of Tibet up to Central Tibet and then up to Central W Tibet as far as the NW margin of the plateau (Figure 1, No. 20, 5) are recorded. New indications from the S Central Tibetan area adjacent to the E (Figure 1, No. 4) which have not yet been published in the former paper on this region (Kuhle, 1988) will be referred to there.

In a last, synthetic chapter, the paleoclimatic importance of the Tibetan ice cover – which can be made understandable by the subtropical radiation energy balance that has significantly changed compared with today – in its globally extremely cooling and, according to the author's Ice Age hypothesis, possibly Ice Age triggering impact, will be once more reflected and deduced, considering hitherto unpublished aspects.

## 2. Geomorphological and sedimentological indicators of the High Glacial inland glaciation on a new profile which starts in the S- and continues towards Central- and NW Tibet (Sections 3–7)

### *2.1. New observations on the S Tibetan glacier cover: the prehistoric outlet glaciers of the inland ice between Shisha Pangma and Cho Oyu (Figure 1, Cho Oyu; Figures 2 and 3 Shisha Pangma and E, i.e., to the right of it)*

The occurrence of an Ice Age Bo Chu (Bote Chu or Sun Kosi Khola)-outlet glacier, suggested according to the results of field-researches done in 1984 (Kuhle, 1988f, p. 458, Figure 2, Nos. 30–35; p. 469, Table 1, pp. 487–493 and Figures 45–52), which drained the Tibetan ice to the S through the Himalaya, has been confirmed, broadened and evidenced more specifically by the following datings, obtained in 1996. The investigations carried out for the first time in 1984, led to the dating for the time being of an LGM ice margin position near the Friendship Bridge (27°56′ N/85°56′ E) of at most 1600 m – probably it was even lower (Kuhle, 1988f, pp. 492, 469). Our researches in 1996 – carried out from the lowest glacial ice margin position valley-upwards – resulted in the following new observations: the Sun Kosi valley chamber into which the Bo Chu outlet glacier extended, is situated at a height of the thalweg of ca. 700 and 900 m asl between 1 km beyond the settlement of Karitscho and 4 km N (up-valley) of the settlement of Bahrabise (27°40′–48′ N/85°45′–55′ E; map 1:50 000 Lapchi Kang, 1985). This is the valley chamber of Lamosango. There are 3 to 4 m long, rounded erratic gneiss boulders (augen-gneiss) occurring as bedrock on the Himalaya main ridge and also on the Shisha Pangma (Kuhle, 1988f, p. 483, Figure 43). They lie on bedrock schists and metamorphic siltstones. Some of them are in the riverbed and show potholes. For their development the boulders might have been held by the hanging glacier ice and then flushed out through the subglacial meltwater, which flowed under high pressure, colliding in a punctiform manner (cavitation corrasion) (Figure 2, No. 1). On the valley floor the red weathering is lacking. It may be that the large boulders have been dislocated by glacier water (high energy flows) or mudflows, but in places they can still be found in the moraine-like matrix formation. Downslope of this valley chamber the lateritic red weathering sets in on the valley bottom and on the debris slopes. Up-valley from Bahrabise there is a glacigenic V-shaped valley cross-profile, i.e., a 'V-shaped trough', typical of the Himalaya, as it is characteristic of steep cross valleys (cf. Photo 1) (Kuhle, 1983, p. 154ff). Polished rock surfaces in the form of roches moutonnées are preserved in the orographic right-hand valley flank up to 1150 m, at least 250 m above the bottom line. They provide evidence of a minimum ice thickness of 200 m. Photos 1 and 2 show the continuation of these flank polishings (◥ ▲ ◤) in an up-valley direction. In the depressions lying between them, there are ground-moraine-like boulder clays, cut by the recently water-bearing slope ravines up to the bedrock. On the orographic right side the metre- to decametre thick covers of boulder clay are undercut by the Bote Kosi river. Their breaking-away produces uneven edges (Photos 1 and 2 □). A 10–15 m high Late Glacial glacier-mouth-gravel-floor terrace with sorted boulders and gravels is also preserved in parts (Figure 2, No. 1). Photo 1 shows flows of schist, intensified by the monsoon rains, in the autochthonous slope debris of the Kathmandu-nappes (△) as well as the more resistant outcropping edges of the strata in the left-hand parts of the slope, which are glacially polished (◤). Due to the narrowness of the Bote Chu and the power of this great Himalaya transverse river, no end moraines remained here. The valley chamber, following upwards as far as the junction with the Chaku Khola has a clearer glacial character. Abrasion-roundings of the outcropping edges of the strata are preserved on both flanks (Photo 3 ◥ ◤; Figure 2, No. 1). The next valley chamber up to N of the settlement of Jhirpu in particular perfectly shows the two closely interlocking valley cross-profiles of the glacigenic and fluvial type (Photo 4). The fluvial V-profile, the development of which has already begun subglacially and then continued in the Holocene, is set into the soft-shaped level of the valley shoulders (◥ ▲ ◤), polished round by the Ice Age (LGM) glacier ground. Up-valley from this point the change from the rather soft relief of the fore-chains to the steep relief of the Himalaya transverse gorge takes place (Photo 5). Thus, glacial forms only remained in some places as flank polishes (▲ ◥ ◤). To a great extent they are already destroyed by the breaking-away of the bedrock. The moraine remnants, preserved here and there, are getting eroded, i.e., dislocated by monsoon-induced mudflows. An example of this is the mudflow coming down early in July 1996, in the Jangbo Khola (Photo 5 ↘). It has reached the Bhote Kosi at 1300 m asl and completely obliterated the settlement of Lartza (45 dead) (Photo 5 ↘) (Figure 2, No. 1). Besides the local material from the 4474 m high catchment area of the

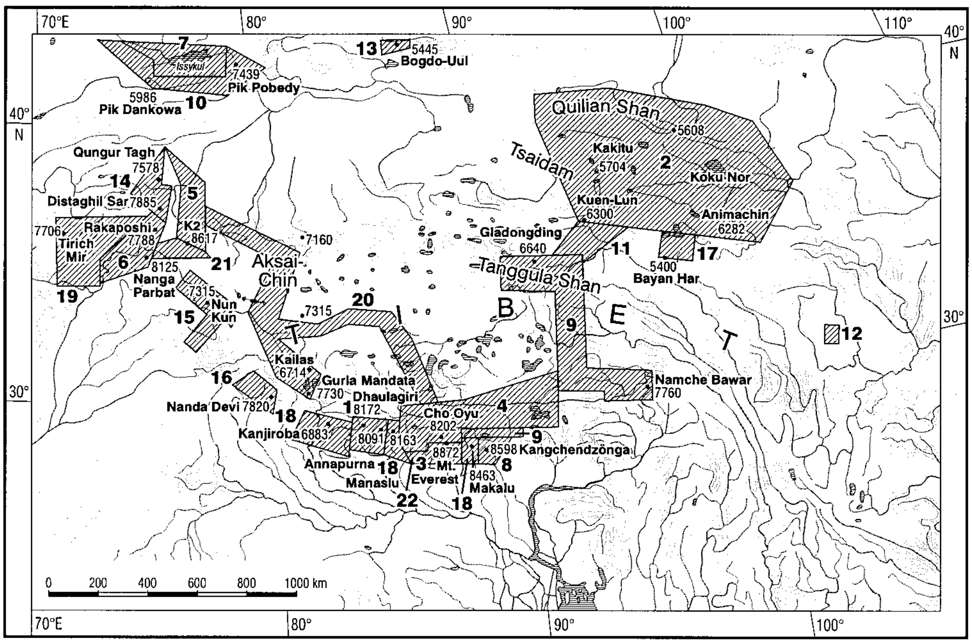


*Figure 1.* Research areas in Tibet and its surrounding mountains visited by the author. The study presented here introduces new observations on the Ice Age glacier cover from area No. 20.

*Table 1.* Glacier stadia of the mountains surrounding Tibet (Himalaya, Kuenlun, Pamir, Karakorum, Quilian Shan) from the pre-Last High Glacial (Riß to the present-day glacier margins and the pertinent sanders (glaciofluvial gravel fields and gravel field terraces) with their approximate age (after Kuhle, 1980–1997b).

| glacier stadium | | gravel field (Sander) | approximated age (YBP) | ELA-depression (m) |
|---|---|---|---|---|
| -I | = Riß (pre-last High Glacial maximum) | No. 6 | 150 000- 120 000 | c. 1400 |
| 0 | = Würm (last High Glacial maximum) | No. 5 | 60 000- 18 000 | c. 1300 |
| I-IV | = Late Glacial | No. 4- No. 1 | 17 000- 13 000 or 10 000 | c.1100- 700 |
| I | = Ghasa-stadium | No. 4 | 17 000 - 15 000 | c.1100 |
| II | = Taglung-stadium | No. 3 | 15 000 - 14 250 | c.1000 |
| III | = Dhampu-stadium | No. 2 | 14 250 - 13 500 | c. 800- 900 |
| IV | = Sirkung-stadium | No. 1 | 13 500 - 13 000 (older than 12 870) | c. 700 |
| V - 'VII | = Neo-Glacial | No. -0- No. -2 | 5 500 - 1 700 (older than 1 610) | c. 300 - 80 |
| V | = Nauri-stadium | No. -0 | 5 500 - 4 000 (4 165) | c. 150 -300 |
| VI | = older Dhaulagiri-stadium | No. -1 | 4 000 - 2 000 (2 050) | c. 100 -200 |
| 'VII | = middle Dhaulagiri-stadium | No. -2 | 2 000 - 1 700 (older than 1 610) | c. 80 -150 |
| VII- XI | = historical glacier stages | No. -3 -No.-6 | 1 700 - 0 (= 1950) | c. 80 - 20 |
| VII | = younger Dhaulagiri-stadium | No. -3 | 1 700 - 400 (440 resp. older than 355) | c. 60 - 80 |
| VIII | = stadium VIII | No. -4 | 400 - 300 (320) | c. 50 |
| IX | = stadium IX | No. -5 | 300 - 180 (older than 155) | c. 40 |
| X | = stadium X | No. -6 | 180 - 30 (before 1950) | c. 30 - 40 |
| XI | = stadium XI | No. -7 | 30 - 0 (=1950) | c. 20 |
| XII | = stadium XII = recent resp. present glacier stages | No. -8 | +0 - +30 (1950- 1980) | c. 10 - 20 |

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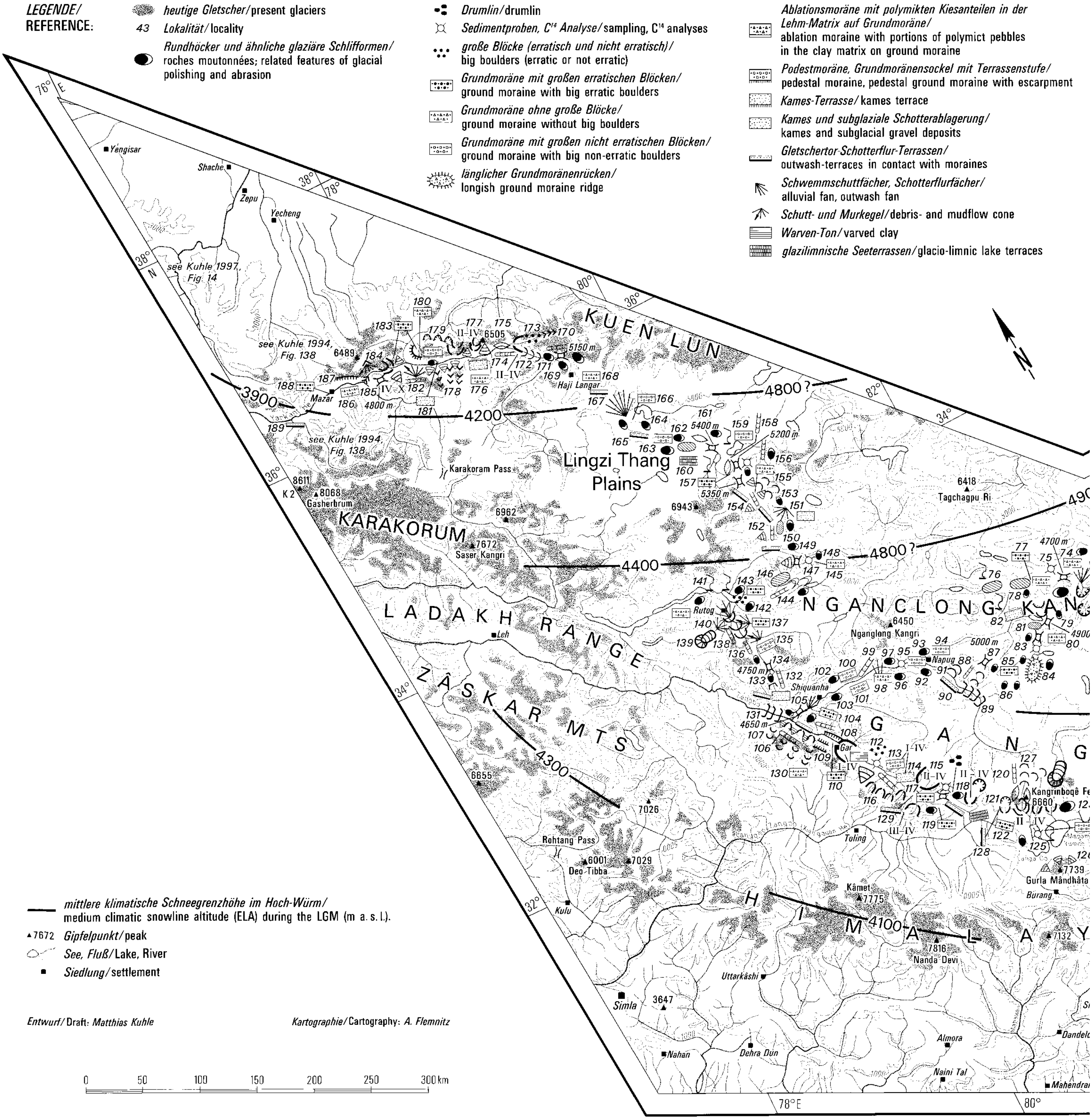



Kyerpa Danda, which has an own glaciation, facetted erratic gneiss- and granite boulders, up to 4 × 5 m in size, which originate from the southern margin of Tibet, are incorporated into the mudflow. The clayey-loamy groundmass shows all the characteristics of moraine matrix. The cirque, set into the Kyerpa Danda, has two lakes on its bottom (Tsomen Tsho) at 4100 m. This documents a High- (LGM) to Late-Glacial snow line (ELA) at this level (Kuhle, 1988f, p. 469 below; cf. Kuhle, 1982, pp. 152–159). In 1996 five heavy landslides happened on the orographic left-hand flank of the Sun Kosi over a distance of 25 km between Bahrabise and Lartza, destroying roads and interrupting the traffic. This is also an indicator of the mobility of the loose sediments. Xu Daoming's study (1988, pp. 589–580) gives an impression of the importance of modern processes, as for instance mudflows or debris flows – as they occur down this main

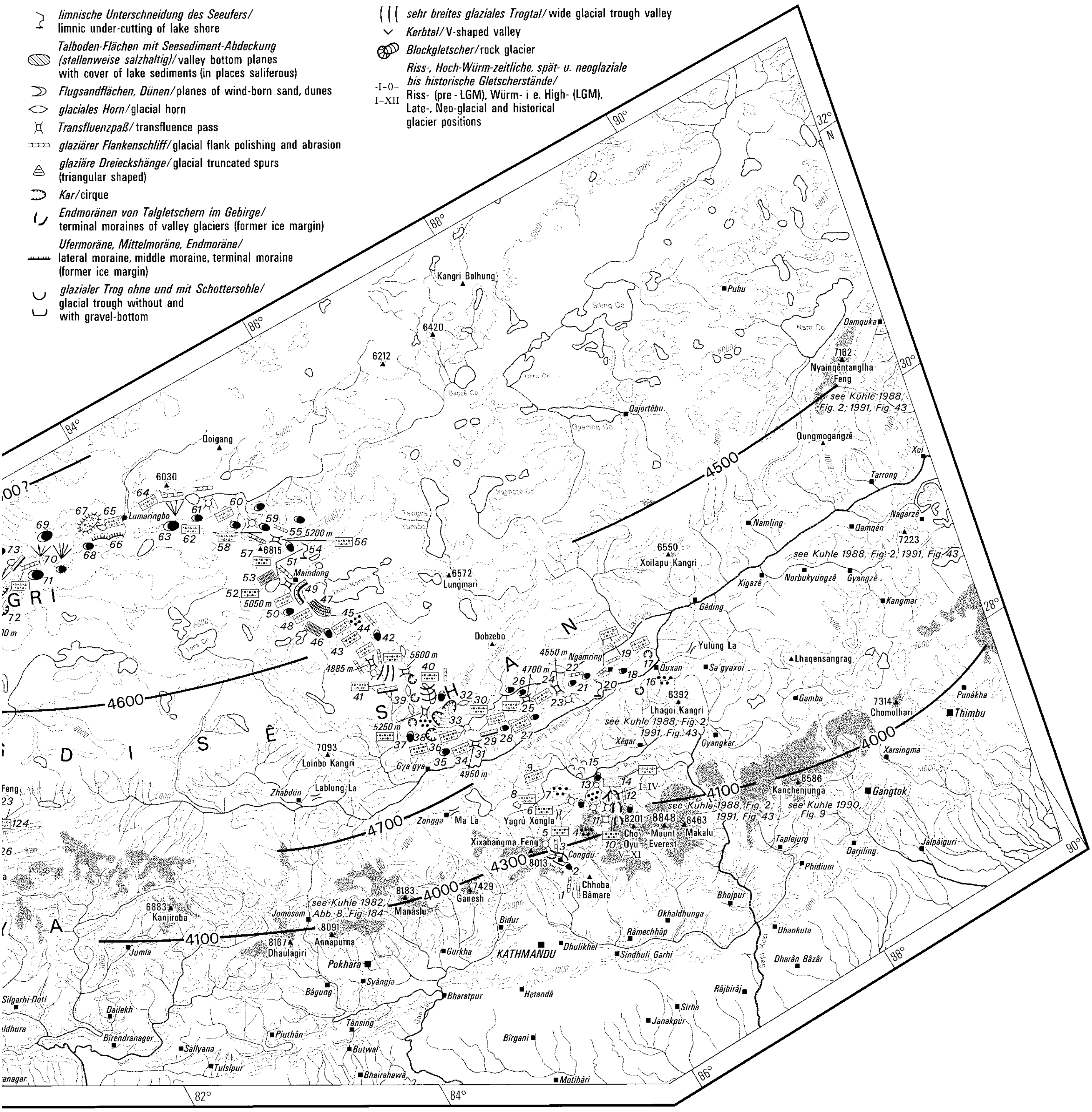
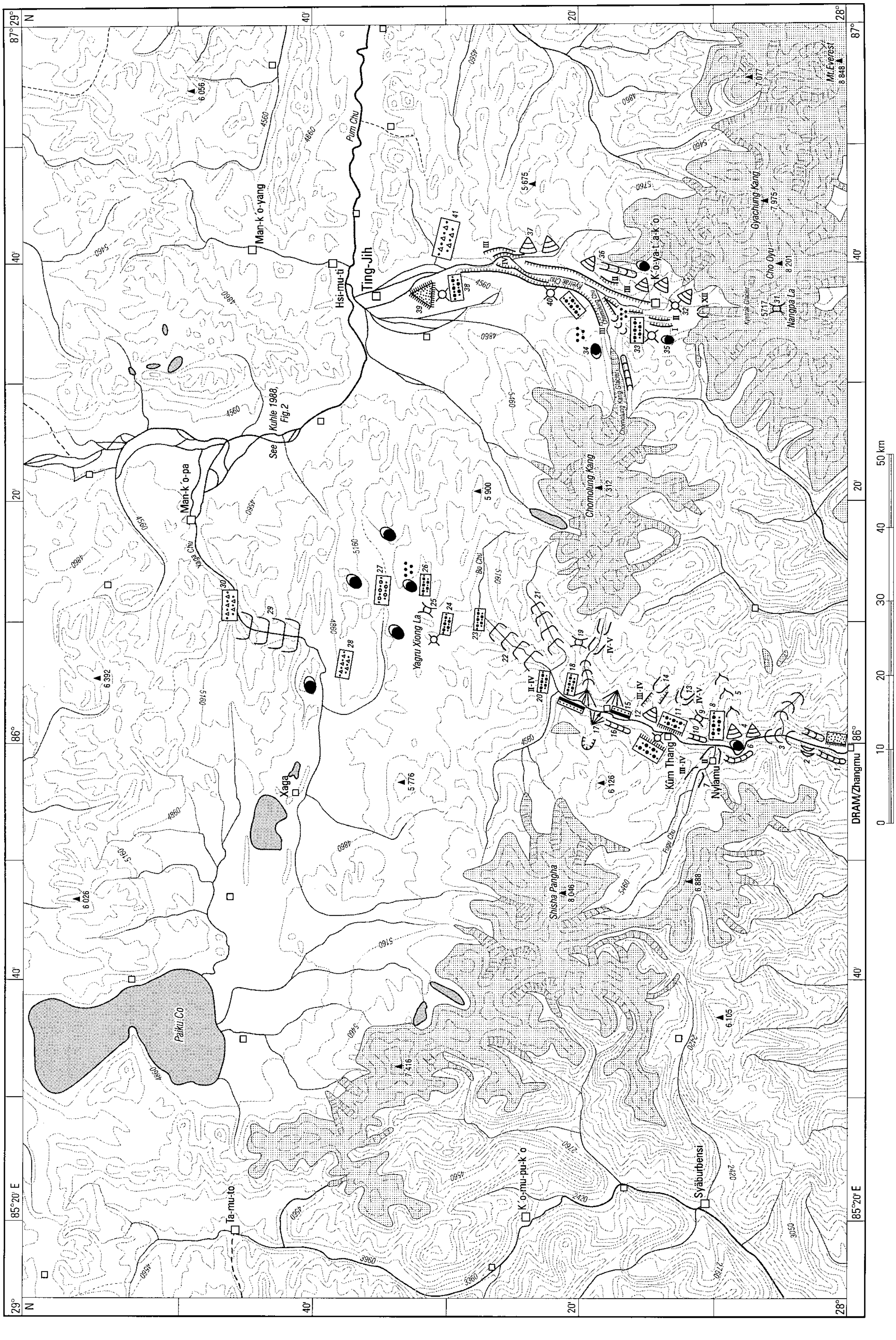



*Figure 2.* Quaternary-geological and glaciogeomorphological map of South-, Central- and West Tibet.

valley – for the reshaping and movement of moraines. It deals with the glacier- and moraine-lake outburst (1981) in the Zhangzongbo valley (Rolwaling Himal) – which joins on the orographic left-hand side 10 km up the Bo Chu from the settlement of Zhangmu – and its sedimentological effects. It was the repetition of a glacier- and moraine-lake outburst in 1964 with similar effects. In 1981 according to Xu Daoming's comments the mudflow, set off by the lake's outburst with a peak discharge of 15 920 $m^3$/s, has distributed 4 to 10 m-thick moraine sediments over a distance of 50 km down the Bo Chu. Near Bahrabise the flood still attained 2316 $m^3$/s. The largest transported boulder lies ca. 6 km downstream of the settlement of Kodari, several metres above the present riverbed. Its dimensions are 17.7 × 11.3 × 6.7 m (Xu Daoming, 1988, p. 577, Figure 11). Besides moraine-containing slope-debris-covers sporadic remnants


Ting-Jih
Hsi-mu-ti
Man-k'o-yang
Man-k'o-pa
Pum Chu
See Kuhle 1988, Fig.2
Xaga
Paiku Co
Ta-mu-to
K'o-mu-pu-k'o
Syäburbensi
Shisha Pangma
8 046
Chomolung Kang
Yagru Xiong La
Bo Chu
Kûm Thang
Nyalam
Po Qu
DRAM/Zhangmu
Cho Oyu
8 201
Gyachung Kang
7 975
Mt. Everest
8 848
Nangpa La
K'o-ya-La-k'o
Kyetrak Chu
5 900
5 776
6 392
6 026
6 056
6 126
6 888
6 105
5 675
50 km
29°
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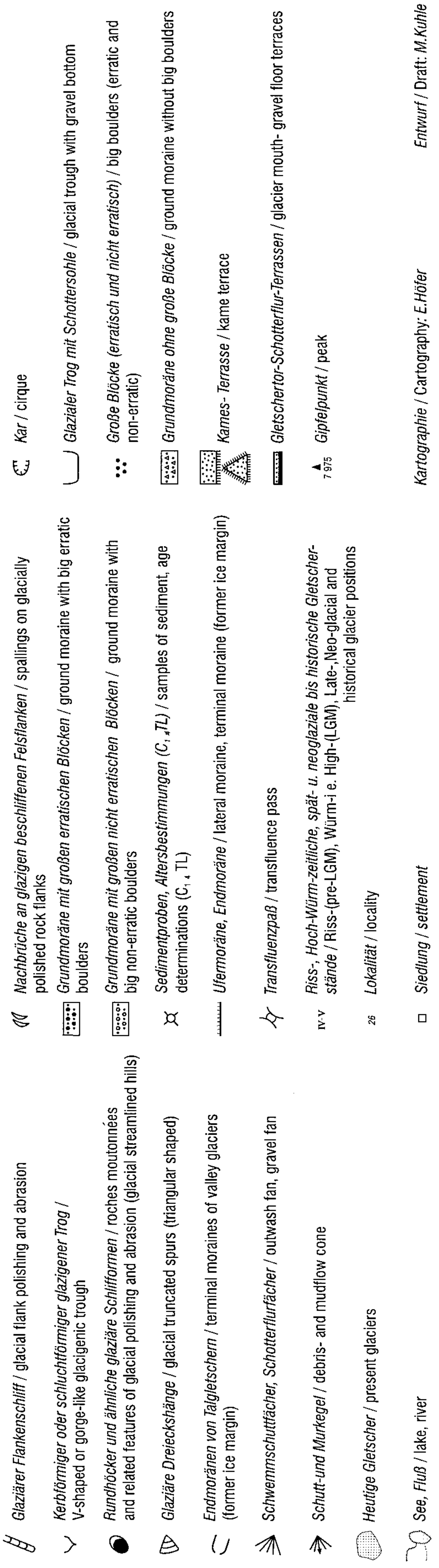



*Figure 3.* Quaternary-geological and glaciogeomorphological map section of South-Tibet with the Shisha Pangma- and Cho Oyu-group (cf. Figure 2).

of Late Glacial glacier-gravel-floor-terraces have been observed (Photo 5 ○). In the valley chamber between Lartza and Kodari flank polishings occur on both sides on the bedrock valley slopes which extend in a gorge-like fashion (Photo 5 ◥◤); they continue as far as the valley chamber of Dram (Khasa or Zhangmu, today a Chinese border settlement) (Photo 7 ▲). On the orographic right-hand side, 20–30 m above the Bote Kosi river, below the settlement of Liding, diamictic material is exposed, including far-travelled boulders (Kuhle, 1988f, p. 458, Figure 2). Parallel to the thalweg, but also on the slopes, it contains dislocated moraine material. However, this is not evidence of a prehistoric glaciation in the very morphodynamic S slope of the Himalaya (Photo 6). Very well preserved and thus unambiguous indicators of a glacier are the orographic right-hand flank polishings in the valley chamber of Zhangmu (Dram) (Figure 3, No. 1, Figure 2, Nos. 1, 2), reaching at least 400 m higher than the thalweg (Photo 7 ▲). Developed in the Khumbu- and Kathmandu nappes (KU 1–3, KN 2, 3), which according to Hagen (1969, p. 129) consist of gneiss-like metamorphites, they provide evidence of a valley glacier level at 2400 m asl (Photo 7 – –) and a glacier thickness of 400 m. A detail of those rock polishings in Photo 7 (◤ on the very left) is shown in Figure 52 in Kuhle (1988f, p. 491). Several fresh and holocene fragmentations on this rock flank document the roughness-producing weathering and the recent reshaping (Figure 3, No. 2). Figures 50 and 51 (Kuhle, 1988f, pp. 490–492) show the V-shaped valley cross profiles (‘gorge-like trough’, Kuhle, 1983, pp. 154ff), which have been slightly concavely-abraded by the Ice Age valley glacier further up the Bo Chu (Bote Khosi) (Figure 3, No. 3; 28°02′ N/85°59′ E, 2700 m asl). Ca. 4 km down-valley the Fuqu Chu inflow (from Shisha Pangma) a gorge-like tributary trough joins the Bo Chu at 3380 m asl (Figure 2, No. 2). In this junction area the rock spurs have been polished back into glacially triangle-shaped truncated spurs (Figure 3, Nos. 4, 5). The bottom of this side valley is so narrow, that it is completely occupied by the modern glacier stream. Typically enough it might have already been laid out in the High Glacial by the subglacial meltwater (Figure 3, No. 5). In the confluence area of the Fuqu Chu – that is the valley from the Shisha Pangma SSE flank – into the Bo Chu there is a Late Glacial end moraine landscape, belonging to the Taglung Stadium II (Table 1) (Figure 3, No. 7, II; Figure 2, No. 2, II) (cf. Kuhle, 1988f, Figure 2, Nos. 33, 34, pp. 490–491, Figure 49). Over large parts it covers older to High Glacial (LGM) ground moraines and glacial ground polishing (Photo 8 ■; Photo 9 ■ white). Only in places occur roches moutonnées, so for instance at 3680 m (Photo 8 ▲), which – in exception of separate erratic augen-gneiss boulders – are without a moraine cover (Figure 3, No. 6; Figure 2, No. 2). On the orographic left-hand valley slope the glacigenic flank abrasions (Photo 9 ▲) are partly covered by ground moraine several metres in thickness (Photo 9 ■ black; Figure 3, No. 8). In between there are preserved rock polishings, even in the comparatively fast weathering outcropping edges of the stratum of the bedrock surfaces (Photo 9 ◤ white). This left-hand flank has been overflowed

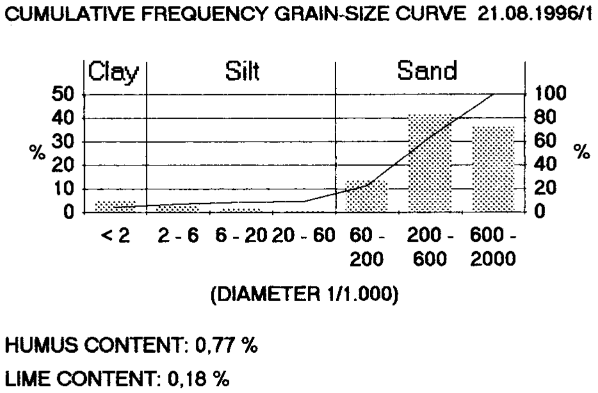
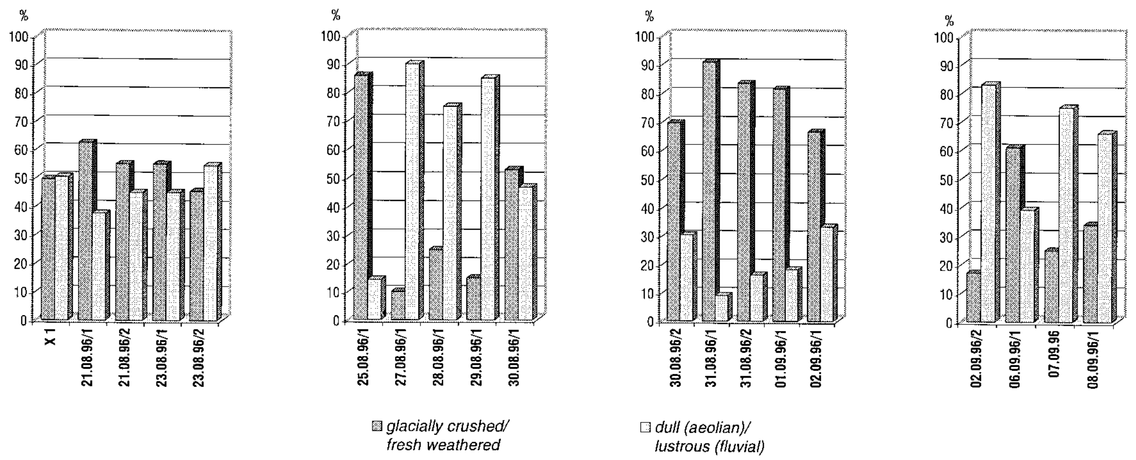



*Figure 4.* Sediment sample taken from a depth of 0.15 m at 3835 m asl on the orographic right side of the Bo Chu near the monastery of Milaripa. Locality: Figure 2, No. 3; Figure 3, No. 11; moraine matrix of a High- to Late Glacial ground- to lateral moraine terrace, which has also been reworked glaciofluvially (cf. Figure 5: 21.08.96/1). A large part of the moraine is built up by erratic augen-gneiss substrate, resulting in a coarse-grained matrix and a low peak of the fine grain in the clay. (Sampling: M. Kuhle.)

up to its culmination and shaped to round mountain ridges with broad transfluence ridges lying between them (Photo 9 ▲ black; Figure 3, No. 9). The following 23 km extend up the Bo Chu between the two large orographic right-hand valleys (cross valleys) which join from the Shisha Pangma massif. Nylamu is located in the Late Glacial (Stadium II) tongue basin of the prehistoric Fuqu Chu glacier (Kuhle, 1988f, p. 458, Figure 2, No. 33, pp. 490, 491, Figure 49). At the junction of the Fuqu Chu, somewhat up the Bo Chu on the orographic left-hand valley slope at 3670–3800 m, there is a very well preserved glacier polishing of the Bo Chu outlet glacier (Figure 3, No. 10). High Glacial ground moraines occur on the main valley floor between the valley chamber of Nylamu and the settlement of Kum Thang (Milarepas monastery). They have been reshaped glaciofluvially by diminishing glaciers right into the Late Glacial and then also in the Post Glacial (Holocene) and are preserved in the form of terraces (Photo 10 □, Figure 2, No. 3, Figure 3, No. 11; 28°15′20″ N/86°00′30″ E; 3700–4120 m asl). Figure 4 shows the conspicuously sandy matrix of this moraine and the bimodal course of the curve with its peak in the clay, characteristic of ground moraine. Figure 5 (column diagram 21.8.96/1) indicates for this matrix of the 200 $SiO_2$ grains investigated a predominance of 62.5% glacially crushed/freshly weathered grains (the genesis of the two cannot clearly be differentiated). The grains included in the dull/aeolian/lustrous/fluvial group account for 37.5% and are proof of the Late Glacial and Holocene glaciofluvial and cold-arid reworking of the ground moraine terrace. In this ground mass are – isolated from each other – large boulders of augen-gneiss (Photo 10 ●), the bedrock of which can be found in many places on the S margin of Tibet (cf. Kuhle, 1988f, Figure 43). The flanks of this valley chamber show postglacially-reworked characteristics of glacial flank abrasion which has back-polished and rounded the rock spurs (Photo 10 ▲ centre; Figure 3, No. 12) and because of that has widened the valley cross profile to the form of a trough. At this altitude near the permafrost line the remaining moraine remnants on the valley shoulders are reworked thoroughly by a powerful movement of the solifluction cover (Kuhle, 1978a, 1985), especially on the W-exposed slopes, which are thawing most deeply (■ white in the centre, ■ black on the right). The left-hand side valley, running down to the W from a presently non-glaciated mountain group S of the Chomolung Kang massif (7312 m), shows Young Late-Glacial to Neoglacial end moraines down to ca. 4100 m asl (■ black on the left; IV–V, cf. Table 1; Figure 3, No. 13). A few kilometres to the N the parallel left-hand side valley joins the Bo Chu. From a basal height at 4100 m upwards at least two Late Glacial lateral- and end moraine generations (Stadium III–IV) are preserved in this side valley (Figure 3, No. 14). Approximately 5 km up-valley the Bo Chu, Photo 11 shows its valley bottom and the orographic right-hand flank with the characteristics of the S Tibetan glaciofluvially-reshaped glacial landscape. The valley bottom is made up by Young-Late-Glacial to Holocene glacier-mouth gravel floors, which – linked with the glacier retreat – have been formed into a flat terrace with steps of a few metres in height (Figure 3, No. 15, Photo 11; 2 to −8, cf. Table 1). The right-hand flank of this trough valley, which according to the gravel infillings has a box-like broad form, is marked by glacial flank abrasions (Photo 11 ▲), preserved only just in sections (Figure 2 No.3, Figure 3 No. 16). The semi-arid continental frost weathering, still further enhanced by the highland climate to more than 200 frost changes per year, and the solifluction have reshaped these flank abrasions to such an extent that their upper limit, the polish line, can only approximately be recognized (Photo 11 — —). The valley flank is interrupted and disintegrated into back-polished mountain spurs (‘truncated spurs’; ▲ on the very right) by steep short valleys, shaped trough-like by local hanging glaciers, leading down from high depressions, i.e., flat cirques (○). These hanging valleys come to an end in alluvial- and mudflow fans (▽) (Figure 3, No. 17), which also contain dislocated ground moraine material of the main valley. Corresponding fans are also found on the opposite valley side, showing scattered, rather large erratic boulders (Photo 11 ●). Ca. 3 km up the main valley a ‘wash-board’-like ground moraine slope with exaration rills (Photo 12 ←) is preserved on the orographic left-hand valley flank of the Bo Chu (Bote Chu or Pa Ho according to ONC-map 1:1 000 000, H9, 1978) up to 300 m above the thalweg (■ and — — on the very left) (Figure 2, No. 3, Figure 3, No. 18; 28°19′ N/86°04′ E about 4100 m asl). On the roundings of the right-hand flank (◤ right), too, ground moraine remnants can be observed in higher positions (■ right). On these valley slopes high basins (○) have been formed, reaching far above the High Glacial glacier level up to 4800–5000 m. During the latest Late Glacial (Stadium IV) they still contained small glaciers and firn shields. In the now glacier-free main valley sander-like alluvial debris- and mudflow cones (▽ right) have been made up by the meltwater run-off. The glacial features and the Late Glacial ice margin positions of the orographic left-hand side valley, joining this valley chamber (Figure 3, No. 19) (the alluvial fan ▹ in the background on the left has been accumulated from this valley), have already been recorded earlier (Kuhle, 1988f, p. 488, Figure 48). 3–4 km further up the main valley (to the N), in the confluence area of a large orographic right-hand side valley, local ground moraine covers the valley floor (Figure 3, No. 20; 4120 m asl). It contains erratic augen-gneiss- and granite boulders (of metre-dimensions), originating from the Shisha Pangma which is only 15–20 km away (see Kuhle, 1988f; p. 483 and Figure 43). According to the topographic arrangements of the positions, it is Late Glacial (Stadium II–IV) ground moraine, laid down last (probably on moraines of older stadia up to the High Glacial). In the same valley chamber, 2.5 km to the NE, an orographic left-hand, scarcely smaller tributary valley joins, and leads down from the 7312 m-massif into the Bo Chu (Figure 3, No. 20). Owing to a gravel floor that fills the valley bottom, it is a box-shaped trough valley (Figure 3, No. 21). Its geomorphology has been investigated in 1984 and published in a previous paper (Kuhle, 1988f, pp. 487–488 and Figures 46–48). Between this valley and the above-mentioned southern parallel valley there was a coherent High Glacial (LGM = 0) ice level over a transfluence pass (Figure 3, No. 19). In the area of this side valley confluences and also 11 km further upwards, the Bo Chu has a classic trough-shaped, box-like valley cross profile (Figure 3, No. 22), developed by the filling of the valley bottom with loose rock, i.e., ground moraine, more or less surficially washed by the meltwater, and sander-gravels (Photo 13 □). From this orographic left-hand side valley junction 9 km (main valley-) up the Bo Chu, a ground moraine overlay has been mapped (Photo 13, centre of the panorama) on the right-hand valley flank with a characteristic lineation, i.e., exaration rills that have been left behind by a valley glacier ice run-off on flank slopes, covered with loose material (↗) (Figure 3, No. 23; Figure 2, Nos. 3, 4; at a valley bottom height of 4310 m asl; 28°28′ N/86°09′50″ E). This ground moraine cover lies on slightly metamorphic, polished sedimentary rocks (■) in metre- to decametre thickness (Photo 13 ↓ centre of the panorama). At the foot of the slope, at points where the moraine mantle has been undercut fluvially, retreating rills and earth-pyramids have been formed (below ■ centre of the panorama). The ground moraine material reaches here as well as on the opposite left-hand valley flank (■ on the left) up the slopes to ca. 400 m above the valley bottom. This provides evidence of a minimum height of the prehistoric ice level about 4700 m (– –). Here, in the source area of the Bo Chu, there was the root of the Bo Chu outlet glacier, which emerged at this location from the connected S Tibetan inland ice complex (Figure 12; Figure 10 on the left below 'High Himalaya'). This is the commencement of the main valley; it arises from two likewise glacially-shaped source branches (Photo 13 in the right third). In the triangular section, at the place where the source branches join, further ground moraine deposits are preserved (Photo 13 on the left, below the left white ☗). The orographic right-hand one leads up to the Yagru Xiong La (Photos 14 and 16 in the foreground; Figure 2 right of No. 6; Figure 3, No. 25; cf. Zheng Benxing, 1988, Figure 11 right margin (Sho La), cf. Kuhle, 1988f, Figure 45 (Lalung La)), increasingly covered with a connected ground moraine overlay. In places it is exposed fluvially (Photo 15). It contains granite boulders. Bedrock metamorphites are in the undermass. In the valley thalweg region the ground moraine is covered with gravel layers, which have been washed glaciofluvially and postglacially. The ca. 5060 m high Yagru Xiong La itself is situated on a S Tibetan plateau section which stretches over kilometres and is covered by the same ground moraine (Figure 3, No. 25; Figure 2, Nos. 5, 6; Figure 6). In the position, where it evenly covers the culmination of the pass, it documents a total glaciation from the N as far as the Himalaya (Photos 14 and 16; Figure 12, I3). There exists a predominance of 56.3% of glacially crushed/freshly weathered $SiO_2$ grains in the matrix of the fine material, which is typical of ground moraines (Figure 5, 21.8.96/2). 2–3 km to the N, already beyond the culmination about 4800 m asl (Figure 3, No. 26), round-polished metamorphic ridges ('glacially streamlined hills') are coated with ground moraine, bearing erratics (Photo 17). Again, further to the N (Figure 3, No. 27), roches moutonnées and extended streamlined glacigenic denudation forms were found in the bedrock granite (Photo 18 ☗). Several of them are postglacially frost-weathered (▲). They are gathering surfaces for local ground moraines (□ □). Here, too, sediment and morphology are witnesses of a total prehistoric glacier cover. We are now beyond the local watershed in a flatly embedded thalweg-network, which drains towards the N and E to the Xaga Chu (Figure 3, No. 28). The Xaga Chu drains the Shisha Pangma N-slope. It is a source branch of the Pum Chu (Figure 2, Nos. 7, 8) which joins the Arun valley, draining E of Mt. Everest and Makalu southwards through the Himalaya to the Ganges. So we are still S of the watershed to the Tsangpo and Brahmaputra. In the orographic right-hand flank of the Xaga Chu the flat (8–15°) N to NW slopes are covered with ground moraine, rich in fine material, in which fist- to at a maximum head-sized polymict boulders are 'swimming' (Figure 3, No. 28). Erratic massif-crystalline components as, e.g., granite and augen-gneiss, also occur. In the undermass there is sedimentary bedrock. A position-specific indicator of the substantial thickness of the ice is the ground moraine overlay, which – completely smoothed on its surface – covers the relief evenly. On the slightly inclined, often far-stretching slopes this cover is cut by separate 2–4 m deep ravines, which are inset box-like and sharp-edged. Only after heavy rains are they water-bearing (Photo 19 ■; 28°38′–45′30″ N/86°06′–10′30″ E). In the more western catchment area of the valley, as well as in the area of the plateau section, situated to the N, there are round-polished hill-ridges (☗). The valley bottom has been made up by glaciofluvial gravel floors at a breadth of kilometres (□ −0 to −5). They have been deposited on the ground moraine, covering the valley bottom, approximately between the Neoglacial and Little Ice Age, thus correlating with the glacier margins of the Shisha Pangma N slope (Kuhle, 1988f, p. 468, Table 1, pp. 479–487) during Stadia V to IX (Table 1). Owing to the infilling with these gravels, which have been washed out of the accumulations of the young ice margin positions and then transported from there up to here, the Xaga Chu receives the cross-profile of a box-shaped trough valley in some sections (Figure 3, No. 29). Down-valley to the E, in the direction of the basin of Mankopa (Kuhle, 1988f, Figure 2, Nos. 29–21), the density of the slope ravines increases with the steepness of the slopes – as this is generally the case for the ground moraine slopes, spread everywhere in Central Tibet (see below) (Figure 2, No. 9; Figure 3, No. 30). In the features of these juvenile ravines, which are not very deeply inset (Photo 20 ⇐), the present, i.e., interglacial fluvial morphodynamics begins to rework and reshape the Ice Age glacigenic, large-scale abrading, i.e., accumulative-covering morphodynamics. A geomorphodynamic which was entirely fluvial during the whole Pleistocene – implied here as a contra-inductive experiment of thought – would have brought about a totally different landscape, composed of a small-scale dissecting V-shaped valley network. The glaciogemorphology of the lower Xaga Chu and the basin of Mankopa (Figure 2 W of No. 15) and its glacier-historic interpretation has already been introduced previously (Kuhle, 1988f, p. 469, Table 1, p. 476, and Figure 31).

A further glaciogeomorphological key-locality on the S border of Tibet is the Kyetrak valley (Photo 28), situated between the settlement of Tingri (or Ting-Jih, Figure 3) and the Himalaya pass Nangpa La (or Khumbu La, 5717 m; Photos 22 and 31, Figure 3, No. 31) at the 8201 m high Cho Oyu. At present the good 10 km long Kyetrak glacier tongue flows down to the N, at the same time following the valley bottom, which is also sloping to the N, down to 4800 m asl (Photos 21 and 23 ■ white, 24 ▲, 30 ◀; locality: Figure 2, Nos. 11–12, Figure 3, No. 32). In glacial times, however, an outlet glacier of the S-Tibetan ice stream network - as was also the case with the parallel Rongbuk valley, running more to the E past Mt. Everest (Kuhle, 1988f, pp. 505–507) – of rather important thickness flowed through the valley towards the S, passing W of Cho Oyu (Figure 12, I3 between Shisha Pangma and Mt. Everest; Figure 10, to the left below ‘Mt.Everest’). Together with the tributary streams the outlet glacier tongue moved down from Mt. Everest into the Himalaya S slope up to ca. 1800 m asl or even somewhat lower (27°38′ N/86°42′ E) (Kuhle, 1987d, pp. 407–408; 1988b, p. 587; Heuberger, 1986, p. 30). Evidence of this transfluence to the S is provided by fields of ground moraines (see Figure 9) with erratic granite boulders, lying very high up, i.e., up to 5500–5600 m asl and thus ca. 700 m above the valley bottom (Photo 27 ○, ■ 0, 28 ↘↘, ■ 0, ↗↗, 30 ↘, ■ 0, 31 ○, ■ 0). Figure 5 (column diagram 25.8./1) shows a predominance of 85.7% of the glacially crushed/freshly weathered quartzite grains, typical of ground moraines. The moraine covers and granite boulders have been mapped over kilometre-distances on the slopes, stretching W of the valley, as well as on valley shoulders and remnants of the upland area on thinly-stratified reddish metamorphic bedrock of silt- and sandstones and light limestone (Photo 27 \ \, 31 ○ ○, Figure 3, Nos. 33, 34, Figure 2, Nos. 10, 11, 13). However, the High Glacial (0 = LGM) glacier cover seems to have reached significantly higher up than the above-mentioned ground moraines and erratic boulders at 5500–5600, because – after the author’s snow line reconstructions (Kuhle, 1988f, pp. 468–470, Table 1) – one is at this important height far above the High Glacial ELA. From this it follows, that these deposits ought to be of Late Glacial age, i.e., that they might belong to a higher than the High Glacial ELA. What leads to this conclusion is the basic glaciogeomorphological law, according to which the highest glacigenic depositions (moraines, erratics) cannot have been laid down above the snow line. Therefore this Ice Age glacier level is a minimum information and 700 m is a minimum thickness for the Kyetrak outlet glacier, which flowed down over the watershed to the S. On the eastern flank of the Kyetrak valley the features of glacial abrasion, as for instance back-polished mountain spurs with rounded crests and edges and glacially triangular-shaped slopes lying between them, have been developed up to at least the same altitude (Photo 24 ◠ centre, 26 ◠ left half of the panorama, 28 ◠ centre of the right half, 30 ◠ left third, 31 second ◠ from the right; Figure 3, Nos. 36, 37, Figure 2, No. 12). The polish line, which can be recognized continuously as the upper edge of the smoothings, declines *counter* to the gradient of the present valley bottom to the S, to the Himalaya, and *equidirectionally* further through its main ridge (Photos 23 and 26: ▬ ▬ 0, 28: 0 ▬ ▬, 30 ▬ ▬ left half, 0 ▬ ▬; 31 ▬ ▬ sparse). With the help of this polish line, the minimum level of the ice stream – dipping in the direction of the run-off of this outlet glacier - is discernible. The prehistoric incline of the level thus slopes down over the approx. 5400 m high or somewhat lower rock saddle – situated ca. 300 m below the present glacier surface of the Nangpa La – in a continuous gradient from Tibet to the S over the watershed of the Himalaya. Afterwards, due to decreasing thickness of the ice, the direction of the run-off of the Late Glacial glaciation switched, following more and more – as is true at present of the entire Himalaya – the small-scale incline of the relief in close dependence on the watersheds. In the Kyetrak valley this happened approximately from Stadium II onwards (Taglung Stadium according to Kuhle, 1982; 1983; cf. Table 1), at least, however – as can be made clear by comparison of the levels (Photos 26, 28, 30: cf. the altitudes of ■ 0, □ I, ■ II and ■ III with the incision of the pass into the Himalaya ridge between the mountains Nos. 5 and 7, Figure 3, Nos. 31, 32–34) – during Stadium III (Dhampu Stadium). The related Late Glacial glacier ends (Stadia II–IV) reached the plain of Tingri and flowed down from the heights of the Himalaya to ca. 4500 m asl, as is confirmed by the hummocky end moraine landscape (up to 28°25′ N/86°37′ E; Figure 3, No. 37, Figure 2 between Nos. 12 and 13). The diametrically opposed directions of the ice run-off from High Glacial to the S and Late Glacial to Holocene to the N is presented by the significant petrographic difference of the moraines concerning their limestone content: whereas the oldest ground moraines of the High- or early Late Glacial contain 17.32%, the younger moraines merely show 0.15–6.99% portions of limestone (Figures 7–9). The Late Glacial end moraines (Photo 31: ■ III; Figure 8, Figure 5 columnar diagram 23.8./2: at least 45.5% are glacially crushed/freshly weathered and further 37.8% are also roughened, but it could not be excluded, that this happened eolianly. Related Late Glacial to Holocene ground moraine:

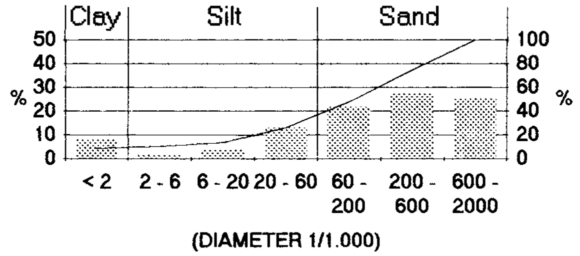



| *Probennr./ Datum* sample No./ date | *0,2 - 0,6 mm ausgezählte Quarzkörner* 0,2 - 0,6 mm counted quartz grains | *glazigen-gebrochen/ frisch (in situ) verwittert* glacially crushed/ freshly weathered (in situ) | *äolisch mattiert* dull (aeolian) | *fluvial poliert* lustrous (fluvially polished) | *Anmerkungen* remarks |
|---|---|---|---|---|---|
| XI | 201 | 49,6% | 26,8% | 23,6% | *Fluviale Überarbeitung ausgeprägter als äolische* - fluvial reworking more distinct than aeolian |
| 21.08.96/ 1 | 200 | 62,5% | 10,0% | 27,5% | *90% Quarzanteil (u.a. Citrin), Feldspate* - 90% quartz portions (eg. citrine), feldspars |
| 21.08.96/ 2 | 142 | 56,3% | 10,6% | 33,1% | *alle Übergangsformen vorhanden; leichte fluviatile Überarbeitung des glazigen-gebrochenen/ frisch verwitterten Materials; geringer Quarzanteil* - all transition froms exist; slightly fluvial reworking of the glacially-crushed/ freshly-weathered material; small portion of quartz |
| 23.08.96/ 1 | 210 | 52,1% | 38,0% | 9,9% | *ca. 80% Quarz* - c. 80% quartz |
| 23.08.96/ 2 | 180 | 45,5% | 37,8% | 16,7% | *heterogene Probe, teilweise hoher Zurundungsgrad; Übergang von glazigen-gebrochen/ frisch zu fluvial gerundet; Varietäten des Quarz vorherrschend (Citrin, Milchquarz)* - heterogeneous sample, partly important degree of rounding; transition from glacially-crushed/ fresh into fluvially rounded; varieties of quartz are predominant (citrine, milky quartz) |
| 25.08.96/ 1 | 140 | 85,7% | 14,3% | - | *sehr scharfe Grate/ junge Bruchflächen, Material kantig-frisch* - very sharp crests/ fresh fracture surfaces, freshly-edged material |
| 27.08.96/ 1 | 50 | 10,0% | 80,0% | 10,0% | *schwierige Analyse, da kaum Quarz vorhanden; viel Muskovit (Glimmer) und braun-rote Aggregate* - difficult analysis, since nearly no quartz does exist, much muscovite (mica) and brown-red aggregates |
| 28.08.96/ 1 | 100 | 25,0% | 55,0% | 20,0% | *leichte Überpolitur der frischen Bruchflächen* - slight polishing of the fresh fracture surfaces |
| 29.08.96/ 1 | 33 | 15,0% | 85,0% | - | *Probe mit sehr geringem Quarzanteil* - sampel with a very small portion of quartz |
| 30.08.96/ 1 | 155 | 53,0% | 20,7% | 26,3% | *heterogene Probe, letzte Transportart jedoch deutlich ausgeprägt* - heterogeneous sample, last way of transport but clearly pronounced |
| 30.08.96/ 2 | 158 | 69,6% | 19,0% | 11,4% | *ca. 50% Quarz* - c. 50% quartz |
| 31.08.96/ 1 | 88 | 90,9% | 9,1% | - | *nur ca. 20% Quarzanteil, sehr kantig-frisches Bruchmaterial, teils oberflächlich modifiziert* - only c. 20% quartz portion, well edged fresh fracture material, partly surficially modified |
| 31.08.96/ 2 | 91 | 83,5% | 14,3% | 2,2% | *frisch gebrochener Detritus* - freshly broken detritus |
| 01.09.96/ 1 | 206 | 81,6% | 13,8% | 4,6% | *klassifiziertes, frisch gebrochenes Substrat, teilweise leicht fluvial überarbeitet* - classified freshly broken substrate, in parts slightly fluvially reworked |
| 02.09.96/ 1 | 102 | 66,6% | 6,9% | 26,5% | |
| 02.09.96/ 2 | 165 | 17,0% | 39,4% | 43,6% | *schön zugerundete Körner, Übergangsformen frisch-gerundet* - nicely rounded grains, transition forms freshly-rounded |
| 06.09.96/ 1 | 170 | 60,9% | 11,7% | 27,4% | *alle Außenkanten zugerundet, jedoch viele klare muschelige Brüche auf Innenflächen* - all outer edges are rounded, but many shelly fractures on inner surfaces |
| 07.09.96 | 240 | 25,0% | 50,0% | 25,0% | |
| 08.09.96/ 1 | 150 | 34,0% | 42,0% | 24,0% | *geringer Quarzanteil; alle Übergänge vorhanden* - small portion of quartz; all transitions exist |

*Laboranalyse (Mikroskopie)* - laboratory analysis (microscopy): O.A. Bauer 9/10/97
*Probenentnahme* - sampling: M. Kuhle

*Figure 5.* Morphometric quartz grain analysis of 19 representative samples from S-, Central- and W-Tibet (cf. Figures 4, 6–9, 11, 13, 15, 17, 21, 22, 24, 26, 27, 29–31, 33, 34.

CUMULATIVE FREQUENCY GRAIN-SIZE CURVE 21.08.1996/2

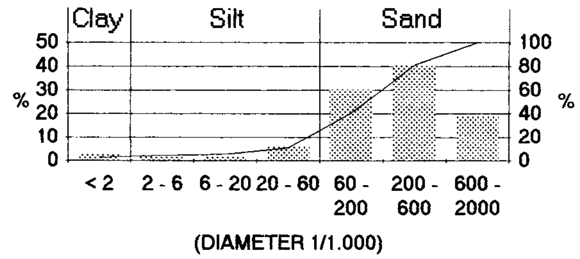



HUMUS CONTENT: 3,73 %

LIME CONTENT: 0,32 %

*Figure 6.* Ground moraine matrix taken from a depth of 0.15 m at 5060 m asl in the high plateau area of the Yagru Xiong La (cf. Figure 5: 21.08.96/2); locality: see Photos 14 and 16; Figure 3, No. 25, Figure 2, No. 6. The characteristic bimodal course of the curve is obviously as well as the fine grain peak in the clay, typical of ground moraine. The ground moraine is slightly weathered on the surface and contains humus. Polymict erratic boulders from granite, quarzite and gneiss are incorporated; some lime components can also be observed. Metamorphic bedrocks occur in the underground. (Sampling: M. Kuhle.)

CUMULATIVE FREQUENCY GRAIN-SIZE CURVE 23.08.1996/1

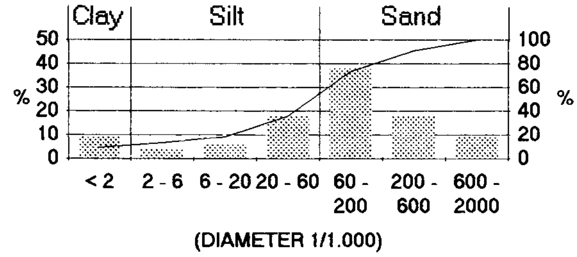



HUMUS CONTENT: 1,89 %

LIME CONTENT: 6,99 %

*Figure 7.* At 4725 m asl, Late Glacial to historic ground moraine taken from a depth of 0.1 m on the bottom of the upper Kyetrak valley left of the gravel floor, 2 km away from the tongue of the Kyetrak glacier. Locality: Figure 3, No. 32; Photo 25 (■ in the foreground), 24 (on the right of ▲). The minor amount of the clay portion is to be reduced to the important portions of local moraine which has been transported not too far. These large portions are typical of the narrow valley landscape of the Himalaya, where the sample locality is situated. See Figure 5, 23.8.96/1. (Sampling: M. Kuhle.)

CUMULATIVE FREQUENCY GRAIN-SIZE CURVE 23.08.1996/2

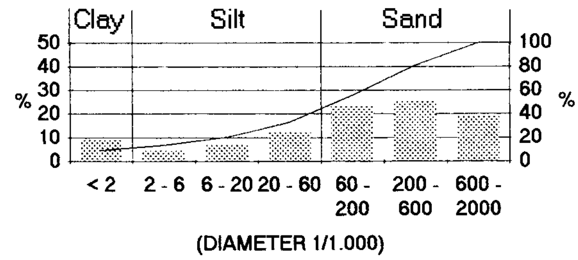



HUMUS CONTENT: 2,58 %

LIME CONTENT: 0,15 %

*Figure 8.* At 4730 m asl, moraine matrix taken from the orographic left-hand Late Glacial ground moraine- or lateral moraine terrace (Stadium III or IV?) ca. 90 m above the present-day gravel floor of the Kyetrak valley. Depth: 0.15 m; locality: 28°22′ N/86°37′50″ E, Figure 3, No. 40; Photo 31 behind ■ III on the left. The bimodal course of the cumulative curve, characteristic of moraines, is obvious. The important differences of the lime content (cf. Figures 7 and 9) within the moraine sediments of one and the same valley immediately show the strong topographic dependence of the ice flow on the thicknesses of the glacier. See Figure 5, 23.08.96/2. (Sampling: M. Kuhle.)

CUMULATIVE FREQUENCY GRAIN-SIZE CURVE 25.08.1996/1




HUMUS CONTENT: 3,79 %

LIME CONTENT: 17,32 %

*Figure 9.* At 5250 m asl, High- to Late Glacial ground moraine matrix taken from a depth of 0.1 m on the orographic right-hand flank of the Kyetrak valley, ca. 600 m above the present-day thalweg. Locality: Photo 27 ■ 0; Figure 2, Nos. 10, 11, Figure 3, No. 33. The bimodal course of the cumulative curve with a pronounced fine grain peak in the clay is typical of the glacigenic character of the sediment. The moraine contains large erratic granite boulders; it covers the sand- and schist bedrocks extensively. See Figure 5, 25.08.96/1. (Sampling: M. Kuhle.)

Figure 7, Figure 5 diagram 23.8./1: predominance of 52.1% glacially crushed/freshly weathered grains (the roughening of 38% could also be eolian)) have been laid down on the High Glacial (LGM = Stadium 0) ground moraine plain (Photo 34: ■ foreground) (Figure 3, No. 38, Photos 29 and 32: |). Zheng Benxing (1988, p. 535, Table 3) classifies these end moraines as being from his Qomolangma Glacial and dates them as belonging to the penultimate and last glaciation. His interpretation, which contradicts that of the author, is published in the Chinese Quaternary Glacial Distribution Map (Shi Yafeng et al., 1991, eds). The different opinions with regard to the age-dating of end moraines are again discussed here. The author considers them to be – at the oldest – of Last Glacial to Late Glacial age (Stadium I, Table 1), whereas Zheng Benxing applies a middle-Pleistocene age. All this has been described and compared in detail for the northern Shisha Pangma foreland in Kuhle (1988f, pp. 479–483). The glacier traces, which the author indicates as being from the High Glacial (LGM = 0), are only reported and mapped in part by Zheng Benxing. He does not declare or consider them to be of glacigenic origin, i.e., as giving evidence of a higher ice level and a resulting ice run-off to the S through the Himalaya (cf. also Zheng Benxing and Shi Yafeng, 1976; Shi Yafeng et al., 1982). Odell (1925, p. 331), however, in view of his findings of ammonite-containing erratic boulders on Phusi La (5411 m asl), 300 m above the modern Kyetrak glacier, argued in favour of a total glacier cover of the basin of Tingri and an ice transfluence over the watershed of the Himalaya into the S slope already 71 years earlier than the author. Without doubt the Phusi La erratics consist of Jurassic rock and lie on pre-Jurassic metamorphic-crystalline bedrock. Odell quotes transport distances of at least 30 km for those erratics from their source areas, far N of Phusi La, up to here (for further details see Kuhle, 1988f, pp. 464–465). A kame, extending about 1 km in a N-S direction (Figure 3, No. 39; Figure 2, No. 14; 4220 m basal height; 38°31′ N/86°34′ E; Photos 32 and 33) is set upon the featureless ground moraine area (Figure 11) of Ting-Jih (Tingri; Figure 3, No. 38) N of the Late Glacial end moraines of Stadium III in the lower Kyetrak Chu (Figure 3, Nos. 37–38; Photos 29 and 32 |). This glaciofluvially formed accumulation with a triangular- to diamond-shaped outline is more than 40 m high and built-up from horizontally lying, sand- to gravel-sized components. It is situated many kilometres away from the E and W valley flanks of the Kyetrak Chu and geomorphologically isolated from them by the ground moraine plain, so that it cannot be interpreted as a kame terrace on the margin of the glacier. Accordingly, the kame is regarded as being a sedimentary body, which was infilled by the supraglacial meltwater into an ice hole in the middle of the outlet glacier, belonging to the ice stream network I3 (Figure 12; Figure 10 right fifth) that melted down during the Late Glacial (Stadia I and II). Thereby the kame was held by the lining ice walls as by a cake tin. The two levels (☐ 1 and 2) shown in Photos 32 and 33 are explained by the expansion of the outline of the ice hole and the connected decrease in thickness of the ice, lining it. The eastern valley border of the Kyetrak Chu consists of hills and mountain ridges of 4400 to 5675 m in height, which have been polished round by the covering glacier ice (Photo 34 ☗ ☗). In places, moraine (■ background) is preserved on the slopes (Figure 3, No. 41). Its lighter loose rock is soft and thus very much exposed to erosion. Already at a distance it can clearly be recognized by fresh and sharp erosion gullies (Photo 34 on both sides of ■ in the background). The region of Rongbuk-, Dzarka- and upper Arun Chu, N of Mt. Everest, which continues E of this hill- and mountain landscape, has already been investigated earlier with regard to its former glaciation (Kuhle, 1988f, 1991d).

Up to now the author has found no clear indicators of a prehistoric ice sheet in the valley chamber of Pum Chu (Figure 3), connected E of the settlement of Ting-Jih (Tingri), which itself is located in the High Glacial (LGM) ground moraine area, attached to a hill that has most probably been polished round by the ice. Therefore an ice-free valley zone is assumed, extending a few decakilometres to the E and probably containing an ice-dammed lake. On the question of the former glaciation of the continuing area in the Pum Chu, again further to the E (E of the map section of Figure 3), field data and pertinent interpretations have been put forward in an earlier study (Kuhle, 1988f).

### 3. New observations on the Ice Age glacier cover in S Central Tibet (from the Tsangpo and N of it, i.e., from Figure 2, Nos. 16 and 17 to the W; Figure 12, I2 above Shisha Pangma)

In addition to the results of two former expeditions (Kuhle, 1988f, Figure 2, No. 16; pp. 466–467 and Kuhle, 1991d, Figure 43, No. 52; pp. 199–200) new observations from the exit of the valley, which runs from the Lhagoi Kangri massif to the N down to the Tsangpo valley to Quxan, are to be reported (Photo 35; Figure 2, No. 16). Here, about 3900 m asl (altimeter measurement; according to ONC map more than 4000 m), the round-polished hills and the ground moraine sheet containing rather large erratic granite boulders (Photo 35 ☗, ■, ↓ ↓), are evidence that the ice (– –), flowing down as an outlet glacier from the more than 5000 m high plateau of the Lhagoi Kangri massif, has reached the Tsangpo valley (Photo 35 ◇), lying at an altitude of 4000 m.

Five km upwards the Tsangpo valley from this junction, one follows an orographical left-hand side valley of the Tsangpo, the ‘valley of Napshi’, to the NW into Central Tibet (Figure 2, Nos. 17–18). Photo 36 has been taken upwards from the inflow of this valley and shows glacially rounded valley flanks and mountain ridges (☗), developed in metamorphic sedimentary rock, in places with moraine cover (■). The gravel floor (☐) with a cover of sand and outwash loess has been filled into the valley bottom during the Late Glacial (Stadia I–IV). From the Holocene up to now it has been cut several metres deep by the river (below ▽), undercutting the opposite slope. Apart from those typically glacial erosion forms of the flank polishing (Photo 37 ☗), there are preserved moraine remnants 4.5 km up the valley. A decametre-thick ground moraine remnant (Photo 37 ■) is in a hollow mould, set into the orographic right-hand valley flank. The yellowish erratic ground moraine material has been diagnosed as being far-travelled moraine because it is lying on anthracite-coloured bedrock mica schist. In the course of the continuing 10 km up-valley, further localities with a ground moraine cover have been mapped on the orographic right-hand valley flank (e.g., Photo 36 ↙; Figure 2, No. 19). Owing to its dense loamy matrix, the clay-bricks for the construction of houses and walls are in many places cut directly out of the ground moraine cover. The metamorphic bedrocks of the left-hand valley flank are preserved round-polished. At the down-valley end of Lake Lang Tso (4250 m asl) on its NE shore there are limestone rocks, polished round by the glacier ice and partly covered by ground moraine (Photo 38 near the left margin). In places these roches moutonnées preserved in the limestone (Figure 2, Nos. 18, 20), have been undercut by the shore line of the lake (Photo 38 ◀ on the very left). Thus, the lake dates from postglacial times. Corresponding undercuttings by the lake level after deglaciation have also been preserved in the form of cliffs at the foot of rock- and ground moraine slopes (■) on the other edges of Lang Tso (Photo 38 the rest of ◀). This post-Late Glacial moraine- and tongue basin lake, located in the valley, is fringed by a mountain ridge landscape, which has been completely covered (Photos 38 and 39 – –) and rounded (☗ ☗) by the High Glacial (LGM) inland ice. Owing to the substantial ice thickness and topographic context which were necessary for its development, the collection of glacial forms in the lower valley of Napshi with its correlative depositions preserved up to the culminations of the relief, i.e., high up the valley flanks, provides evidence that the outlet glacier flowing down through this valley from Central Tibet, has reached the Tsangpo valley

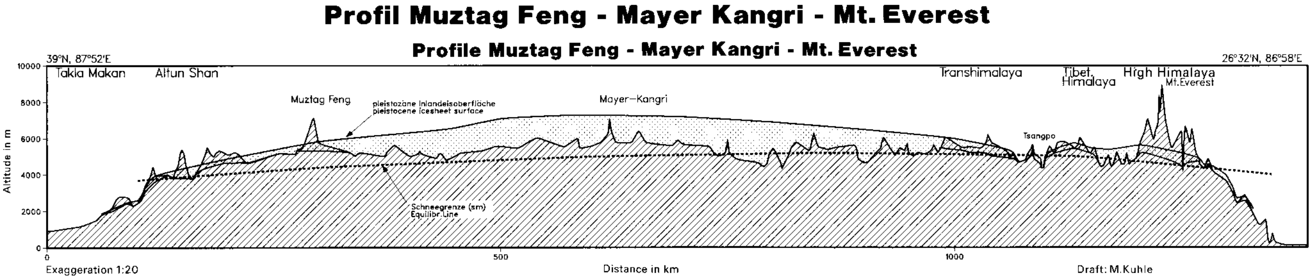



*Figure 10.* Cross-profile of the Pleistocene inland glaciation of Tibet (according to Kuhle, 1993c, p. 137). This older reconstruction is supported in this paper by the observations regarding the S margin of Tibet, introduced in Section 2, which are evidence of the transfluences of the outlet glaciers through the Kyetrak valley and the Bo Chu W of Mt. Everest over the watershed of the Himalaya; in Sections 3 and 4 by the findings concerning the Tsangpo as far as the Transhimalaya and in Sections 5, 6 and 7 concerning the western Central Tibet and the NW border of the Tibet plateau.

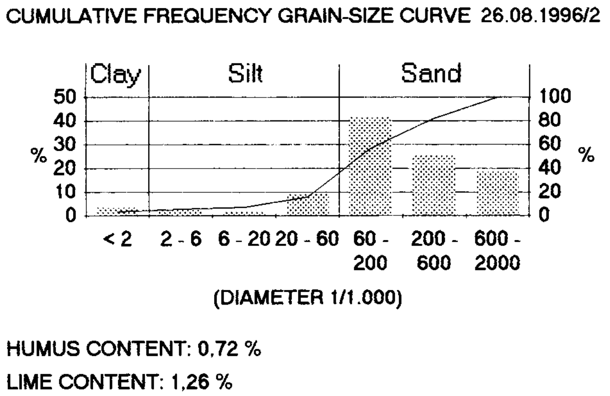



*Figure 11.* 4265 m asl, matrix taken from a depth of 0.1 m from the ground moraine plain of Tingri (Figure 3, No. 38; Photo 33 ■). It belongs to the LGM (= Stadium 0). The cumulative curve of the grain sizes shows the bimodal course, characteristic of moraines. The fine grain peak of the clay is only weakly developed (4%), whereas the peak in the fine sand (41%) is very conspicuous. The lime content evidences that the material has been transported from the N, where the limestone bedrock is located. (Sampling: M. Kuhle.)

(Yarlung Zangbo Jiang: Figure 2, Nos. 17, 18). Further up-valley and WNW of the upper end of the lake at a distance of 5–8 km from the locality in Photo 39 in the area of the orographic left-hand hills of the Napshi valley – this valley is already many kilometres wide now, showing the character of an only flat high-lying valley –, in places local moraines in the form of a grey ground moraine cover are preserved on limestone ridges and roches moutonnées of an also grey bedrock schist (4300–4350 m asl; 29°14′ N/87°16′ E; Figure 2, No. 21). In an orographic left-hand (northern) source branch of the valley of Napshi, at a distance of 3 to 13 km from the above-mentioned locality, round-polished and abraded sedimentary rock- and metamorphic ridges are preserved almost connected over large areas (Photo 40). This is also evidence of an inland ice sheet (Figure 2, No. 22). In the area of the head of this northern source branch of the Napshi valley there is at a distance of 3 km, below Doka La (4550 m), about 4500 m asl, a metre- to decametre-thick moraine cover, which almost completely cloaks the landscape. It is exposed in these loose rocks by a Holocene to modern, ramifying fluvial backward erosion and the development of microfluvial rills (Figure 2, No. 23; Photo 41). The grain-size spectrum (Figure 13) is very similar to that of North-American inland ice ground moraine (cf. Figure 14). It indicates the evident fine grain peak of its matrix which – being 30% – is conspicuously high. Photo 42 shows the very colourful polymict composition of erratic stones, the size of pebbles which, isolated from each other, are contained in the matrix. The morphometric analysis (Figure 5 diagram 27.08./1) and the related petrographic information (almost no quartz, abundant muscovite) confirm the important portions of local moraine, already indicated by the significant peak in the clay, which the inland ice has taken up from the fine-grained bedrock mica schists. The max. 10% glacially broken grains (which might partly have been also developed by frost weathering) could only derive from the $SiO_2$-grains of the far-travelled moraine portions. In Photo 41 the minimum height of the covering inland ice (LGM) is marked (▬ ▬), which must be deduced from the round-polished mountain ridges (☗ ☗). Below these glacial erosion forms a classic Late Glacial (ca. Stadia II–IV) ablation landscape is visible: a more than 10 m thick ground moraine (Photo 41 ■ black) is covered by an ablation moraine (■ white) (↑). Simultaneous typically intra- or subglacial meltwater activities (they have been described from N- to middle Finland) as they are consistent with a Late Glacial ELA, already raised since the LGM, can be proved with the help of glaciofluvial gravel bodies (□), incorporated into the moraine coverings. There exists no alternative periglacial or fluvial model to explain the prehistorically glacial genesis of this landscape.

In this area of metamorphic sedimentary bedrock, the landscape of Doka La (Doka Ri) consists of perfectly glacially-rounded rather large hills up to mountain ridges (Figure 2, No. 24; Photo 43 ☗ ☗). In view of the highland climate that is rich in freeze-thaw cycles and thus weathering-intensification (Kuhle and Jacobsen, 1988; Kuhle, 1990c) their condition is relatively fresh, showing exaration rills in the bedrock and lineations (↙↙) in the ground- and ablation moraine coverings (▽). This points to the fact, that the melting ice disappeared only in the Late Glacial, ca. 14 Ka or more ago (Stadia II–IV ?; cf. Table 1). In this connection it seems remarkable, that here and in the surrounding area of south Central Tibet no patterned ground can be observed despite the relief available everywhere. This, too, is considered to be an indication of a long-lasting inland ice sheet, i.e., no long-lasting ice-free period during the Pleistocene. Beyond the pass and in the course of the continuing 50 km towards the WNW as far as the cara-

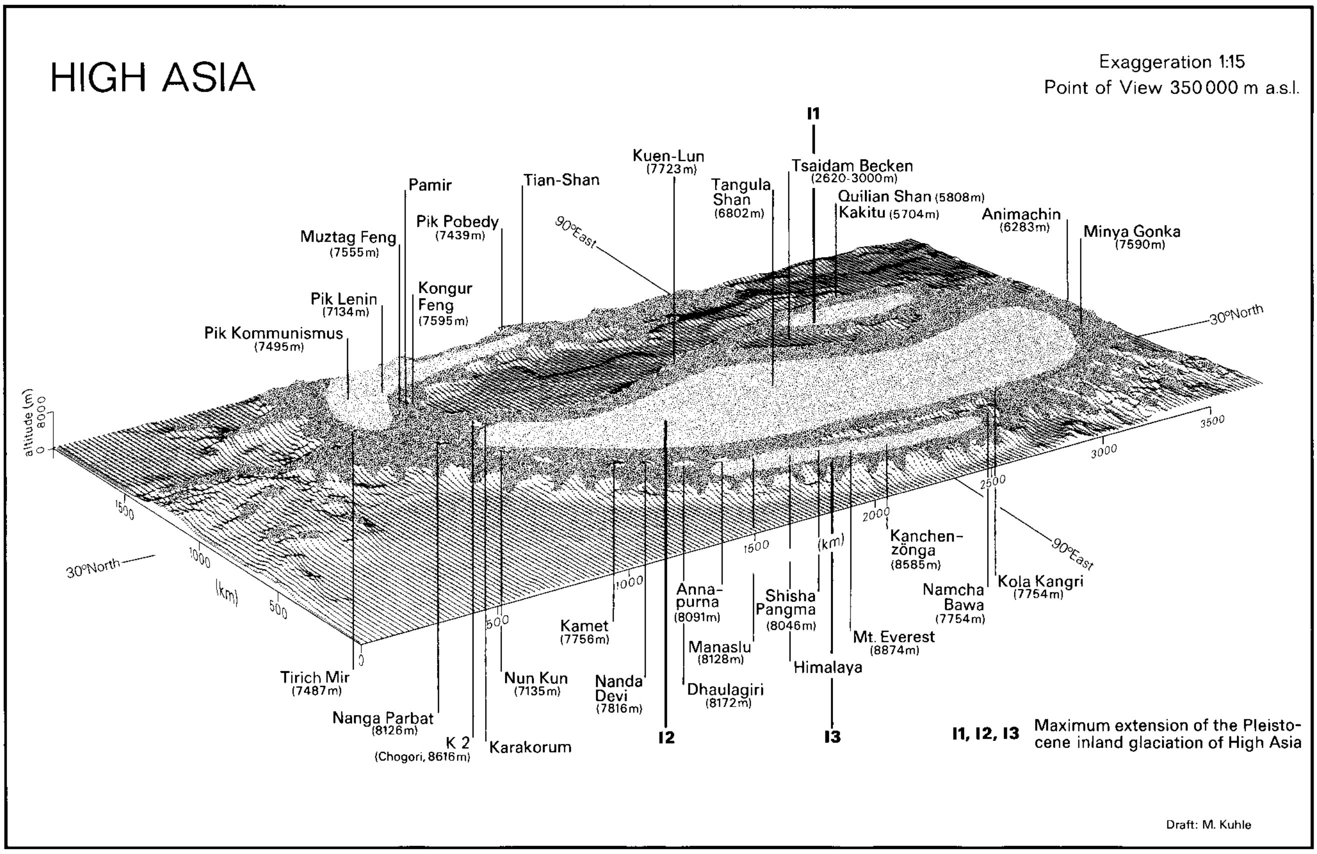



*Figure 12.* The High Glacial Tibetan ice had an extension of more than 2.4 million km$^2$. The three centres of glaciation I1, I2 and I3 were separated from each other by the Tsaidam lake and the Tsangpo valley. To the NW the ice complex of Pamir and Tian Shan continued, covering wide expanses as well. The light, highest ice faces were glacier feeding areas. On the darker faces ablation was predominant.

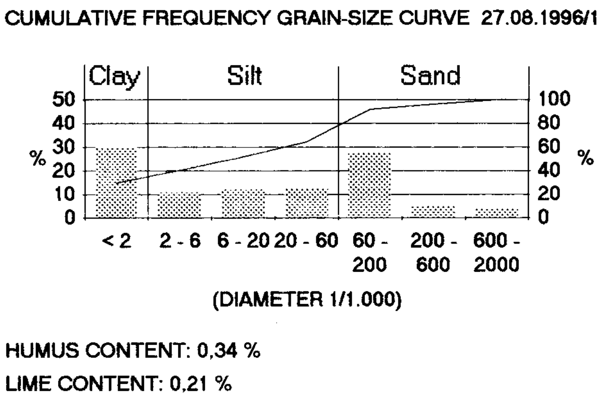



*Figure 13.* 4500 m asl, Central Tibet, 3 km SE of the Doka La (pass). Locality: see Photos 41 ○ and 42; Figure 2, No. 23. Ground moraine matrix taken from a depth of 0.2 m from a 3 m-thick moraine on bedrock phyllites with polymict, mostly pebble-sized, far-travelled boulders. The diagram shows characteristics, which are almost identical with a ground moraine matrix taken in Canada, in the area of the Late Glacial North American ice shield (see Figure 14). The very large clay portion (30%) is striking, though in general typical of the heavy trituration within a ground moraine. However, here it also profits by the very fine-grained bedrock in the underground of the nearer and further environment, which – as an always involved portion of the local moraine – has been incorporated. The almost as high second fine grain peak (ca.28%), situated in the region of the fine sand, depicts the markedly coarser portions of far-travelled moraine. Cf. Figure 5: 27.08.96/1. (Sampling: M. Kuhle.)

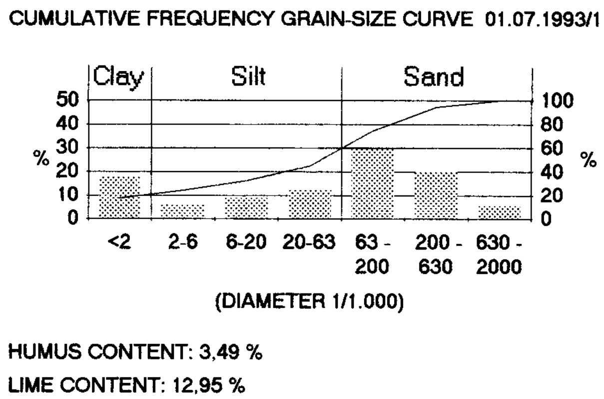



*Figure 14.* Ground moraine matrix from the area of the Last Glacial (LGM) Laurentide Ice Sheet in the Canadian North America, taken for comparison with prehistoric Tibetan ground moraines. Locality: Canadian prairie at Moose Jaw, 40 km N of Old Wives Lake and 85 km ESE of Lake Diefenbaker. Cf. Figures 6, 8 and above all 13. (Sampling: M. Kuhle.)

van settlement of Sang-sang, there follows a landscape of glacigenic polish thresholds and depressions, which consists of roches moutonnées and rounded mountain ridges (glacially streamlined hills), situated at an altitude between ca. 4200 and 4900 m asl (Figure 2, Nos. 25, 26). Over large parts this completely round-polished and abraded landscape has even been formed in steeply or vertically standing metamorphic rocks, which cannot be smoothed easily and which, were it to be preserved in a smooth condition in the frost climate, is even more difficult because of their splintering away (Photo 44). Five to 6 km WNW of Doka La (Figure 2, No. 24) a remnant of a lake is situated at 4150 m (aneroid measurement) in a glacigenic polish depression, fringed and elongated by lake sediments which have been drained in the meantime. The adjacent slopes are mantled by ground moraine (loamy drift). It contains polymict gravel stones, rounded at the edges, with, e.g., porphyry- and lydite components, i.e., erratic material (far-travelled moraine). Slope debris, produced *in situ*, is lacking. Three km to the W a further small lake is situated in a polish depression. Here, the hills are also covered by a thin moraine sheet. In the places where it is interrupted, polishings on sedimentary bedrock can be observed. When lake sediments are lacking, the small polish depressions are also cloaked by ground moraine. Where several metre-thick deposits of loose rocks line the foot of the slopes, it concerns moraine laid down *in situ*, bearing an overlay of ground moraine, which has immediately been washed down the slope (Photos 44–46). Despite the extremely different resistance of the rock beds, forming the surface of the roches moutonnées, the polishings of the outcropping edges of the strata have been preserved in a remarkably well-adjusted way (Photo 44 ☁ and 45 ▾). This points to a minor, namely Last High- to Late Glacial age (Würm, LGM = Stadium 0) of these glacial erosion forms. At present the glacially polished rocks are cut a few decimetres- to metre-deep by microfluvial gullies, following the slope gradients of the hill surfaces (Photo 44 ▽ and 45 ▽). So far this small-scaled postglacial gullying has been developed to such a small extent, that the typical character of a totally round-polished and abraded glacial landscape could as yet not be destroyed or evidently modified. In many places (29°20′ N/87°07′30″ E; 29°19′30″ N/87°05′ E; etc.) and also within the following 6–7 km (distance from the locality in Photo 46) the roches moutonnées and rounded hills and ridges are covered by a thin, only few decimetres- to metre-thick ground moraine sheet. Due to the portions of far-travelled erratic material, its colour is light-grey to yellow or light-orange (Photo 45 ↘). It strikingly contrasts with the dark bedrocks and as a rule has already been rinsed from the rock ridges, especially in the area of the culminations (Photo 46). On the hill slopes and particularly in the slope depressions, down to the base of the hills and mountain ridges, the ground moraine sheet increases in surface as well as in thickness (Photo 46 □). Due to the slope ravines, which suddenly become deeper and are lying close together downslope (Photo 46 △), this basal ground moraine cloak of the mountain ridges can already be recognized at a distance as a relatively soft material. In places this can be observed even better by the exposed earth pyramids (Photo 46 ↗). In the basin of Sang Sang a large-scale ground moraine occurs, which is covered with ablation moraine (Figure 2, No. 27). The ablation moraine is recognizable by its polymict pebble scatter of 1–2 cm-long components, edged to rounded at the edges, the portion of which is markedly greater than that of the subjacent ground moraine (cf. Photo 47 ■). Following our profile to the W, glacially streamlined mountain ridges, with partly overlying ground moraine (Figure 2, No. 27), could be mapped 8 km away from Sang Sang (4400–4550 m asl; 29°27′ N/86°40′ E); corresponding features occur at a distance of 11 and 19 km. At the last-named locality limestone bedrocks have been observed, showing steeply out-jutting ridges which are glacially polished (4500 m asl; Figure 2, No. 28). At the localities: 29°27′30″ N/86°35′ E; 29°28′ N/86°34′30″ E, etc., from ca. 4450–4600 m asl up to a 4700 m high pass (29°29′40″ N/86°22′ E), there is a glacial landscape, abraded by glacier ground scouring, with streamlined mountain ridges of dark metamorphosed sedimentary rocks (phyllites) and a lighter ground moraine cover, containing rounded boulders (Photos 47–50). Rather small lakes and ponds occur in many places, thus showing the characteristics of a (probably during the Late Glacial) thawed dead ice landscape (Figure 2, Nos. 25–28). 24–26 km W of Sang Sang (Figure 2, No. 28) further glacially rounded hills rise above the ca. 4425 m high plateau surface from a water-retaining ground moraine plain. In the area (4430 m asl), again connected to the W, a Late Glacial glaciofluvial gravel floor terrace is preserved on both sides of the Dogxung Tsangpo (northern source branch of the Tsangpo river) (Figure 2, Nos. 28–30). Meanwhile, the river has cut 8–15 m deep into the glacier mouth gravel floor. The northern, i.e., orographic left-hand flank of the E-draining Dogxung Tsangpo valley, shows truncated spurs which have been polished back by the down-flowing ice. They are covered by ground moraine, partly glacigenically striated (Figure 2, No. 30). In the hilly landscape S of Dogxung Tsangpo, again connecting to the W, light remnants of ground moraine on vertical, polished metamorphic hills provide evidence of the prehistoric inland ice sheet (Figure 2, No. 29; Photo 48). This type of landscape continues westwards, where a ground moraine sheet, surrounded by a hilly band of polished edges of the strata has developed a ramp-like incline (Photo 49 ■). Such a slope cannot be the result of periglacial-fluvial morphodynamics; it is typically glacigenic. Following the thalweg, shown in Photos 48 and 49, and the corresponding valley bottom up to the head, the culmination of a ca. 4700 m high classic glacial transfluence pass with a ground moraine cover (Photo 50) is reached. In the area of the continuing 16 km beyond the pass, a thick ground moraine sheet with large erratic granite boulders covers wide expanses of polished hills of crystalline schists (Photo 51 ■). The phyllites stand vertically, showing band polishing of outcropping edges of the strata (Figure 2, Nos. 28, 29). A 10 km extended lake, lying in a Late Glacial (Stadium III; Table 1) tongue basin, follows to the W (Photo 52). Along its shore line erratic porphyry- and granite boulders, metres in size, have been washed out of the ground- and ablation moraine by the surf (Figure 2, No. 30). The fringing end moraine hills have been cliff-like undercut by the lake (ca. 4600 m asl). In contrast to the usually more clayey-silty ground moraine, this Late Glacial end moraine (Photo 52 ■ III) shows a proportionally sandier matrix. But the older ground- and ablation moraines (Stadia 0–II) are also rich in sand in this area (cf. Photo 51). Differently coloured polymict pebble- and gravel components of metamorphites such as quartzite as well as of granite, porphyries and other source rocks (Photo 53 ■

foreground) ‘swim’ – separated from each other by ground mass – in High- to early Late Glacial (i.e., Würm or Stadium 0 = LGM to II or III) ground- or ablation moraine SW of this lake (4600–4650 m asl). This ground- and ablation moraine sheet is markedly even and therefore cannot be mistaken for a very large and flat alluvial fan. Only on the margins are there adjusted rather small to medium-large fan forms of surficially outwashed ground moraine material to its surface as postglacial formations, created after deglaciation (△). In this area the inland ice run-off, reconstructed with the help of the forms of roches moutonnées and ground scouring, took place from NNW to SSE (←). In the course of the following 17 km of this profile to the W, the terrain rises to a ca. 4950 m (4840 m aneroid measurement) high prehistoric transfluence pass (29°28′ N/85°56′30″ E; Figure 2, No. 31), which has been smoothed by the overflowing inland ice. Here, the metamorphic bedrocks are covered by an only decimetre-thick ground moraine without large boulders. In places it has been cut and used as loam bricks for the construction of enclosures of cattle kraals. Extended basin- and valley bottom plains, with ground moraine covers, follow N and NW of the pass and ca. 200 m lower (4645 bis 4610 m asl aneroid measurement). They are interrupted at the surface by glaciofluvial gravel fields. In some places and also at a distance from the slopes, 1–2 m long erratic gneiss- and granite boulders are situated (Figure 2, Nos. 29, 30). Thinly stratified metamorphites occur in the underground. The ground moraines around here can be differentiated with regard to the time of their origin. In many places (e.g., at 29°24′30″ N/85°47’E) a ground moraine, particularly rich in boulders on its surface, overlies the High Glacial (LGM) ground moraine with less boulders. Accordingly, it belongs to the Late Glacial (Stadia III–IV). Summits, sharpened by the prehistoric inland ice, are rising in all directions at a distance of decakilometres from this locality. Sometimes they manifest the forms of glacial horns (Figure 2, No. 32). In this area N of the Yarlung Zangbo Jiang (southern source branch of the Tsangpo river) they are ca. 5800–6150 m high and might have pierced the glacier level, at least since the Late Glacial. When the glacier level has dropped still further, cirques ‘nestled’ in some of the highest of these summits (Figure 2 between Nos. 32, 33 and 38), and even at present partly contain small glaciers. This makes clear, that these summits have towered above the Late Glacial (Stadium IV) to Holocene snow line and at least reach the historically climatic snow line. Figure 15 presents an example of the classic composition of High- to Late Glacial ground moraines in the Transhimalaya (or Gangdise Shan, cf. Figure 2) of South Central Tibet (Figure 2, No. 33), evidenced by the amazing similarity with the Last Glacial Canadian inland ice ground moraine (Figure 16). The fact of a five times smaller portion of humus (3.03% against 13.99%) indicates a present-day climate far more hostile to vegetation, i.e., in this relatively humid area of Central Tibet with a precipitation of ca. 500-700 mm/yr markedly colder, i.e., closer to glaciation. Figure 5 (28.8./1) presents about 25% of the quartz grains contained as freshly weathered or glacially crushed, while 75% show a slight polish of the fracture surfaces. Further W, 19 km away from this sample locality, a ground moraine area stretches, which covers the schist bedrock (Photo 54 ■). It contains large erratic granite blocks (○). These far-travelled blocks are partly edged and rounded at the edges, but also facetted and somewhat better rounded. The next granite bedrocks have been found ca. 30 km NW (Figure 2 between Nos. 32 and 39). This might be a possible source area of the erratics, which can also be considered as being probable because of the declination of the Tibetan plateau and the resulting direction of the inland ice run-off (see above). Owing to the pelite portions of the local moraine taken up from the underground, the ground moraine contains clay, so that the monsoon rains lead to damming wetness (□). Turfs and ground moraine are used as building material (▼), which points to their compaction and

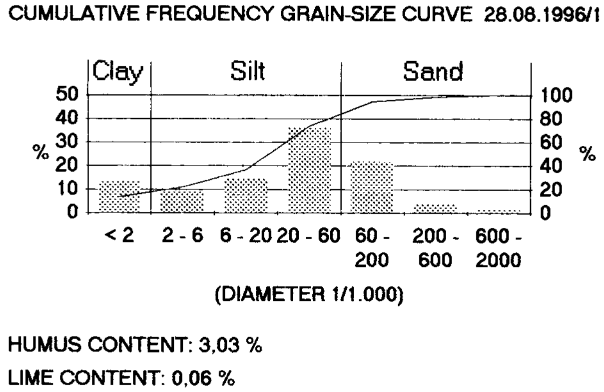



*Figure 15.* 4680 m asl (aneroid measurement), ground moraine matrix in Central Tibet, taken from a depth of 0.1 m. The moraine contains erratic granite boulders and lies on thinly stratified bedrock schists. The relatively great portion of clay of ca. 13% – though the sample was taken close to the surface – as well as the bimodal course of the curve evidence the morainal character. Locality: Figure 2, No. 33; 29°25′ N/85°17′30″ E; cf. Figure 16. (Sampling: M. Kuhle.)

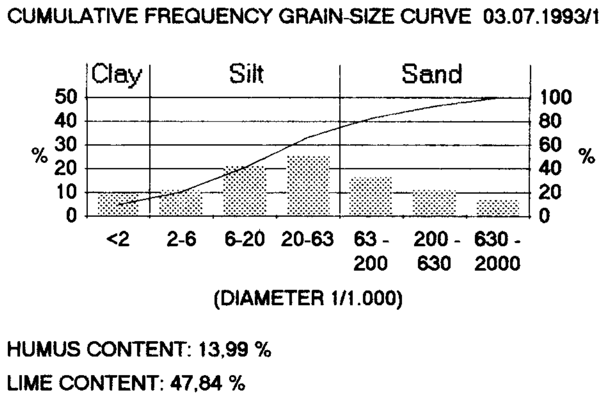



*Figure 16.* Ground moraine from the area of the Last Glacial (LGM) Laurentide Ice Sheet in the Canadian North America, taken for comparison with the prehistoric Tibetan ground moraines. It is the so-called far-travelled ‘Canmore Till’ from the Bow valley in the Rocky Mountains. Locality: ca. 100 km W of Calgary near Banff and the Lake Minnewanka in the eastern mountain foreland Cf. Figure 15: the similarity of the course of the curve of the histogram, i.e., the arrangement and height of the separate columns of the diagram is obvious. Because of the much lesser vegetation of today, the humus content of the Canadian ground moraine, which is almost five times greater than that of the Tibetan one, points to the far colder climate of High Tibet, being much closer to the prehistoric glaciation. (Sampling: M. Kuhle.)

coherence. Some of the small hills, rising over the moraine surface, are perfectly rounded roches moutonnées of the 'whaleback' type (☗ centre). The wide ground- and ablation moraine plain around the nomad settlement of Raka (4705 m asl aneroid measurement; 29°28′ N/85°09′30″ E; Figure 2, No. 34) shows several shallow lakes on the water-damming material, the extensions of which fluctuate according to the seasons. The area is fringed by partly streamlined mountain ridges, round-polished by the glacier ice, which consist of metamorphites (phyllites, thinly layered schists) (Photo 55). From the hill complexes reaching several hundred metres in relative height, which have correspondingly extended local catchment areas of down-flowing precipitation water, some fans of displaced ground moraine material have been accumulated out of small valleys and gullies on this primary ground- and ablation moraine plain. Due to its evenness it is the relative accumulation base for this displacement. About 10 km WNW of Raka (Figure 2, No. 35) the ground- and ablation moraine landscape changes a little, because now the moraine cover also overlies forms of ground scouring, such as flat roches moutonnées, and the coarser moraine components consist to a great extent of polymict crystalline pebbles, gravels and blocks (Photo 56). Following from here an initially flatly inset furrow of the main valley towards the NNW into Central Tibet, the washed to out-washed moraine (Photo 56 □) is obvious, modified to gravel floors in the course of the meltwater run-off. This process took place in accordance with the large-scale deglaciation of the Tibetan plateau since the late Late Glacial (Stadium IV; Table 1). Further up from this location (4725–4820 m asl aneroid measurement; 29°30′–37′ N/84°57′–58′ E), following the gravel string and its thalweg towards the NNE, a glacigenic threshold landscape in metamorphic rock can be observed over a distance of 15 km. It is composed of roche moutonnée-like elevations and also covered by a ground moraine, including polymict erratic massif-crystalline boulders (granite, etc.) (Photo 57). In places, the surfaces of the inserted moraine covers which have been outwashed to gravel fields, also show – besides the kind with longish-band-shaped outlines – those which diverge laterally. Some of the roche moutonnée-like rock threshold segments have been undercut and exposed by the postglacial to modern meltwater rivers (Photo 58; Figure 2, Nos. 36, 37). Photo 59 shows a more up-valley position of that meltwater run-off, situated ca. 5 km further N. There is a post-volcanic thermal spring with recent limestone sinter formations on rock surfaces, polished by the ground scouring. N of this thermal spring, which indicates a deep-reaching tectonic faulting, a glacially rounded, at least partly granitic mountain ridge landscape sets in, showing the forms of Scandinavian fjells (Photo 57 background; Photo 59 ▽). In the same way as in Scandinavia the high plateau-, hill- and mountain landforms of Central Tibet were completely covered by the inland ice complex I2 (Photo 59 ▬ ▬; Figure 12, I2 N of Manaslu and Annapurna) during the High Glacial (LGM = Würm = Stadium 0) and then at least up to the early Late Glacial (Stadia I and II; perhaps also III). This is evidenced by the above-mentioned indicators. In the 4–6 km-wide, valley-like area of excavation (Figure 2 between Nos. 38 and 39), stretching from the thermal springs 17 km N as far as the 5250 m-pass, extends a classic glacial landscape, made up in part of granites and in part of sedimentary rocks. It corresponds to the Scandinavian fjell-landscape in all details (e.g., Rondane in S Norway). On the valley bottom, N of a trough lake, Late Glacial to Neoglacial glacier mouth gravel floors (No. 1 to -0 = Sirkung Stadium IV to Nauri Stadium V, see Table 1) have been laid down on the High Glacial ground moraine cover in a thickness of over 10 m and cut into terraces (at 29°45′ N/84°54′ E) (this has also happened in Rondane). W of the pass, where cirques of the Alpine type as well as of the type 'Norwegian Botner' have been set into the lower mountains during the Late Glacial (Figure 2, above No. 37) and the higher mountains have pierced the inland ice cover, so that forms of glacial horns occur now (Figure 2, No. 39), a cirque-, hanging- and valley glaciation exists today, showing ice streams of a maximum of several kilometres in length (Photos 60 and 61 ○). This late Holocene and historic to modern glaciation (Stadia ′VII to XII; Table 1) with ELA depressions of max. 80–150 m compared to those of today, has sharpened the mountain ridges and intermediate valley ridges – rounded by the glacial inland ice (Photo 60 ☗) – on their firn- and ice borders by marginal undercutting and very intensive frost weathering along the black-white borders. In places it has partly destroyed the High Glacial features (Photo 60 below ▬ ▬ on the left margin). The complete covering of the 5250 m pass with ground moraine (Photo 60 ■, 61 ■ left) proves the transfluence of the glacial ice (LGM to Stadia II or even III) (inland ice level: Photo 60 and 61 ▬ ▬). N of the pass a late Late Glacial (Stadia III–IV) tongue basin lake is situated (Photo 61 □), which has reached higher level positions either by an impounding glacier tongue at the lower end of the lake and later by dead ice, damming up the run-off, or has come into being by the impounding end moraine (Photo 61 |), i.e., by a combination of all these blockages. Its level, lowered in the meantime, has left behind prehistoric cliffs and lake shore ramparts. These cliffs interrupt and reshape the glacial forms by small steep steps (Photo 61 ▼). Owing to the especially intensive frost weathering in the surf zone they have developed within a few years or decades. A very short, step-by-step depression of the lake level would point to an impounding glacier tongue from a side valley connected from W to E or from E to W in the area of the lower end of the lake (Photo 62 ↓). N of the lake, decimetre-thick covers of wind-blown sand are laid down on the surface of ground moraines, younger glaciofluvial gravel floors and lake bottom, which get hold through dwarf shrubs and in places have been accumulated to over metre-high knolls ('Kupsen' = small hills of wind-blown sand heightened by the dwarf shrubs).

The profile continued N of the lake further to the N as far as the 5600 m-high Transhimalaya main pass across the E Gangdise Shan (Figure 2, No. 40; 29°56′ N/84°39′ E), which begins at an altitude of ca. 5000 m and rises continuously up to this pass at a distance of ca. 30 km, is throughout marked by glacigenic forms. Apart from the round-polished mountains, which are evidence of a complete inland ice cover (Photo 62 ◤ and in the further background), a multitude of younger ground moraines and youngest end moraines overlies the basal High Glacial ground moraine sheet in this high valley area, the valley bottoms of which are situated only just 200 to 800 m below the present-day snow line. The end moraines show fresh rampart- and hill forms and, correspondingly, a locally more important thickness. Up to the late Late Glacial (i.e., Stadium IV) the ice completely covered this area as far as the summits. The even younger depositions of ground- and end moraines have been left behind by the Holocene glaciers above 5600–5700 m asl during the Neoglacial (Stadium V, Table 1). The ground moraine covers which, dependent upon the incline, have been heavily reshaped in many places by solifluction, could not be systematically-chronologically differentiated until now. Here, the periglacial morphodynamics profit by a precipitation estimated at least at 500–700 mm/yr, which only falls as (mostly wet) snow (cf. Photos 63–65) even in summer. Its humidity is held for a long time by dense monsoon clouds and the water-retaining ground moraine matrix (cf. Photo 67). A very broad glacial trough valley leads down to the WNW as far as a valley chamber set into metamorphic sedimentary rocks like a box, the ground moraine bottom of which is situated at 4780 (i.e., ca. 4950) m asl (Photo 63). Here, too, geomorphology and sedimentology unquestionably point to a last glacial inland ice cover (Photo 63, minimum level of the ice ▬ ▬). Figures 17 and 5 (diagram 29.08./1) confirm the glacigenic condition of the ground moraine matrix of the valley bottom (Photo 63 ■). Because part of the ground moraine surfaces merge into late- to neoglacial glacier-mouth-gravel-floor-terraces (Photo 63 ▼ ▼), a surficially glaciofluvial rinsing and washing of the ground moraine is obvious. Accordingly, diagram 29.08./1 (Figure 5) shows a dull (eolian)/lustrous (fluvial) 85%-peak in the surfaces of the quartz grains. This confirms a fluvial reshaping of glacially broken grains which, despite the reworking, still have somewhat rough surfaces, and thus are a reminder of an eolian reshaping. As is shown by the comment on Figure 5 (diagram 29.08./1), those 85% of the grains have been classified as being dull/eolian by microscopy in the laboratory, i.e., without field knowledge. Due to the geomorphological field analysis of the accumulation area where the sampling has taken place, which shows no eolian characteristics at all (cf. Photo 63 ■), here, at approx. 5000 m asl, an eolian reshaping of this fine material matrix has to be excluded. Thus, the dullness of the slightly rounded grains must be understood as being a glacigenic residual roughness of the glaciofluvially reworked material. Figure 18 shows that the Canadian ground moraine laid down by the Last Glacial (LGM) North American inland ice (Laurentide Ice Sheet) and the one taken at this locality (Figure 17) are evidently homogeneous.

The westerly adjacent area of a transfluence pass (Figure 64) shows the continuation of the unambiguous glacial character of the landscape of S Central Tibet. Geomorphologically similar landforms in a region of sedimentary bedrocks as here, occur in the High Glacial glaciation area of Mt. McKinley (Denali National Park, Alaska) and in many

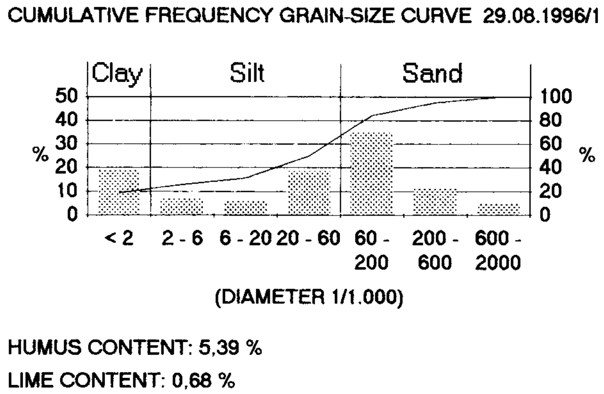



*Figure 17.* 4780 m asl (aneroid measurement), Central Tibet, ground moraine matrix taken from a depth of 0.1 m. Locality: Photo 63; Figure 2 between Nos. 41 and 42. The curve shows the bimodal course characteristic of moraines; the fine grain peak lies in the clay and attains nearly 20%. This is especially typical of ground moraine. As for the morphometry, cf. Figure 5 diagram 29.08.96/1: according to the sedimentary bedrocks, which here and in the more distant environs are more or less metamorphic, only a few quartz grains are incorporated, from which 15% are glacially crushed, i.e., freshly weathered. To confirm the obvious ground moraine character, the analysis of a ground moraine from a classic Canadian area (Figure 18) is put beside this diagram (Figure 17). (Sampling: M. Kuhle.)

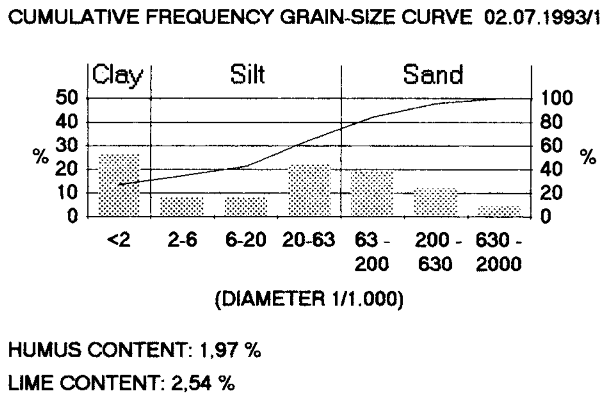



*Figure 18.* Sample for comparison: ground moraine matrix of the ground moraine plain between the Bow River and the South Saskatchewan River ca. 32 km NW of the Medicine Hat in Canada; Wisconsinian W Laurentide Ice Sheet. The sample was taken from a depth of 0.1 m. (Sampling: M. Kuhle.)

places in the foreland of the actual inland ice in W Greenland, e.g., on the Nugssuaq peninsula (Kuhle, 1983c). Especially the infillings of glaciofluvial gravel floors in the late Late Glacial and the Postglacial (Stadia IV–X; Table 1) after the down-melting of the inland ice and ice stream network belong to this character of landscape (Photo 64 |).

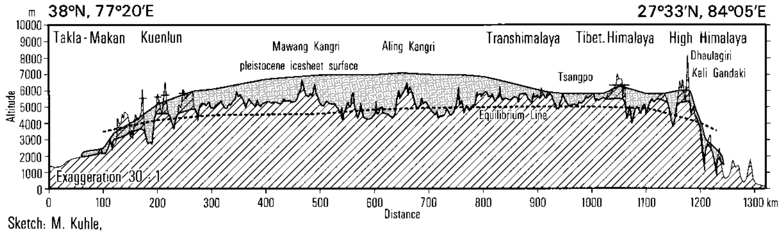
### *3.1. Summary of Section 3*

It should be stressed that, from locality No. 17 up to locality Nos. 40–41 (Figure 3), a great wealth of obvious indicators has been found on a continuous glaciogeomorphological profile and field datings (sample analyses) have been reported, which provide evidence of an relief-covering inland ice of the area concerned.

The series of indicators from S Tibet introduced as far as this locality (Nos. 41 and 42) and described with regard to the arrangement of their positions, will now be continued in their entirety on an immediately connected profile of field investigations further to the N into middle Central Tibet. The reason for this detailed manner of description is that the complete glaciogeomorphological and glaciosedimentological, immediately empirical evidence is the strongest confirmation of a prehistoric glaciation which can be provided at all.

## 4. Continuation of new observations on the prehistoric inland ice cover in middle Central Tibet (Figure 1, No. 20 below the 'i' of 'Tibet'; Figure 2 between Nos. 40–41 and No. 64; Figure 10 left of the Transhimalaya; Figure 12 in the area of I2 below 'Tangula Shan'; Figure 19, Transhimalaya and somewhat left from it)

N of the 4885 m-pass (Photo 64) the ground moraine plains continue with at most fist- to head-sized boulders (Photos 65 and 66 ■) on the high valley- and intramontane basin bottoms. It is mainly local moraine but no far-travelled moraine from areas with massif-crystalline bedrocks. In fact, the round-polished hills surrounding (☗), from which the glacier bottom has eroded and removed the material, consist of sedimentary rock, the stratification of which determines the maximum size of the stones and boulders. During the late Late Glacial, when the ELA was running over 5000 m, the overlying ground ice changed from cold to warm ice with an increasing and subglacially concentrating portion of meltwater. At the exits of the hanging valleys, this subglacial water flowing down under hydrostatic pressure, has eroded V-shaped profiles and small gorges into the rock thresholds and rounded steep steps, so that their fresh slopes are set off against the round polished forms above by pronounced working edges (Photo 65 ↑ ↑). Although nearly all mountains and rock ridges show clear traces of glacial rounding (Photo 66 ☗ black), the glacial genesis of which in contrast to periglacial convergence forms is proved by the lack of debris cover weathered *in situ*, perfect roches moutonnées are scarce. In Photo 66 (☗ white) such a roche moutonnée is shown in sedimentary bedrock (phyllites). Those key forms more frequently, i.e., more easily develop in granite bedrocks (Photo 68 ☗ ☗). The cause of this are the release joints of massif-crystalline boulders, performing smooth hill surfaces by the glacial ground scouring. The precipitation does not flow off the flat valley- and basin bottoms but forms slowly evaporating water faces (Photo 67, above ■ in the foreground). This provides two sets of geomorphological/sedimentological informations: (1) the relief is so flat, i.e., it even shows flat thresholds with slight counter-slopes, that over large parts no fluvial streamlet-system has so far been developed; (2) the cover of loose sediments has such a dense, clayey matrix that it is perfectly water-retaining. Both aspects are direct and indirect indicators of glaciers. Without a Pleistocene inland ice sheet, an extended fine-meshed streamlet-system would have been developed in the course of many 100 000 years. If a fluvial gravel cover of this accumulative bottom had existed alternatively to the ground moraine overlay, no water faces, persisting over several days up to months (in an extreme case even years) could have been developed because of the much larger pore volume of the matrix. For that the typical fine grain peak in the clay fraction is necessary. The local change in the composition of their material, characteristic of inland ice ground moraines, is obvious. In places where granite bedrock occurs or – more generally – coarse-crystalline bedrock, as, e.g., at locality No. 43 (Figure 2), the ground moraine contains relatively great portions of large granite boulders (Photo 68 ■). A few kilometres down-valley to the N only a small portion of granite components has been added (Figure 2, No. 44) and the coarse block fraction has completely receded. Here sedimentary bedrocks occur which are the cause of a local moraine with small coarse components (Photo 69 ■ white); but here, too, the ground moraine is polymict. All debris bodies forming rather huge slopes and cones of loose material, contain moraine cores. They are built up by glacial deposits, which have surficially been reworked and dislocated down the slopes as, e.g., kames, lateral- and ground moraines (Photo 69 ▽) (cf. investigations of Iturrizaga, 1998, Karakorum and Himalaya). In some places the ground moraine bottom of this flat, broad valleys from the N-slope of the Gangdise Shan (Transhimalaya) down into Central Tibet is marked by deflation pavements (Photo 70 ■). This is a surficial concentration of components the size of coarse pebbles up to gravels in the form of a pavement, covering the fine matrix. It has been developed on these surfaces over 4500 m asl, which are poor in vegetation, due to the drifting of the fine matrix since deglaciation. The lack of a weathering debris cover created *in situ*, i.e., its replacement by a ground moraine overlay on the hill slopes (Photo 70 ▼), has already several times been quoted as an inland ice indicator in this research report. The form of the valley bottoms, inclining flatly ramp-like in the valley cross profile (Photo 70 between ■ and ▼), which push with their upper edges against the lower edges of the mountain slopes (below ▼ ▼) is convincing in the same way. Apart from the ground moraine material already mentioned, of which they consist, this form can be explained by no other deposition-mechanism of loose material than that of an inland ice cover, which always has its most substantial local thickness in the middle of the valley. Because of that and because the velocity of the ice flow and the plasticity of the ground ice are also at the maximum there, the soft ground moraine has drifted towards the valley edges and has slightly, i.e., in the form of a flat ramp, been upthrust (Figure 20). Following our S/N profile a good two decakilometres to the N (30°53′ N/84°59′ E; Figure 2, Nos. 45 and 46), a further area with granite bedrock is reached, showing coarse-weathered boulders (Photo 71). Owing to the granite the Ice Age features of ground polishing, among them a classic roche moutonnée (☗ centre), are markedly more heavily roughened than in the regions with sedimentary rock, which is much more widespread in Tibet. Nevertheless, they are still clearly recognizable (☗ ☗). Late Glacial lateral- and ground moraine remnants preserved here (Photo 71 ■ white), are rare in these regions of Central Tibet, which show only little gradient. They mainly occur in the valleys and the immediate periphery of mountains, towering up to or above the present-day snow line.




Profile Takla Makan-Dhaulagiri

*Figure 19.* Cross profile across Tibet and the High Glacial Tibetan inland ice between Takla-Makan and Kuenlun in the N and High Himalaya with Dhaulagiri and Kali Gandaki in the S (cf. Figure 12).

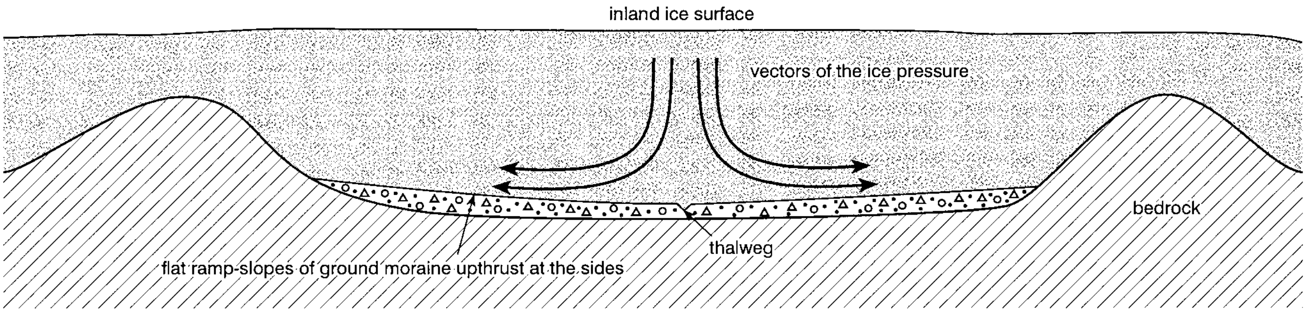



*Figure 20.* On the genesis of flat glacial ramp-slopes in High Glacial ground moraine.

From the locality mentioned down the same valley as far as its inflow into the decakilometre-extended basin with the Zhari Nanico, glaciofluvial terraces with three main-levels and two sub-levels are preserved (Photo 72). These are sander and gravel floor deposits accumulated after the down-melting and decay of the High Glacial inland ice on the lowest levels of the Tibetan plateau, as, e.g., at the settlement of Maindong (or Coqen). They developed between the complexes of ice remnants which – as is shown here – were still lying on the higher mountain groups in the Late Glacial. Their meltwater discharged gravels and sands from the valleys (Photo 72 |) into such intramontane basins. In contrast to the gravel floors the sanders are dependent on very flat discharge gradients. Thus, they have been developed here by the backflow of the water of a large ice-dammed lake existing in the 'Basin of Maindong' (or Coqen) in the Late Glacial. This happened during a post-High Glacial phase, when the Late Glacial glaciers still blocked the valleys which were possible as discharge outlets, whilst this large basin was already free of ice. The existence of this glaciolimnical lake, which was the forerunner of the modern Zhari Nanico (lake; Figure 2, No. 47), is proved by delta accumulations (Photo 72 △). Peripherally the sander areas have been overthrust by the edges of glaciers, advancing again in some places. Evidence of this is provided by a hanging ground moraine (Photo 72 ■) on the NNW margin of the basin (Figure 2, No. 49). The ground moraine cover continues to the N, NW and NE, i.e., it passes into an older, High Glacial (LGM = Stadium 0) ground moraine area (Photo 73 ■). At the place where hills and roughnesses of the field provide wind-shadow and create lee-whirls, the sand blown away from the near sander areas has been deposited as a sheet of drifted sand (Photo 73 ○). Because these wind-blown sand deposits here at over 5000 m asl belong to the highest on earth, their existence is also due to the glaciolimnical sediments around here and the favouring factor of the eolian transport in the near vicinity.

### *4.1. Insertion on the characteristic unchanged preservation of High Glacial subglacial forms of the Tibetan inland ice even after deglaciation*

To the south as well as on the 5050 m-high pass (Figure 2 between Nos. 50 and 51), it becomes exemplarily clear that the landscape in the geomorphological sense is extremely 'featureless' (Photos 73 and 74). This is an important characteristic of prehistoric cover glaciations noticeable over wide areas of the Tibetan High Glacial inland ice. Only rounded mountain ridges with a large-scale ground moraine cover merely decimetres in thickness (☗ ■) could be observed. This widespread observation is essential insofar as it points to a nearly complete lack of an inner moraine of the inland ice. The occurrence of upper moraine above the ELA has to be ruled out anyway, because the debris which falls down onto the inland ice from the summits (nunatakr) which pierce the ice surface, is immediately covered with snow and thus incorporated into the ice body (as inner moraine). In a similar way, as the occurrence of upper moraine is dependent on a steep relief, from which the debris falls down on to the ice and is thus reduced to mountain glaciers, inner moraine occurs only in places where flank polishing exists, i.e., in the steep mountain relief. After deglaciaton the exclusive ground scouring which took place in these high plateau landscapes of Tibet, can be recognized by ground moraine preserved without a covering layer of ablation moraine. Because this ought to have been accumulated by supraglacial and intraglacial meltwaters, the process of thawing-down here concentrated no inner moraine at all. Subglacial accumulations by meltwater like eskers or kames such as have been observed in a central valley bottom position in the

Kyetrak Chu (valley) N of the Himalaya (Figure 3, No. 39, Photo 32) have been found by the author in Tibet only below 4600 m asl (Kuhle, 1991d, e.g., p. 141; pp. 161–162, Photo 40; pp. 229–230, Figure 43, Nos. 8, 16, 25), mostly on valley bottoms or even near the thalweg, where the meltwater could concentrate. Up to the complete deglaciation, which due to a cold and at the same time subtropically arid Late Glacial climate mainly took place by sublimation, here, at a height of over 5000 m, the ice bottom of the glacier, i.e., its ground ice was obviously so cold that the small amount of subglacial meltwater was unable to bring about displacements of ground moraine, other fluvial accumulations, or denudation forms on the convex (Photo 72) to large-scale flat land surface (Photo 73). In subtropical latitudes at 4600–5000 m the proportional increase of the evaporation ablation at the expense of the melting ablation at a rising altitude above sea level has probably caused the qualitative geomorphological leap in the remains of the Tibetan inland ice described. Obviously the process of deglaciation is geomorphologically so defensive up here, that the High Glacial subglacial features have been preserved nearly complete and unchanged (as is shown in Photo 74).

### *4.2. Continuation of Section 4 with regional observations*

Beyond, NW of the 5050 m-pass (Figure 2 between Nos. 50 and 51), the forming of which presents all the important characteristics of a transfluence pass covered completely by a very thick inland ice down to the last details (cf. Photo 74), a further large basin continues, part of which has up to now contained a residual lake (Photos 75 and 76). Its bottom lies at ca. 4500 m asl and is overlain by High Glacial ground moraine with far-travelled granite erratics and local boulders of sedimentary rock and phyllites (Photo 75 ○ ○). Here, too, the Late Glacial ablation landscape of the High Glacial inland ice has left behind a wealth of traces of high ice- and moraine-dammed lake positions in the form of water lines with lake shore ramparts or cliff formations (Figure 2, No. 54) incorporated into Late Glacial lateral moraines and kames (Photo 76 →). To the key forms of such late-Late Glacial glaciolimnic features belongs a classic spill-way developed within a very short time, the totally new break-through of which has been made up by the glacier ice, barring the normal water discharge of a valley during the Late Glacial (Photo 76 ▽). Accordingly, all these large basins in High Tibet – that means in the upland area covered by the inland ice during the High Glacial (LGM) – in part with but little or no discharge at all today, are regions of a great short-term geomorphological reshaping. This rapid change of the forms of a High- to Late-Glacial glacial landscape to a late Late Glacial lake landscape, the levels of which firstly dropped sharply and afterwards steadily, presents a local- and relief-specific contrast to the primary glacial landscapes treated in Section 4.1, which have been created under the inland ice and left behind unchanged. Whilst those areas are situated higher and are more convex, so that they favour neither the ice- nor the water concentration, these lowest basins have the opposite effect. They are the true areas of the disintegration of the inland ice into large dead ice complexes and the rapid change to a glaciofluvial to glaciolimnic reshaping of the field. Beyond the northern fringing heights of this basin an unchanged glacigenically-shaped upland of hills and mountain ridges, with intermediate flat high valleys, again follows (Figure 2 between Nos. 51 and 55; 31°25′–31′ N/85°10′–15′ E). Its bedrock surface has been rounded by the inland ice ground scouring and covered with an at most few metres-thick ground moraine (Photos 77–79: ☗ ■). Only on the valley bottom areas do traces of reshaping fluvial dynamics occur (Photo 78 □). This results from the melt- and precipitation water, which only there flows together at a quantity sufficient for the development of forms. It mainly concerns the interval between the late Late Glacial (Stadium IV) with lateral erosion of the branches of the glacier meltwater on the lower slopes (Photo 78 ▼) and the Neoglacial (Stadia V–′VII), with the build-up of youngest gravel floors (gravel field, sander) (Photo 78 □ −0 to −2). Today only a fluvial (not glaciofluvial) reshaping of the gravel fields of the valley bottom (i.e., of the ground moraine which in many places is merely outwashed) takes place by the meandering mountain river (Photo 78).

### *4.3. Similarity of the glacial landscape with that of Central Spitzbergen*

There is an enormous similarity between this glacial landscape influenced in its overall character by the sedimentary bedrocks on the one hand, and the glacial landscape of Central Spitzbergen (e.g., Dicksonland), which has also been created by a thick inland ice sheet, on the other. In Spitzbergen the outcropping edges of the stratum – which are similar with concern to their rock structures –, modify the forms of ground polishing even more heavily than here (e.g., Photo 79 ||). With the similarity preserved, the modern climatic contrast of subtropical continentality to arctic oceanity under the influence of the Gulf Stream seems to be unimportant, in particular as the precipitation of Dicksonland of only 250 mm/yr is even less than that of this Tibetan area. During the High Glacial the conditions were similar, namely semi-arid-cold with cold-based ice on the glacier bottom, which in many places was frozen to the rock and thus has not polished the bedrock but broken away rock fragments, removing them from the rock formation.

### *4.4. Continuation of the section with regional observations and the indication of a large-scale covering spread of thin ground moraine overlay which is glacial-specific*

First, the continuing ca. 65–70 km of the geomorphological profile further to the N, i.e., into Central Tibet, are to be described (Photos 80–83; Figure 2, Nos. 55–59). It is a glacial landscape of polish thresholds (☗) and - basins with a complete ground moraine cover – on the conditions of a flat incline of the relief (■). This nearly total covering seems to form a contrast to the thin overlay of loose material, which for the most part only amounts to decimetres (cf. Photo 80). But just the minor thickness over a wide area is a typical key-characteristic of the ground moraine left behind by an inland ice. Almost independent of the relief differences of the undulating terrain, the inland ice very evenly spreads out over large parts a mixture of predominantly local moraine, to which is added a minor proportion of moraine from far away (cf. Photos 82 and 83 ■ fore- to middleground). In contrast, a large-scale fluvial accumulation and overlay of the bedrock in the underground with loose rock is connected with very great differences in thickness. Fluvial accumulations experience a substantial loss in thickness from their roots (usually valley exits) down into a mountain foreland. By the filling of valleys and depressions in mountain forelands,which also imply small-scale differences in thickness dependent on the relief, they bring about a perfectly level horizontal surface (cf. in contrast the undulating surface with ground moraine cover (■) in Photo 80). On the other hand, pre-Pleistocene fluvial gravel- to pelite bottoms – which means at the same time that they were filled into basins before the entire Quaternary Ice Age era –, are also possible on the Tibetan high plateau. Since the uplift of Tibet above the snow line, and in the course of repeated inland glaciations during the Pleistocene High Glacials (cf. Kuhle, 1993, 1995), they would have been covered – in the same way as bedrock – by ground moraine, which has been slightly reworked and probably only slightly drifted during the Last Glacial (LGM, Würm, Wisconsin). Such conditions of development could be the cause of the nearly horizontal ground moraine areas N of the 6815 m-massif (Photos 82 and 83 ■).

On the E slope of the 6815 m-massif (Photo 81) the younger glacial history in this area from the inland ice of the last maximum glaciation with a minimum ice thickness of 1200 m (— — 0 — —) as far as to the historic glacier positions (■ III to ■ X) and the present-day glaciation (▼) becomes understandable. First, the destruction of the High Glacial rounding of the area by the small-scale denuding modern glacier tongues and their influence by lateral erosion can clearly be recognized (Photo 81 between ▽ and on the right above ☗ white and black). Secondly, the great glaciogeomorphological discrepancy is shown between the end moraines (■ X) visible immediately in the forefields of present-day glaciers as direct indicators of the prehistoric glacier extension and the inland ice cover with pertinent end moraines and indicators of ice margin positions at a distance of hundreds of kilometres, which can be evidenced more indirectly by ground moraines (■ 0) and roundings (☗ ☗). This discrepancy, impeding the approach of the forms, is a reason for the misinterpretation over decades of the maximum prehistoric glacier cover of Tibet. This has existed from v. Wissmann's (1959) compilation up to the recently published Quaternary Glacial Distribution Map of the Qinghai-Xizang (Tibet) Plateau (1991) of the Chinese research group in the charge of Shi Yafeng et al. (eds.), which represents the predominant scientific opinion. The entire region, as far as it is located below the ELA and outside the areas covered by present-day glaciers (as, e.g., in Photo 81), lies within the periglacial altitude and for the most part even above the permafrost line (cf. Kuhle, 1985), so that it might have been strongly reshaped by solifluction. However, there is no deformation of the sprouts of the dwarf scrub typical of solifluction and thus no indication of travelling material worth mentioning (Figure 2, Nos. 40–66; Photos 64–84). The sprouts grow nearly vertically into the moraine cover and so have not been deformed by solifluidally-removed debris. An additional reason for this are the relatively minor slope gradients. The important accumulation of coarser components the size of pebbles on the ground moraine surface (Photos 84–86 ■) is the result of surface rinsing by rainwater, of deflation and of periglacial development of rock pavement through rather large debris particles of fine matrix which freeze onto it.

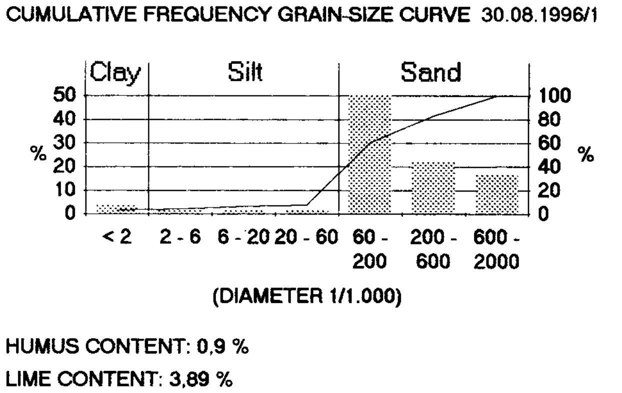



*Figure 21.* Ground moraine matrix from Central Tibet (see Photo 85 near the right margin, background); sampling at 4280 m (aneroid measurement at high pressure; actual height about 4500 m asl); Figure 2, No. 59; 31°56′ N/85°04′ E; taken from a depth of 0.2 m. Despite the rather insignificant peak in the clay of ca. 4%, the typical bimodal course of the curve is evident. The coarser fine grain peak of 50% in the fine sand is very pronounced. It points to a relative coarse crystal structure of the bedrock from which this material has been abraded. For the morphometry of the quartz grains, cf. Figure 5 diagram 30.08./1. (Sampling: M. Kuhle.)

The condition of the ground moraine matrix can be drawn from the laboratory analyses in Figures 21 and 5 (diagram 30.08./1). Its comparatively coarse composition can be explained by the reddish coarse-grained sandstone bedrocks in the surrounding area (Photos 84 and 86). A further indication of the fact that large parts of the ground moraine here (Figure 2, Nos. 59 and 60) consist of local moraine which has not travelled far, is seen in the pebbly condition of the coarsest stones contained already mentioned. Actually, the pebble fraction is typical of all those Tibetan regions in which sedimentary bedrocks exist and the fact is that sedimentary bedrocks are everywhere in the region concerned (Figure 2, Nos. 59 and 60). The morphometric analysis yielded 53% of glacially crushed matrix grains (= quartz grains); 20.7% of dull/eolian show the aeolian reshaping of the ground moraine obvious by the deflation pavement; 26.3% of fluvially polished (lustrous) point to the effect of the surficial out-washing (Photo 85 ■).

At the point where the investigated profile leaves the N direction into Central Tibet changing towards the WNW into Central W-Tibet, a further representative ground moraine landscape will be decribed (Figure 2, Nos. 60, 61; 31°56′–32°12′ N/84°58′–84°35′ E; 4275–4365 m asl aneroid measurement). On a W/E valley axis of a 35–40 km broad excavation area in between W/E trending hill chains, which are softly-formed but non-glaciated today (Photos 85–87), the impermeability to water of the ground moraine cover

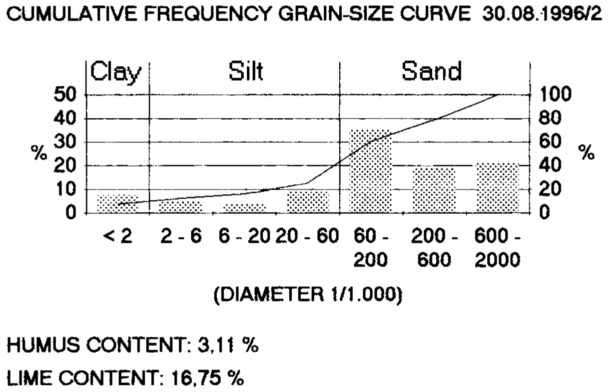



*Figure 22.* Ground moraine matrix at 4365 m asl (aneroid measurement) in Central Tibet, taken from a depth of 0.15 m. The material covers an area built-up from more or less metamorphic sedimentary bedrocks. Locality: Figure 2, No. 61. The bimodal course of the cumulative curve with the two characteristic fine grain peaks is obvious; however, the clay peak attains only 8%. For the morphometry of the quartz grains, cf. Figure 5, diagram 30.08./2. (Sampling: M. Kuhle.)

has caused the development of a lake system (Photos 85 and 85a □). Kilometres- to decakilometres-long lakes as the Tung Hu (Figure 2, No. 61) E of the settlement Lumaringbo (Gertse or Kaitse in the ONC-map) belong to it. Figure 22 (Figure 2, No. 61) shows the condition of the moraine. The second culmination of its cumulative curve, the coarse grain peak (34%), is symptomatically situated within the fine sand fraction. This is a result of the grain size of the sandstone bedrocks in the surrounding area (e.g., Photo 84). However, the glacially trituration of the material can be evidenced morphometrically. Figure 5 (diagram 30.08./2) indicates 69.6% of the grains as being glacially crushed. The possible development of these angular forms of grain surfaces by fresh weathering immediately from the bedrock – which cannot be excluded microscopically – is disproved by the fact that the sampling took place at a distance of over 12 km from the bedrock (Photo 88). Those extended lakes the water of which is retained by the ground moraine, are shallow, without outlet and salty. Their salt concentration can be clearly recognized by the broad whitish-encrusted shore line (Photo 85 ▼). The seasonal fluctuations of their levels controlled by snow melting and evaporation are the cause of important pulsations of the lake faces. Correspondingly, the down-melting process of the inland ice can be imagined as cold-arid and mainly influenced by evaporation, i.e., as extremely poor in meltwater. In this semi-arid fashion the glacial erosion- and accumulation landscape, marked by a High- to Late-Glacial covering glaciation – only little modified by meltwater activities during the process of down-melting – has been preserved in a state which is nearly not reshaped (Photos 86–88). Only a small-scale reshaping in detail is to be observed on the W/E trending mountain chains running along this excavation area. However, this did not happen during the down-melting of the inland ice, but was controlled by the late Late Glacial (Stadium IV, Table 1) self-glaciation of the highest elevations, which at a snow line depression of only 700 m as against today, at least rose insignificantly above the snow line. Actually, small glaciers have settled in the valley source depressions (Photos 86a, b, 87a ○) the meltwater of which, flowing down steeply and continuously, has created more distinct thalwegs and V-shaped features as they had existed under the inland ice during the LGM. The more obviously fluvial reworking takes place in the area of glacial accumulations. The reason for this is that loose material, moraines etc., can be reshaped more easily. Apart from that, the forms of cone sanders (Photo 88 ▽), i.e., glaciofluvial removals of moraine material, eroded in the side valleys and again laid down on the main valley bottom in a fan form, must be considered to be a process intervening between highglacially-glacigenic and postglacially-fluvial shaping. There are no river terraces in the wide W/E-trending excavation area, being the most extended regional thalweg. Only cone sanders can be observed, distally undercut by the lateral erosion of the river and thus forming several metre-high steep steps (Photo 88 ▼). In many places the late Late Glacial (Stadium IV) glaciofluvial to recently fluvial reshaping also occurs in the area of older ground moraines (Photo 89). On the one hand, cone sanders (▽) are adjusted to the ground moraine (■ black), i.e., laid down upon it; on the other hand, the late Late Glacial glacier meltwater thread has cut into the older (Stadia 0-II or III; see Table 1) ground moraine (■) and thus traced the present-day water course (□). Dependent in the same way on the glacigenic relief development is the sedimentation of pelites which takes place in the valley bottom area. They have been washed down from the ground moraine surfaces in the Holocene (i.e., more generally: interglacially) (Photo 91). A process which continues today. The next step prepared glacially-genetically is the accompanying deflation of these stillwater sediments, sorted by the water and concentrated in advance near the thalweg (Photo 91 □). A last step is the drift and loess sedimentation observed in many places in Tibet (Péwe et al., 1995). Over wide expanses, however, the primarily glacigenic character of the landform is dominant (Photo 90). This is not only true of the glacigenic large-scale erosion forms and roundings (☗) which can be observed nearly everywhere, but is also recognizable in the extended, slightly undulating ground moarine surfaces (■ ■). There are further systematic intermediate steps. One of that sort is shown in Photo 92: no late Late Glacial glacier meltwater has cut into the ground moraine landscape here, but the postglacial up to present-day precipitation – and running down so far – followed the primary depressions in the moraine surface, thus creating a temporary net of streamlets very flatly inset (□). Also the mudflow discharges which can neither be derived from a very steep relief nor from substantial quantities of precipitation on the Tibetan plateau (Photo 93 □), require the Ice Age ground moraine as far as their material is concerned. According to these unfavourable conditions of relief and climate, the edaphic prerequisites for humid mass movements are exclusively met by the clayey moraine matrix.

What can be noticed regularly in the extreme mountains surrounding the Tibetan upland and which has enabled the author in the course of his investigations to differentiate the High- from the Late Glacial (Stadium 0 from Stadium I–IV) and then also to provide evidence of the Late Glacial as being subdivided into those four stadia (Kuhle, 1980, 1982, 1983, 1986e, 1987c; Heuberger, 1986; Ono, 1986; Shiraiwa and Watanabe, 1991; Shiraiwa, 1993), applies to Tibet only at a few places. Photo 93 shows such a locality. The High Glacial inland ice cover of the entire relief of the hills and mountain ridges (▬ ▬ 0) is proved (in a more large-scale spatial connection as it is shown in Photo 93) by the glacial arrangement of the positions (see Photos 88–92, etc.). On the N-slopes of the hills concerned (Photo 93), end moraines in the form of lateral- and front moraines (■ white) are preserved over a distance of several kilometres (Figure 2, No. 66). The example represented in Photo 93 makes clear that the moraine ramps have not been pushed by a small hanging glacier down the slope, but have been thrust against the slope from below to above (■ white). This points unambiguously to a new glacier advance at a time, when the connected inland ice had to a great extent already melted down and turned into several ice complexes separated by these mountain ridges. This advance must have taken place in the Late Glacial, i.e., at the earliest during Stadium I or alternatively during Stadium II. A later stadium is out of question, because it must have concerned the margin of a still very large ice shield, taking up the whole decakilometre-wide Central Tibetan excavation- or basin- i.e., high plateau area of over hundred kilometres in length. Such an ice shield was only possible at a snow line depression of at least 1000 m below the present-day snow line and thus no longer during Stadium III (cf. Table 1). Essential is the fact that the moraines are evidence of a new advance, because at one time such an ice mass must have consisted anyway in the course of a slowly down-melting inland ice. Owing to a chronological displacement characteristic of extended ices, this was still quite possible at a time when the snow line was already running at a much higher level. This ice mass, however, at an advance requiring a positive mass balance, is dependent on a minimum depression of the ELA.

### *4.5. Summary of Section 4*

Continuing the area treated in Section 3, 330 km further to the N and NW, i.e., into Central Tibet up to 32°15′ N, glacial forms of a large-scale ice cover have consistently been mapped (Figure 2, Nos. 40, 41–66). This concerns the classic denudation- and accumulation features. Roches moutonnées and the much larger hills rising several hundred metres, which are glacially round-polished and partly streamlined, occur all over the place. They are preserved in the crystalline unstratified bedrocks as well as in the varyingly metamorphic bedded rocks occurring the most in similar fresh forms as in the Scandinavian and Scottish inland ice areas of Europe. Ground moraine covers exist almost throughout in the basins and high valleys. Up the mountain slopes they regularly get thinner. However, roches moutonnées, mountain ridges and transfluence passes are also partly overlain by ground moraine as far as the culminations. As a result of the degradation of the predominant sedimentary bedrock, most of the ground moraine is relatively fine-grained. In some places coarse-crystalline erratic boulders are incorporated; these are the localities with a more coarse-grained ground moraine (cf. Figure 2). On the over 5600–5800 m high mountains the late Late Glacial to postglacial reshaping of the landscape, marked by the High Glacial inland ice cover, took place through the settling of a late Late Glacial to Holocene local hanging-, i.e., mountain glaciation. It has sharpened the formerly rounded summits and crests and also eroded the slopes, where afterwards ravines have been cut into the ground moraine now free of ice. Areas of the basin- and high valley landforms of the true Tibetan high plateau level are covered with glaciolimnic sediments of Late Glacial ice dammed lakes and tongue basin lakes, so far not silted up. The High Glacial ground moraines still existing in the underlying bed have been undercut and washed-off along the prehistoric and modern shore lines of these lakes. At places near the main thalwegs, where running water was effective, the ground moraines are superficially out-washed and covered by decimetre- to metre-thick gravel bottoms. Out of the side- and high valleys occupied by valley glaciers still in the Late Glacial, flat cone sanders of glaciofluvially dislocated moraine material have been accumulated on the Ice Age ground moraine sheet of the main valley floor in some places. The main valley river has marginally undercut these gravel floor fans by lateral erosion, so that steps up to several metres in height have been developed in their loose rocks. As a whole the postglacial reshaping is minimal, i.e., a High Glacial glacial landscape remained, which during the time available since deglaciation has only been little changed by the present-day fluvial morphodynamics and its completely different formative style.

## 5. The Quaternary-geological and geomorphological datings on the continuing profile across Central Tibet from Lumaringbo (Gertse or Kaitse) towards the W as far as Shiquanha (Ali) (Figure 2, Nos. 67–105)

### *5.1. The pre-Pleistocene fluvial loose sediments of Central Tibet, developed during the former minor altitudes of the plateau, were covered by the ground moraines of the Pleistocene inland ices*

Looking across the extended high plateau landscape of Central Tibet 35–50 km W of Lumaringbo (Figure 2, Nos. 67 and 68), the division of this glacial landscape into two parts becomes particularly obvious. On the one hand there are the polished mountain ridges (☗ ☗) partly with an only thin (a few decimetre) ground moraine veil and on the other hand there are the basal faces with a thicker overlay of loose rocks (■). The out-jutting mountain ridges provide the glacially-erosive denudation areas, whilst the faces – according to their flow-dynamic shadow position – develop the accompanying accumulation areas. Because the history of the debris accumulations of Tibet is inevitably older than its glacial history, which only sets in with the uplift of Tibet above the snow line and the resulting inland glaciation in the early Pleistocene (Kuhle, 1993c, 1995, 1998), in this region as well as in the whole of Tibet the purely fluvial sediments previously built up at lower altitudes in the valleys and basins have been raised up to the future glaciation level. Consequently, on the present-day high valley floors and high basin bottoms with towering mountain ridges, i.e., on these basal high plateaus (Photos 94 and 95 ■ ■), fluvial debris accumulations are probable, which then in the Pleistocene have been covered by the ground moraines (■) of the particular High Glacial inland ices. With the help of these landscape-historical insight becomes understandable, why the large basal accumulation areas with their surficial ground moraine sheet (■) are in many places set off against the steep mountain slopes (Figure 23) with a concised, i.e., relatively sharp foot bend (Photos 94 and 95 ↓↓). To put it another way: looking down the slopes it becomes clear why the steep mountain slopes – the consistent ground moraine overlay has an only little intervening effect – pass with an obviously sharp-concave transition bend (↓) into a flat (1–3°) moraine foot slope (Figure 23). The reason is, that this foot slope contains pre-glacial (i.e., also pre-Pleistocene) alluvial fans in the underlying bed of the ground moraine. Thus, the accumulation form with a ground moraine cover observed in some places (Photo 95 ■ ■ ■ centre), which is a reminder of a large alluvial debris fan deposited through a valley, finds its explanation: actually, an alluvial fan exists in the underlying bed, the form of which still shines slightly through the polyglacial ground moraine sheet (developed during several ice ages). Thus, the inland ices, according to the author's interpretation (Kuhle, 1993c, 1995, 1998) newly built up during each new Ice Age of the Pleistocene, were unable to remove the pre-Pleistocene sediments. These have been overthrust several times and surficially covered with ground moraine. At the same time portions of their immediate surface layers have been pushed away by the ground scouring of the ice and dislocated, i.e., glacially redeposited, and thus incorporated into the ground moraine. This process corresponds very well with the viscous to brittle, or even jerky ground ice movements of a cold-based inland ice.

### *5.2. Continuation of the representation of field datings on the profile across Central Tibet to the W*

A conspicuous feature is represented by a roche moutonnée, classic in its outlines, near the pasture settlement of Yueko (Figure 2, No. 69; Photo 96). However, on its surface it has been roughened and resolved to such an extent, that the observer firstly tends to classify it as belonging to the penultimate Ice Age (Stadium −I = Riß Glacial). But an exact analysis (Phototext 96) makes clear that its form has already been roughened under the ice. It is a forming that goes back to the structure of the bedrock. For methodical reasons it has not been taken into consideration that the manifold indicators in the surrounding area point to a Last Glacial (LGM) complete ice cover anyway.

In a particular clear way the area W of Yueko (Figure 2, No. 70) shows a characteristic of glacial landscapes, which can almost be referred to as typical; namely, the occurrence of glacial key forms brought into association with indifferent forms or even forms which could be interpreted in a genetically different way. Here, mountain ridges perfectly rounded to the form of 'glacially streamlined hills' by an absolutely certain glacier ground-scouring (Photo 97 between ☗ and ☗) are adjacent to sharply-crested mountain chains (visible in Photo 97 directly behind the round ridges), which – as must be concluded from the arrangement of the positions of the entire forms – have also been completely overflowed by the inland ice. Further W one of the rare places was found where Late Glacial gravels of the glacier advance are exposed, overthrust by the ice (Photo 98). They have been compressed by the ice load (□) and are covered by ground moraine. Another place of this kind is situated W of the settlement of Coqen (Photo 72). In this context it is remarkable, that the lowest high plateau plains which the ice had already left during the Late Glacial (Stadium IV), have again been covered by a large-scale re-building inland ice, or at least a local ice cap. This took place here as well as at the location already mentioned, though the two high plateau areas are situated at a great distance and are separated from every other high mountain group. In the area of the yak pastures of Alt Oma following to the W (Photo 99), which extend over ground moraine with large boulders (■), a postglacially periglacial reshaping can be observed. Here, at about 4500 m asl, we are already at the actual altitude of permafrost. Thus, on the humid shore of Ningchu Tso (-lake; □) earth hummocks are lifted by freezing and a sorting of the material has taken place in the flooded moraine plain. The first signs of periglacial patterned grounds occur. This actual form association corresponds to that one of subarctic landscapes covered by an inland ice in the High Glacial. In view of the extended flatly-polished transfluence passes in the surrounding area (Photo 99 ∪), the slopes of which are overlain by ground moraine, there are indications of a Late Glacial direction of the ice run-off from approximately E to W. Evidence is given by a ground moraine train (■ small, background on the right) on the E-exposed leeward slope of the mountain spur between the two central transfluence passes in Photo 99 (∪ ∪). It has been sedimentated in the flow shadow of the spur – a process which is not possible in the luff, i.e., in the direction of the scour-side of the ice.

Photos 100 and 101 provide glaciogeomorphological details of the transfluence passes mentioned and the glacial landscape which here in Central-Tibet is not too mountainous but more evenly-extended. The continuation to the W (Photos 102 and 103), marked by polished and rounded hill chains (☗ ☗) with flat polish thresholds (∪) and ground moraine covers, has been investigated sedimentologically by spot checks. Figure 24 demonstrates the condition of ground moraine in a very flat bowl-like polish depression lying between those polish thresholds. Its important portion of fine grains (over 40% clay) points to the trituration by a very thick inland ice overlay. This is a moraine condition, which can generally be observed as well at ground moraines of the Laurentide Ice Sheet (cf. Figure 25). Figure 5 (diagram 31.08./1) shows the greatest portion of glacially crushed quartz grains of all moraine samples analysed, i.e., 90% – a further indication of the heavy trituration by a thick inland ice cover. The possibility of a convergent fragmentation by frost weathering is out of the question because the location

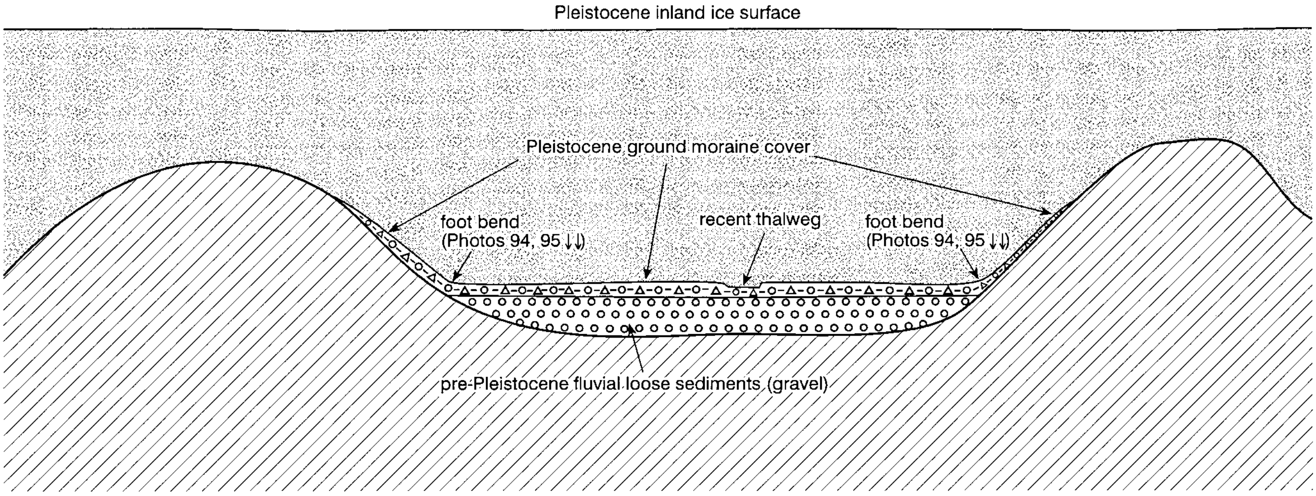



*Figure 23.* (cf. Photos 94 and 95). Ground moraine cover over pre-glacial (pre-Pleistocene) purely fluvial gravel bodies.

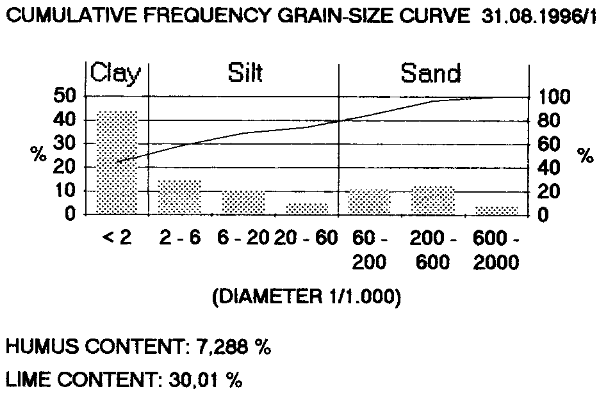



*Figure 24.* Ground moraine matrix at ca. 4450 m (aneroid measurement at high pressure: 4270 m asl) in Central Tibet, taken from a depth of 0.15 m. There are limestone- and phyllite bedrocks in the immediate catchment area, so that the important content of limestone points to 30% local moraine in this ground moraine. Locality: Figure 2, No. 75; 32°31′ N/82°30′ E (see Photo 103). For the morphometry of the matrix, cf. Figure 5, diagram 31.08./1. The conspicuous fine grain peak of 43% in the clay exceeds all the other fractions of the matrix. To make the glacigenic character of the matrix still more evident, a ground moraine sample from Canada is introduced in Figure 25. Here, the clay dominates the pelite-portions as well, although the limestone content is ca. 1/5 of that of the sample from Central Tibet. Thus, the high content of clay is to be understood as a direct indication of a heavier trituration by a thick inland ice sheet. (Sampling: M. Kuhle.)

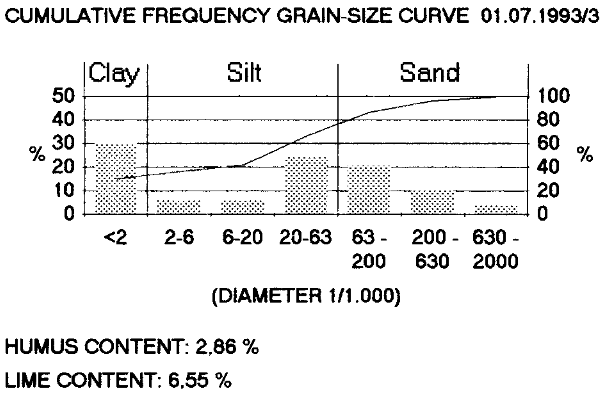



*Figure 25.* Sample for comparison: matrix of Last Glacial (LGM) ground moraine of the Laurentide Ice Sheet in W Canada, 4 km W of the settlement of Swift Current, 40 km S of the South Saskatchewan River (cf. Figure 24). (Sampling: M. Kuhle.)

of the sampling (Photo 103, foreground) is far away from bedrocks. This Central Tibetan landscape introduced in detail by Photos 99–103 bears all the glaciogeomorphological characteristics of a very extended high plateau, formed by a cold-based inland ice. Owing to the insignificant central incline and the steep edge – lying 300–800 km away from the centre – with its increased ice run-off in the form of fast outlet glaciers, the vast surface area of the Tibetan plateau of over 2.4 million $km^2$ was in part the cause of the only slight movement of the local central inland ice and the resulting tendency to freeze to the bottom. Thus, the ground-scouring might have been only insignificantly heavier at those places where the ice was never, or not permamently, frozen to the ground. Due to an increasing friction-dependent fixing, caused by the border of hill- and mountain thresholds, the ice complexes frozen to the plateau surface occurred in the depressions and basins, i.e., at the locations where the present-day postglacial lakes and temporary water faces are situated (Photo 99 on the right above □; 103 ■ black). So, the frozen ground ice complexes covering the lower areas have protected them from the ground-scouring of the inland ice. The fringing of the hollow forms by mountains hold the ice like a tooth-filling up to relative heights of about 100–600 m. Accordingly, it has only been sheared-off above and overflowed by the layers of the inland ice near to the surface. This has brought about a centre-periphery run-off without including the much older layers of the ground ice in the moving, and thereby lacks a geomorphologically-effective ground scouring. Indications for such a vertical separation of the moving ice, polishing the higher mountain cupolas of the upper inland ice level and the frozen ground ice, filling the relief, can be found on the rough, i.e., small-scaled slopes and hill complexes below (Photo 101 between ▲ right and – – right; 103 above ■ ■ in the background) in contrast to the towering rounded mountain cupolas above (which without ice polishing ought to be sharpened the most) (Photo 101 ▲ left; 103 ▲ right). In the area continuing to the W is situated the basin of Tuerhko Hu stretching W–E and occupied by relict lakes. Its bottom lies about 4400 m (Figure 2, Nos. 75 and 76; Photos 104–106). Its Tertiary excavation area is covered by Pleistocene ground moraine (■), which on the surface is late High Glacial (LGM = Stadium 0). Limnic rhythmites lie on top (□), a great portion of which has been washed out of the ground moraine matrix. The present-day lakes are without run-off and saline. There are crystallized evaporites (□) on their edges, classifying the postglacial to holocene climate development as being semiarid. A further geomorphological indicator of the cold-semi-arid upland climate with a precipitation of less than 200 mm/yr, occurs in the small-scale faces of wind-blown sand on several slopes (Photo 105 △) of the fringing hills. The lake phase observed can be traced back until the Late Glacial when, during Stadium IV, a 60 m-deep and probably connected lake partly covered the Tuerhko Hu area. In all probability it has been dammed-up by flat outlet glacier tongues of the already down-melted glaciation of the ice caps, which in many places was full of holes. Though the High Glacial (LGM) ground-scouring and ground pressure of the inland ice by shifting and nipping-out of the loose pre-Pleistocene rocks (cf. above and Figure 23) and Pleistocene ground moraine covers has led to the slight over-deepening of the basin currently damming up the relict lakes, the 60 m-deep lake would have run out without the relief-damming Late Glacial glacier tongues. Altogether four lake levels are preserved by shore platforms, shore lines and cliffs with wave-cut notches, the highest of which runs at a relative height of 60 m (Photos 104 and 105 ↑↑). At the place, where the southern shore lines of that Late Glacial lake stretched, S of the settlement of Yan Hu situated on the present-day relict lake Tsa Tso (Photo 106 △), a change of the condition of the subjacent ground moraine is to be observed. Whilst in the area of the prehistoric lake face further E – introduced so far – the coarsest ground moraine components are at most fist-sized (Figure 2 on the left below No. 75; Photo 106 ■ foreground), the large components 'swimming' in the fine material matrix here, attain the size of boulders (Figure 2, No. 77; Photo 107 ▽). The locality of this change of material is situated at (☗ on the very left and left ■ white, background) in Photo 106. Here, a trough valley from the S (Photos 108 and 109) joins the large W–E-stretching excavation area of Tuerhko Hu, a glacier tributary stream of which has added the large erratic granite boulders to the ground moraine. Their source area lies only 4 km away. There, the same light granite bedrock already occurs (Photo 108 /). At the exit of the trough valley there are no end moraine hills. The ground moraine cover stretches on a consistent level from this tributary valley into the excavation area of Tuerhko and mantles the base (■ white) of the roches moutonnées (Photo 107 ☗). Further out in the foreland of this tributary valley, a granite-containing ground moraine fan, contrasting with its environs through its lighter colour, marks the reach of the transport achieved by this tributary glacier component (Photo 106 ■ white in the background). These field datings and the arrangement of their positions do not permit one to realize that the inland ice (Photos 106 and 107: 0 — —) had already melted down when the tributary glacier flowed into the Tuerhko excavation area. On the contrary, the continuous ground moraine plain without hills evidences its High Glacial (LGM) age. That means that the Late Glacial ground moraine overlay – deposited on the High Glacial ground moraine by a local valley glacier coming from that granite trough valley at a time when the Tuerhko Hu excavation area was already free of ice – is lacking. Positively formulated: already during the High Glacial (LGM) the granite-bearing local moraine has been deposited by a southern ice flow vector of the inland ice which followed the incline of the tributary valley (Photo 109 ←). Once again sedimentary bedrocks occur in the upper area of the valley concerned. They produce small coarse components, providing a more homogeneous local ground moraine with a minor grain size spectrum (Photo 110 ■ white; Figure 2, Nos. 79 and 80).

The mountain area of the Nganclong Kangri, set upon the Tibetan plateau, into which this valley (Photo 109) is embedded as one part of an entire valley system, reaches a height of ca. 5200–5400 m here. Showing no glaciers today, it was totally covered by the inland ice (— —) during the High Glacial. This is confirmed by the ground moraine cover (Photo 110 ■) as well as by exaration rills (⇓) and round-polished mountain ridges (☗). Hitherto a problem that cannot be solved is the question, whether the High Glacial inland ice cover was frozen to the underground, i.e., to the rough, small-scaled surface of this mountain landform, so that the subglacial relief in its preserved form has only been developed by the fluidity of the warmer Late Glacial inland ice, or whether this landscape presents the High Glacial (LGM = Stadium 0) features.

S of the 4900 m-pass (Figure 2, No. 79) a basin follows, the bottom of which is covered by ground moraine (Photo 111 ■). On top of it are Late Glacial to Holocene and historic lacrustine clays (□) (Figure 2, No. 81), the pelites of which have been washed out of the ground moraines, forming ramp-slopes (■ in the background) (Figure 2, No. 80). Several lake level positions are preserved by rather striking shore lines, which have undercut the ground moraine (▽). They prove a connected lake of deca-square metres with a depth of up to 8–10 m during the climax stadium. According to the very insignificant inclines, which actually would not allow this lake depth, it is probable that one or several Late Glacial (Stadia III–IV) glacier tongues have been involved in its up-damming. During the late-Late Glacial Stadium IV, i.e., at an ELA-depression by ca. 700 m compared with the current snow line to about 5100 m, the E- to NE exposition of the mountain ridges visible in Photo 111 was still glaciated. This concerned small hanging glaciers which had occupied the source depressions of small valleys, i.e., their valley head facettes (○). Their tongue ends only just reached down to the proximity of the valley exits, where they left behind flat cone sanders (glaciofluvial fans) only a few metres in thickness (cf. Photo 112 △). Here, as also in the mountain group ca. 14 km away presented in Photo 112, the glacigenic roundings of the mountain cupolas and -ridges (☗), as well as the ground moraine remnants on the slopes (Photo 111 and 112 ■ in the background), show the complete inland ice cover of this low mountain relief, which definitely can only be evidenced by such a large-scaled arrangement of the positions. End moraine ramparts in front of the lower slopes of a mountain flank alignment (Photo 112 I–III) indicate that a Late Glacial upland ice complex, lying on the surfaces of the Tibetan plateau which here are locally the lowest, flowed against the higher mountain ridges. They are in the position of frontal- or lateral moraines. Owing to the special topographic situation, their outer slopes fall away only slightly towards the mountain. By contrast their inner slopes, which were attached to the ice (I–III), are 120 to 180 m high. An ice complex advancing with its edges and thus upthrusting such moraine ramparts, was dependent on the time after the disintegration of the complete inland ice cover. It must therefore be classified as belonging to the Late Glacial Stadia I, II, III. Corresponding conditions have also been found 170 km further E (see above; Figure 2, No. 66). Somewhat W (right) of Photo 112 there is an embankment-like gravel body of round-edged material, which according to its isolated position and narrow, long form can be regarded as a kame (Figure 2, No. 82). Specified more exactly: this could be the filling of a gutter valley laid out subglacially, i.e., it might be an esker. This form is definitely of glaciofluvial genesis and – because of the necessary meltwater – corresponds to the Late Glacial. With regard to a subglacial genesis in this basin area, the existence of the above-mentioned ice complex of Stadia I–III could be taken in consideration, most probably Stadia II and III, with a snow line altitude already 300-500 m higher than in the High Glacial (Stadium 0) (Table 1). Only then and not earlier, a subglacial meltwater supply sufficient for the development of an esker was guaranteed at this altitude about 4500 m. Created as a kames, Stadia III–IV would be the most probable dates of origin for this gravel body. Only at the time of an ELA increase by 400–600 m against the High Glacial, would the disintegration of a local plateau ice complex have been in progress so far, so that only glaciofluvial gravel accumulations canalized by the glacier ice, which were situated centrally or on the margins, could develop by the ice contact, whilst at that time the existence of tunnel valleys was no longer probable. The author addresses the halved roche moutonnée form (the two ☗ on the left) in Photo 113, which is located ca. 7 km to the S, as remains of subglacial meltwater erosion. The originally intact roche moutonnée has been developed by the rather cold ground-scouring of the High Glacial inland ice cover, which was free of meltwater or at least poor in meltwater. Afterwards it has been cut within a Late Glacial ice tunnel (↓). Following our profile somewhat more to the SSW (Figure 2 between Nos. 81 and 83), a ca. 1 km wide transfluence pass depression continues (Photos 114 and 115), above which and even above the hill chains on both sides must have been a complete inland ice cover (‒ ‒). Evidence provides a continuous ground moraine sheet (■) reaching as far as the lower slopes of the hills and a glacigenic rounding (☗) up to the hill culminations. This, too, can only be explained by a connected inland ice cover of at least several hundred metres in thickness. Figure 26 shows the bimodal course of the grain size columns in the ground moraine matrix. The peak in the clay is comparatively inconspicuous. The high limestone portion of 32.4% is specific to local moraine, because limestone outcrops in the underground rock (cf. Photo 115). Figure 2 diagram 31.08.96/2 shows the high portion of 83.5% glacially crushed quartz grains, triturated under a heavy ice pressure. The examination under the microscope has made clear that freshly crushed and sharp-edged material is concerned. This points to a Late Glacial (LGM = 0) ground moraine and not to an older one. The sampling took place on a flat locality of nearly no incline, 200 m away from the bedrock (cf. Photo 115). Thus, the alternative possibility of freshly weathered bedrock is inapplicable. In Photo 114 the two-phase glacigenic forming of the landscape can be noticed: on the hills rounded by the Last High Glacial (LGM) inland ice, old Pleistocene cirque forms (○) have once again been reshaped, i.e., further deepened by isolated small hanging glaciers during the Late Glacial. S of the 4850 m-pass the glacial landscape formed by the High Glacial inland ice continuous with roches moutonnées (Photo 116 ☗ big) and round-polished ‘glacially streamlined hills’ (☗ small) being much more extended and up to 20 times higher. Here, too, the glacial erosion forms consist of limestone, built up of decimetre- or metre-thick layers. The postglacial (Holocene) to present-day weathering, attacking only bare rock surfaces without a ground moraine overlay, has led to insignificant crumblings (▽) and surface roughenings of the glacial polishings. Ground moraine ridges (Figure 2, No. 84) can be observed (Photo 117 ■ background; Photo 118 ■ small, second from the left) on the somewhat deeper bottoms of the polish depressions and the basal faces lying between the hill- and mountain ridges – which form the lowest relief unit of this Tibetan plateau area. Owing to the topographic positions, these ridges can be interpreted as upthrustings of the ground moraine in the underlying bed of the greatest local ice thicknesses. This concerns drumlin-like streamlined bodies, which – developed in the accumulative loose material as counterparts of the roches moutonnées and ‘glacially streamlined hills’, formed in bedrock – indicate the flow direction of the local inland ice in a similar way, i.e., by the direction of their longitudinal axes (Photo 117 ←). The parallel arrangement of these longitudinal axes and the direction of ice flow is confirmed by the exaration rills on these ground moraine ridges (↑ ↑) running in the same direction. According to the current state of knowledge and observation the author was not able to clarify which portion of these ground polishing forms must be traced back to the High- and which one to the Late Glacial ice movement. The rampart-like attachment of moraine to the flattened streamlined hill (☗ black on the left) visible in Photo 118 (▲), can roughly be classified as Late Glacial front moraine of the Stadia I–III (Table 1). It is an indicator of the Late Glacial marginal advance of an ice complex, filling this local basin area after the disintegration of the Tibetan inland ice. Such Late Glacial advances of ice complexes have been introduced above with regard to two other areas of Central Tibet, situated more N and NE (Figure 2, No. 66, Photo 93 and Figure 2, No. 81, Photo 112).

Adjacent to the ground moraine ridges, which are dependent on depressions and associated with them, lakes of a lake district occur (Photo 118 □), the single lakes of which were still connected with each other during the late-

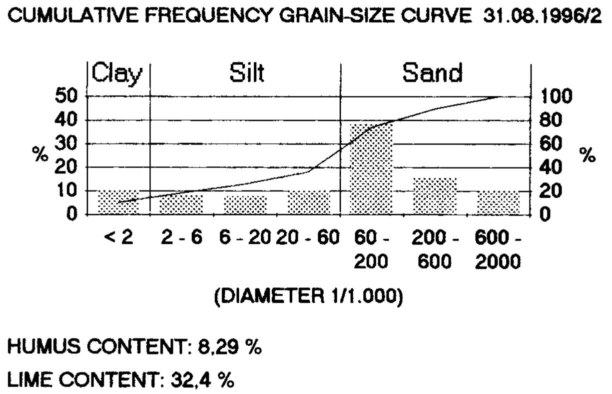



*Figure 26.* At 4850 m asl (aneroid measurement: 4675 m) in Central Tibet, High- to early-Late Glacial ground moraine matrix with limestone content from an area, where limestone bedrock is in the underground; sample taken from a depth of 0.2 m. Far-travelled erratic boulders up to pebble- or fist size 'swam' in the matrix. Locality: Figure 2, No. 83; Photos 114 and 115 foreground. Cf. Figure 5, diagram 31.08./2 with a predominance of over 82% glacially crushed quartz grains. (Sampling: M. Kuhle.)

Late Glacial (ca. at the end of Stadium IV), forming one lake face. Seasonally or at least episodically the lake face is more extended than in the photo taken at the end of August (Photo 118). The still damp lake bottom spread in the foreground of Photo 119 (■) indicates the seasonally greater extension of the lake, as well as the fresh shore line (■ in the background on the right). With regard to the history of landscape development, lakes and lake basins of that kind must be understood as unambiguously glacigenic, insofar as they occur in depressions on the Tibetan plateau which have been overdeepened by the ground-scouring of the inland ice. Since in this region corroded rocks such as limestones are absent in the underground, an alternative basin development by subrosion (karst processes in the underground) is impossible. To assume small-scaled, locally tectogenetic subsidence, however, does not allow for the continental crust, created by multiple subduction and horizontal compression, which several times has been deposited on top of each other. Its plate-tectonic build-up applies to the tectonic opposite, that is to the uplift of Tibet. Thus, the observations argue in favour of the probably polyglacial occurrence (i.e., in the course of several Pleistocene inland glaciations) of a polish depression landscape, developed by ice-scouring. Depending on the substantial hardness of the rocks and/or its minor joint density the depressions have been interrupted and dissected thereby by polish thresholds (Photos 118 and 119 ▲). This explains the irregularly frayed outline of basins and lakes.

The area connected to the W (Figure 2, Nos. 85–87) is marked by inland ice ground-scouring, which without exception had an erosive effect on the mountain ridges and cupolas (Photos 120–130 ▲), whilst in the depressions – at least during the last period of a covering inland ice – it was also accumulative, leaving behind a ground moraine sheet (■). The gradual transition from metres-thick ground moraine in the depressions to an only a few decimetres-thick moraine overlay which clings to the slopes (Photos 120, 122, 124 ■ background) but totally breaks off towards the hill cupolas exposing the polished bedrock there (Photos 120 and 124 ▲), is thereby to be observed. This is a gemorphological indication of the fact that the sub-moraine has been scraped off the inland ice by the towering hills and mountain ridges. Afterwards this sub-moraine was deposited on the lee side of the corresponding hills. It has been rolled out and smoothed and at the same time drifted into the depressions to the extent that the greatest possible thickness was attained (■). During the later to late-Late Glacial (Stadia III–IV), after the ELA had increased by 400–600 m to ca. 5000 m asl or even higher (see Table 1), the connected inland ice sheet had melted down. Ice caps remained only on the fjell-like high plateaus (Photos 121, 123, 125), rising 200–350 m above the Tibetan basal high plane. These left behind local ground moraines, lying on the plateaus (Photo 121 ■, 123 ▽, 125 ■). They contain the High Glacial (LGM) ground moraine which – due to changes of the ice flow direction within the local ice cap, in contrast to the large-scale inland ice and different thermal conditions under the minor thick plateau ice cap – occur in a reworked form. Here, on the steep edges of the plateau, shown in Photos 121, 123, 125, the High Glacial ground moraine, also left behind by the inland ice, has been washed away at the same time from the rounded and polished rock hills and - slopes by the meltwater of the plateau ice cap (Photo 121 ▲; 125 ▲ middleground). This washing led to the re-sedimentation of the ground moraine as alluvial fans in the piedmont region of this fjell-like plateau, i.e., on the Tibetan basal high plane (Photo 121 △ and black ■ on the right). Whilst in this region (Figure 2, No. 85) the High Glacial inland ice has left behind classic streamlined roches moutonnées (Photos 122 and 123 ▲ big) in sedimentary rocks like, e.g., schist, there are hill forms of limestone in the immediate vicinity which the ground-scouring of the inland ice has shaped somewhat differently and is thus typical of this rock (Photo 126 ▲ left half; 127 ▲). Their surface is formed irregularly and shows subglacially developed rock crumblings corresponding to the coarse banking structure of the limestone, i.e., following it more or less directly (cf. Photos 83 and 115). Such glacigenic mountain ridge forms of limestone can also be met in the classic glacial inland ice areas of Scandinavia (see above).

### *5.3. Local indications of High Glacial (LGM) snow line depressions and ELA courses as well as the minimum thickness of the inland ice*

As far as this can be deduced directly from the complete inland ice cover of the relief up to beyond the 5600–5900 m-summits shown in Photo 125, the High Glacial (LGM, i.e., Stadium 0, see Table 1) snow line ran at ca. 4650 m asl (see Figure 2 at locality No. 85 between the snow line contour lines at 4600 m in the S and 4800 m in the N, but closer to the 4600 m line). The actual climatic snow line, derived from the mountain chain concerned which is still glaciated today, runs at an altitude of ca. 5650 m (the orographic snow line of the glaciers visible in Photo 125, the position of which due to afternoon-radiation in W exposition is unfavourable to glaciation, amounts to 5750 m). This yields a local LGM snow line depression of ca. 1000 m. It is a cautiously calculated minimum value concerning the lower limit of the snow line depression, so that ELA depressions of 1100–1200 m might also be possible.

The minimum thickness of the inland ice derivable from the rounding of the summits (Photo 125 ☗ background) which, geomorphologically speaking, implies a minimum height of the ice level lying 100–300 m above the 5900 m high summits, amounts to 1200–1400 m in this test region of the investigation area (Figure 2, No. 85).

### *5.4. Continuation of the presentation of field datings on the gemorphological and Quaternary-geological profile of Central Tibet to the W*

On both sides of the 5000 m-pass (Figure 2, No. 87), i.e., E (Photos 127 and 128) and W (Photos 131 and 132) as well as N (Photo 129 in the background half-left) and S of it (Photo 130), the complete prehistoric inland ice forms can be evidenced. Flatly-sloping high valleys show classic trough cross-profiles (Photo 130 ■ background on the left). The 5000 m-pass itself bears the characteristics of a kilometre-wide transfluence pass with ground moraine overlay (Photo 129 ■). The valley bottoms falling away on both sides are also covered with ground moraine (Photos 128, 131, 132 ■). Since the post-High Glacial deglaciation they have only locally undergone a slight glaciofluvial or – in the Holocene – fluvial reshaping (Photos 131 and 132 □) (Photo 128 left of ■ in the foreground and ▽; 132 ↗). By way of contrast, in the rather unimportant, but nevertheless existing Holocene to actual reshaping by the down-flowing water, an indication can be seen of the totally different kind of denudative High Glacial forming without a linear effect. At the same time this means that the actual fluvial morphodynamics – without the repeated High Glacial breaking-off in the course of the Pleistocene which lasted ca. 2 million years – would have left behind a totally different, i.e., linear-erosive and fluvial-accumulative formation.

#### *5.4.1. Indicators of the local direction of the inland ice run-off*

Classic band polishings of the outcropping edges of the strata and exaration rills are also widespread (Photo 130 ▽; 132 △). They confirm a local direction of the down-flowing inland ice from NNE to SSW. This direction of the ice run-off, locally modified by the pre-glacial valley network, corresponds to the configuration of the Tibetan inland ice (Figure 12) insofar, as the general ice run-off must have taken place centre-peripherally, i.e., approximately radially in all directions from the centre of the inland ice up to the marginal outlet glaciers, which then flowed down to the plateau. This tallies with the geometry of the run-off dependent on the topography and central thickness of the ice. For orientation: this test area is situated in Figure 12 above (NE) the Kamet in the central nourishing area of I2 (light). The trough-like valley W of the 5000 m-pass leads down to the Indus valley, the thalweg of which is running here at 4600 m. This connection of the ice run-off from Central Tibet down to the SW has determined the observed direction of the inland ice flow. The roches moutonnées, ‘glacially streamlined hills’ (Figure 2, Nos. 81–105) and drumlins point to the same NNE–SSW run-off direction.

#### *5.4.2. Continuation of the presentation of field datings from Central Tibet to the W*

In the surroundings of the 5000 m-pass, which – as is evidenced by the minimal surface heights of the ice (Photos 128–132 ▬ ▬) – was completely covered by the inland ice, the variations in degree of the relief roundings as a result of the ground-scouring of the inland ice make clear that important rock-specific differences occur. In some regions the sedimentary bedrocks (limestone, marl, sand- and siltstones) have been shaped by the ice to streamline-like rounded forms (☗). However, in the reddish-brown sand- and siltstones in the vicinity, sharply formed mountain ridges and steep slopes – in dependence upon their layers and ac- and bc-joint structure – have been developed subglacially as well as having been preserved subaerially in the Postglacial (Photos 128 and 131). Here, a strong inner grain-cohesion of the very resistant rock and at the same time loose layer- and joint structure, has determined the development and preservation of the small-scale dissection and roughening of the relief. Such formations can also be observed in corresponding rocks in the Ice Age glacigenic ground scouring regions of, e.g., W-Spitzbergen (Dicksonland at 78° N; Kuhle, 1983a) and W-Greenland (Nugssuaq peninsula, Sarqaqdalen at 70° N; Kuhle, 1983c).

The northern source branch of the Indus, the Senko Tsangpu (Figure 2, No. 89), is reached at 4600 m asl by the trough-shaped side valley descending from the 5000 m-pass (No. 87) from the ENE (Photo 133). The main valley is a box-shaped trough. Its 400 m to in parts 2000 m-wide bottom, consisting of glaciofluvially reshaped ground moraine with a gravel cover (□), is broken through by glacially round-polished ‘riegels’ (first ☗ from the left) and mountain spurs (third ☗ from the right). Glacial flank polishing occurs in places (☗ black). Since deglaciation modifications took place at other sections of the valley flanks in the form of crumblings (Photos 133 and 134 ▼), debris cones and -slopes, as well as mudflow- and alluvial debris fans (△). Moraine accumulations which have been reshaped little if at all (■), stretch down-valley along the orographic right side of the Senko Tsangpu valley between the glaciofluvial valley bottom (□) and the valley flank (◤). Ten km down-valley from the viewpoint of Photo 134, a very substantial Ice Age glacier stream has left behind a broad, flat, classically trough-shaped transfluence saddle (-pass) the cross-profile of which amounts to ca. 1 km in width. It is connected to the Senko Tsangpu in a softly-formed confluence step (Figure 2, No. 88). On the left valley flank, remnants of a moraine cover are preserved on the 400–700 m high mountain ridges, rounded by the glacier ice (Figure 2, Nos. 92–96). The orographical left Senko Tsangpu flank shows similar conditions (Figure 2, Nos. 91, 93, 94; Photo 135). Here, polymict ground moraine washed by the Late Glacial meltwater since deglaciation, covers the slope-foot areas (□). Over large parts a ground moraine overlay can be identified on the slopes (■ black). It is preserved up to the culminations

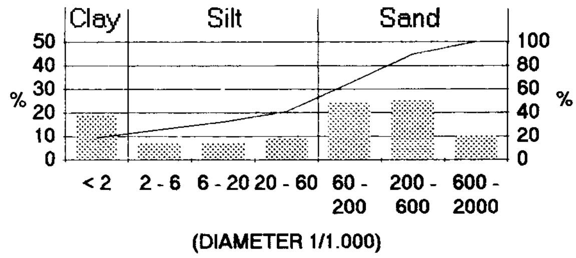
(■ white) of the glacially polished limestone ridges (☗). During the Late Glacial (ca. Stadia II–III; Table 1) the U-shaped cross- and hanging valleys (▼) set into this hilly landscape, were still glaciated by separate glacier tongues branching out like an ice stream network. Thus, local end moraine ramps left behind by the ice margins have developed. At the same time glacial ravines have been cut very sharply into the round-polished confluence steps (between ▼ and △) by the meltwater streams. Figure 2, Nos. 95 and 96 locates a further strikingly glacigenic cross-profile in the Senko Tsangpu valley (down-valley its name is Gar Zangbo; this concerns the northern source branch of the Indus). Here, too, – consistent and corresponding with the arrangement of the positions of the above-mentioned glacial indicators as far as the valley flank culminations - both mountain ridges fringing the valley at the sides were completely covered by the inland ice. Accordingly, they are polished and covered with moraine remnants. At the place where the orographic right trough flank resulting from the glacial flank polishing has been undercut particularly steep, characteristic crumblings have created postglacial flank roughnesses as well as debris cones and -slopes which continue downwards. Considering the limestone bedrock on both sides and in the underground, the ground moraine sample taken from this cross-profile (Figure 27) is conspicuously poor in limestone. This classifies the portions of moraine matrix as being far-travelled moraine. The bimodal arrangement of the columnar diagrams and the clear peak in the clay are classic characteristics of ground moraine. Figure 28 shows a very similar ground moraine matrix of the LGM Laurentide Ice Sheet in N America. Figure 5 (diagram 1.9.96) testifies to the classic ground moraine character and important glacigenic trituration due to a heavy glacier load, i.e., ice thickness by a 81.6% portion of glacially crushed quartz grains.

With regard to the nearly perfect roche moutonnée formation preserved on the orographic right side of the Senko Tsangpu, 9 km down-valley from the sampling locality of Figure 27 (Figure 2, No. 97; Photo 136), and its similarity to the features in the Last Glacial Scandinavian and Scottish inland ice regions, the following excursus is made as an aid to better understanding.

### *5.4.3. An excursus intended to facilitate comparison of the warm and cold inland ice areas with regard to the preservation of the forms of roches moutonnées and 'glacially streamlined hills'*

Despite the approximately identical age of the prehistoric ice sheets, two aspects actually contradict the similar condition of preservation of roches moutonnées and related ground-scouring forms of the more oceanic, warm-based inland ices at sea-level like the Scandinavian and Scottish inland ices: (1) In Tibet a highland ice is concerned, the base of which was situated at a height of 4400 to 5200 m asl. Its feeding may have been of the arid-continental type, so that it was a cold-based ice. Thus, these climatic conditions must have led to the freezing of the ice as far as the ground, causing detraction- and exaration processes which rather roughened the rock. (2) Since deglaciation in continental High-Tibet, the weathering as a result of intensive nocturnal insolation and cooling as well as nearly perennial freeze and thaw, brings about a roughening and destruction of the ground polishing faces left behind by the inland ice which is raised to several times the tenth power of that in the oceanic lowland. Seen from this point of view the complete absence of glacier striae in the feeding areas of the Scandinavian and Scottish inland ice sheets, i.e., in these comparably lower highlands, becomes readily understandable, albeit not in the Tibetan mountain ridges (glacially streamlined hills) which in many places are preserved in an even smoother and rounder condition than in Europe. They can be reduced to a more connected ground moraine sheet in this arid region of Tibet, which preserves the round-polished rocks in the underlying bed. Here, the example from Central Tibet has to be mentioned: Photo 136 shows the locality concerned (Figure 2, No. 97). This hill, consisting of thinly-layered outcropping edges of the strata of sedimentary rock, has been rounded by the ice. The bedrock is covered by a thin

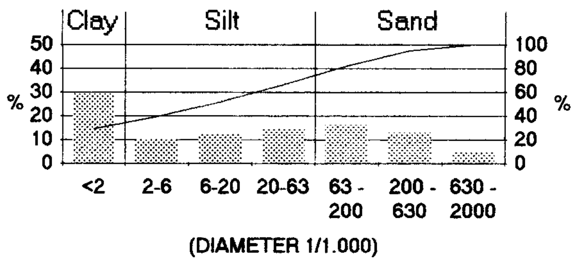
CUMULATIVE FREQUENCY GRAIN-SIZE CURVE 01.09.1996/1




HUMUS CONTENT: 7,98 %
LIME CONTENT: 11,09 %

*Figure 27.* At ca. 4500 m (aneroid measurement: 4325 m asl at high pressure), ground moraine matrix from the bottom of the N source branch of the Indus valley (Senko Tsangpu) in SW Central Tibet; sample taken from a depth of 0.5 m. Despite the local occurrence of limestone, the limestone content of the moraine is relatively insignificant. This provides evidence of a far-travelled moraine from the very central W-Tibet. The important content of clay of ca. 19% is characteristic of the heavy trituration by a very thick hanging ice body and its high overburden pressure. Cf. the similar ground moraine sample from Canada. See Figure 5, diagram 01.09./1. Locality: Figure 2, No. 95; 32°31′20″ N/80°45′10″ E. (Sampling: M. Kuhle.)

CUMULATIVE FREQUENCY GRAIN-SIZE CURVE 01.07.1993/2




HUMUS CONTENT: 3,33 %
LIME CONTENT: 11,2 %

*Figure 28.* For comparison: Ground moraine matrix from the W segment of the Last Glacial (LGM = Late Wisconsin) Laurentide Ice Sheet in a Canadian area. Locality: NW of the settlement of Moose Jaw, ca. 100 km ESE of Lake Diefenbaker; cf. Figure 27. (Sampling: M. Kuhle.)

ground moraine ‘veil’ of only a few decimetre up to 2 m in thickness (the two small black ■ in the background on the left and the two small white ■ in the background on the right). Figures 27 and 5 (diagram 1.9.96/1) indicate an example of this type of ground moraine matrix. Only in the places where – due to a greater steepness of the slopes – the ground moraine cover is lacking, the weathering had a roughening effect on the glacial hill surface. However, since deglaciation the quantity of ground moraine flushing in general is rather insignificant here, compared with that of the oceanic areas mentioned above. Thus, the moraine cover may have preserved the rock surface in the underlying bed over quite a long time. During the maximum of 13 000–15 000 years available for a non-glacigenic reshaping, only small rills have been developed until now, cutting the soft loose material of the ground moraine only just down to the bedrock (↖). Only at some places the free-washed bedrock itself has been insignificantly incised (i.e., decimetres-deep). Other linear rock injuries are geological disturbances in the sedimentary rock which have been reworked (e.g., on the right of the second ☗ from the left). They can be recognized by the fact that they do not usually follow the slope gradient.

The rills in the surface of the strikingly round and smooth roche moutonnée or ‘glacially streamlined hill’ following the slope gradient (Photo 136 ↖), are about to roughen it and to destroy not only its surface but also the entire form by further cutting. So, today the rounded form cannot be understood as being in the process of a continuous development. On the contrary, the present-day rills provide evidence of a prehistoric origin under different conditions, i.e., by the ground-scouring of the inland ice. The minor depth of the rills, which for the most part are dependent on the soft overlay of loose material and which can be described at most as microfluvial rills, also makes clear that this inland glaciation did not happen long ago but during the last High Glacial (LGM = Stadium 0) up to the early Late Glacial (Stadia I–II). This contradicts (apart from the observations which the author has accumulated in the course of 23 years of investigations in Tibet (Kuhle, 1980–1998)) the assumption of a completely absent Pleistocene inland ice cover (Shi Yafeng et al., 1991; Zheng Benxing et al., 1998; Feng, 1998, and others) as well as the dating of a Tibetan inland ice into the early Pleistocene, i.e., 500–1000 Ka retrochronologically, by Han Tonglin (1991).

### *5.4.4. Continuation of the glaciogeomorphological profile across SW Central-Tibet, down the Senko Tsangpu to the basin of Shiquanha (settlement of Ali)*

Fourteen km down the Senko Tsangpu from that roche moutonnée, the valley chamber shows the following characteristics, being part of the system of the arrangement of the positions of glacial indicators: steep-standing dark sedimentary rocks on the orographic left valley slopes (Photo 137 ↑) are mantled by metre- up to 15 m-thick lighter erratic ground moraine (■ above and next to ↑). In places, these moraine depositions are set off against the higher-lying parts of the slopes by saddles with counter slopes (e.g., at ↑ and above ■). This is a further reason why this loose material can under no circumstances be interpreted as autochthonous slope debris. On the opposite valley side the moraine cover at decreasing thickness reaches locally as far as the culminations of the mountain ridges (the two ■ on the right). Besides sharp edges on fresh linear-erosive cuttings (↗), more or less flatly-inset fluvial rills (/) are characteristic of these ground moraine covers. Part of the material has been washed into the shape of alluvial fans (△) since deglaciation. Kame-like lateral forms (▲ black and □) have been developed syngenetically to the down-melting of the Late Glacial valley filling. They have been glaciofluvially and fluvially deposited against the margins of the valley glacier, melting more and more back towards the middle of the valley. The valley bottom (□ left) consists of Late Glacial to postglacial gravels, sedimentated on the ground moraine bottom, which at the same time has been washed and reworked as well as resedimentated in this gravel body. The only really precipitous forms of this valley cross-profile have been created by postglacial fluvial outer bank forms, i.e., undercuttings by the river (↙). On a further orographic right outer bank 8 km down-valley, polymict ground moraine has been exposed on undercut crumblings of sandstone (Figure 2, Nos. 99–101; 32°32′30″ N/80°33′ E). Here (Photo 137), as well as in the area of Senko Tsangpu (N source branch of the Indus valley) ca. 10 km further down-valley (Photo 138), mountain ridges have been continously round-polished (☗), thus showing the High Glacial (LGM) complete inland ice cover of the relief (level: – –). At many places on the upper hill slopes the removal of the ground moraine overlays by denudation and erosion can be observed (Photo 137, second black ☗ from the right; Photo 138 ☗ on top). This has its cause in the local hanging glaciers with their small-scale ground scouring and the down-flowing meltwater, which only there persisted up to the late-Late Glacial (Stadium IV). The nearly complete preservation of an unambiguously glacigenic landscape is the more remarkable, and suggests a Late Glacial inland glaciation of the relief, because thinly-layered sedimentary rocks are concerned, which can be very easily roughened by subaerial weathering and disfigured beyond recognition, but which here are obviously preserved in a glacially rounded condition (Photo 139 ☗).

The W-parallel side valley shows – beside glacigenic roundings of the relief (Figure 2, No. 100; Photo 140 ☗) in metamorphic sedimentary rocks with remnants of ground moraine (■ background) – a confluence step by which the side valley is connected to the Senko Tsangpu (□). Its core has been built-up by bedrock, in parts covered with ground moraine which has already been washed subglacially (□). Overlays of subglacial loose material of that sort usually take place during the last phase of the ice cover and its thawing (late-Late Glacial Stadia III–IV; see Table 1) with the typical subglacial tendency to level the unevenesses by ice and meltwater. With regard to the prehistoric glaciation, the valley chamber of the upper Indus valley (Senko Tsangpu or Gar Zangbo; Figure 2, Nos. 102 and 103) located further W, is in particular expressive. This is the direct junction with the much broader, basin-like valley chamber of Shiquanhua (Photo 141 half-right in the background). On the orographic left valley side a 1.2 km-long rock pedestal from sedimentary rock has been rounded and smoothed by the inland ice ground scouring (the four ◓ in the middle) and cloaked with ground moraine (■ black centre; ■ white, small, on the left above ◓). Late Glacial subglacial undercutting by meltwater has led to the marginal steepening of the rock pedestal and accompanying crumblings (second and third ▼ from the left). On the opposite valley side flank polishings are preserved in places (◤). However, in parts they have also been destroyed by postglacial crumblings (▼ on the very right).

*5.4.5. High Glacial rounding by ground scouring and early- and Late Glacial sharpening of the summits by glacial lateral erosion – a balance phenomenon with summits of a medium relative height*

A phenomenon known from the Alps, which during the LGM have been glaciated up to an ice thickness of 2000 m as well, is the small-scale geomorphological discrepancy between the polished and rounded flat forms as, e.g., valley shoulders and remnants of old plains on the one side and the sharpened summits on the other side. With regard to the Alps the latter ones – so-called glacial horns and rock-sills (‘riegels’) – have been explained as sharpenings by the late-glacially dropped ice level since ca. 100 years (Penck and Brückner, 1901–1909). Here, too, the surface of the inland ice and ice stream network which had been lowered towards the Late Glacial, has sharpened the summits, currently towering above the ice level, by glacial lateral erosion (◇). Something corresponding took place during the early-glacial period, when the summit (◇) was not yet totally covered by the surface of the up-building ice. Such relatively low mountain tops, which during the High Glacial were completely mantled by the inland ice (LGM minimum surface height = — —), must be considered as being polyglacial forms, developed in the course of many Quaternary early- and late-glacial periods. By analogy one might refer to the numerous sharp summits in Greenland, rising only a few decametres above the current inland ice, which during the LGM lay under the ice level, but are not rounded today. Accordingly, the temporary lateral erosion must have exceeded the rounding temporary ground scouring with regard to the geomorphological effectiveness.

*5.4.6. Continuation of the section: observations in the basin of Shiquanha (Ali) (Figure 2, Nos. 103–105)*

The basin of Shiquanha is surrounded by hill- and mountain groups reaching a maximum height of 5800–6200 m. From there valleys join this basin – so, e.g., the Senko Tsangpu being the N source branch of the Indus. Kilometres-extended Late Glacial glaciofluvial gravel floor fans (Figure 2, No. 105), belonging to Stadia III–IV (see Table 1), have been deposited through the valley exits onto the basin bottom, interlocking with the corresponding adjacent fans. These gravel floors can be explained as glacier mouth gravel floors. They have been sedimentated into this lowest area lying about 4200–4300 m asl by the still existing ice stream network- and valley glaciers of the bordering mountain groups, i.e., from nearly all directions, thus covering the underlying ground moraines. The glaciofluvial gravel cover must have been the more intensive, the more numerous and longer the Late Glacial ice streams were which almost reached the basin. Especially the fact that the Late Glacial glaciers were located close to the basin of Shiquanha is the cause of the heavy reshaping of its surface by the glacier meltwaters and their sediments. Therefore the geomorphological indication of a High (LGM)- to early-Late Glacial (Stadia I–II) inland ice cover of the basin can only be provided indirectly, namely with the help of the minimum thickness of the ice at the valley exits, documented by the corresponding forms. By way of the flank polishings and ground moraine overlays at the Senko Tsangpu-junction (Photo 141 ◤ and ■) as indicators of the minimum surface height of the ice (— — 0 — —), a complete glacier cover of the basin is made probable, because the accompanying minimum ice thickness was 500–600 m.

On the W margin of the basin, 10 km away from Shiquanha, in the region where one of the large gravel floor fans (Figure 2, No. 105) reaches the basin bottom at 4200 m asl (32°26′40″ N/80°02′ E), flatly-inset, rythmically sedimentated limnites (varved clays), a few decimetres- to 1–2-m in thickness, document small-scale lake forms, into which the gravel floor had extended. With regard to the geomorphology, this sequence of sedimentations belongs also (see above) to the later- or last-Late Glacial (Stadia III–IV). Following the gravel fan over a distance of ca. 6.5 km from its distal margin upwards to the WSW as far as its proximal area, the gravel field surface passes at ca. 4420 m into the characteristic substrate of glaciofluvially washed ground moraine, rich in fine material. Seven km further in this direction, the culmination of the 4700 m-pass leading into the upper Gar Zangbo, and thus the root of this accumulative ramp which comes to an end in that fan, is reached (Figure 2, No. 105; Photo 142). This pass is a classic transfluence pass, abraded by the overflowing glacier ice. As far as the rounded rock ridges (◓) it is covered with a ground moraine sheet (■), the thickness of which decreases from below to above. Hitherto it has not been ascertained, whether the large boulders of sedimentary rock contained within it (○) are actually far-travelled erratics (Figure 2, No. 104). The SW source branch of the Indus valley, the Gar Zangbo, located beyond, i.e., W of the pass, has a valley bottom height of 4200–4300 m asl as well (Figure 2, No. 131), thus lying as high as the bottom of the basin of Shiquanha (see above). Insofar as there is no difference in the level from which the direction of the ice flow over the ca. 400–500 m higher transfluence pass could be deduced, the ice could have flowed over this pass either into the basin or out of it. However, owing to the generally higher Central-Tibetan surface level continuing NE of the basin, it must be assumed that the inland ice flowed down from the Senko Tsangpu (Photo 141) through the filled basin of Shiquanha and then over the transfluence pass into the Gar Zangbo. But even without this additional information it is sure that the ice flowed over the at least 5000-m high hills in the vicinity of the immediate pass depression (Photo 142 ◓) with a thickness of further ca. 300 m, i.e., that its minimum surface height amounted to 5300 m asl (— —). Thus, a prehistoric ice level of at least 1000 m above the bottom of the basin of Shiquanha is documented. This makes probable that the basin must have been filled and covered by the inland ice during the High Glacial (LGM). The same applies to the simultaneous ice filling of the Gar Zangbo valley SW of the pass which – this is to anticipate the data analysis (see below) –, as is evidenced by flank polishings (Photo 142, the right black ☗) and summit forms, had its level at about 5500–5700 m (▬ ▬ fine, half-right in the background).

*5.5. Summary of Section 5*

The 420 km-long Quaternary sedimentological and geomorphological Central-Tibetan profile between 32° and 33° N and from 84° to 80° E to the west across the high plateau with the hill- and mountain land of the Nganclong Kangri set upon it (Figure 2, Nos. 67–105), shows an uninterrupted sequence of erosive and accumulative indicators of a prehistoric maximum glaciation, which has completely covered the highland relief (see Figure 12 in the light patterning above the Kamet). The indicators entered in Figure 2, the exemplary field sketches and sample analyses (Figure 5 (diagrams 31.8./1–1.9.96/1) and Figures 23–28) as well as the arrangement of the positions and the geomorphological data, reproduced in the photos and panoramas (Photos 94–142), here confirm (as well as in Sections 1–4) the detailed observation of a connected inland ice. With the help of glacially abraded and thus rounded mountain summits, evidence is provided of inland ice thicknesses of at least 1200–1400 m in the central plateau area of Figure 2, No. 85 (Section 5.3). The same applies to the area No. 105 and No. 131, tapped by the upper Indus valley (Senko Tsangpu, i.e., Gar Zangbo) and its prehistoric ice run-off, where ice thicknesses of at least 1000–1400 m have been documented (Section 5.4.6). The accompanying LGM minimum surface height of the ice ran at locality No. 85 between ca. 6000 and 6200 m asl, and at No. 105 and No. 131 between 5300 and 5700 m. The High Glacial (LGM) ELA of the area concerned ran at a height between 4700–4800 m asl in the E and 4300–4400 m in the W (see Figure 2). At places where 5900 m-high mountain ridges have been overflowed so that an inland ice thickness of 1200–1400 m is probable (No. 85), the snow line depression amounted to at least 1000 m. This can be deduced by the comparison of the present-day ELA about 5650 m, documented by actual glaciers, with a prehistoric (LGM = Stadium 0) ELA at 4650 m asl. However, a depression of even 1200 m cannot be ruled out.

## 6. The maximum High- (LGM) to Late Glacial glaciation of the Gar Zangbo (S source branch of the Indus) on the SW margin of Central-Tibet between the NW Gangdise Shan at Shiquanha (Ali) in the NW and Gurla Mandhata and Kangrinboqé Feng (Kailash) in the SE (Figure 12 between the marking of I2 and on the left above the Kamet; Figure 2 Nos. 105–131)

Beyond, i.e., in continuation of the glaciogemorphological profile of the preceding chapter SW of the 4650 m-high glacigenic transfluence pass (Figure 2, No. 105), the Gar Zangbo (S source branch of the Indus) is located (Photo 142 □). It wears the characteristics of a glacigenic trough, the valley bottom filling of which (Photo 143 □ white) has led to its current box-like shape (Figure 2, No. 131). The round-polished hill- and mountain ridges on the SE side of the transfluence pass (Photo 142 ☗ in the centre and on the left) as well as those NW of the pass, confirm a very much extended Riss- (penultimate) and High Glacial (LGM) ice transfluence, completely covering the entire relief (Photo 142 ▬ ▬ middleground and 143 –I to 0 ▬ ▬). The overlays of ground moraine, ablation moraine and drift-cover-sand (■) provide further evidence for this. In which direction the ice flow took place cannot be diagnosed geomorphologically. An ice flow from the basin of Shiquanha to the SW into the Gar Zangbo can be deduced from the more large-scale relief incline. The ground polish forms in the shape of roches moutonnées and rounded hills, marked in Photos 191, 190 and 189 (☗), testify to an ice transfluence over the depression of the 4650 m-high pass into the Gar Zangbo as well as to a total glaciation, the level of which reached over the orographic right flank of this main valley (0 ▬ ▬, ▬ ▬ 0, ▬ ▬). Here again, the reconstruction of the High Glacial ice cover can be considered to be reliable according to the interpretation of the separate indicators observed in the field and the arrangement of their positions (which can be made intersubjectively understandable by means of the photos).

Owing to the high-mountain form of the orographic left valley flank of the Gar Zangbo, reaching heights of up to 6836 and 6739 m (Photos 143 and 144, Nos. 2 and 3), a more exact estimation of the inland ice level and ice thickness is possible (Photos 142–145 ▬ ▬ and 0 ▬ ▬ fine, background). The extracted minimum surface height of the ice amounted to ca. 5700 m. The valley bottom, elevated by moraines and Late Glacial gravel floors, runs in these cross-profiles of the Gar Zangbo about 4250–4300 m asl (□ white), so that a minimum thickness of the inland ice of over 1400 m is to be suggested. Thus, the inland ice surface was lying 700–1100 m above the simultaneous glacier snow line (ELA). This has not only made possible the preservation of the orographic left flank polishings (Figure 2, No. 106) of the Gar Zangbo (it concerns the eastern continuation of the Zaskar Mountains) and their upper snow limit (cf. Figure 2), but also their late-Late Glacial (Stadia III and IV; Table 1) and Holocene reshaping and partial destruction by side glaciers. At least six massifs of this investigation area are still glaciated today (Photos 143 and 144 |). In the NE exposition almost 10 km-long side valley glaciers (Photo 143 | between 3 and 2) occur. But cirque glaciers also exist (Photo 143 | on the left of 3 and on the very right; 145 |). During their post-late-Late Glacial history of retreat these side- and hanging glaciers, as well as their meltwaters, have marginally undercut and destroyed the intermediate valley spurs of their side valleys – which at the same time form the main valley flank – by their erosive work (Figure 2 between Nos. 107 and 109). In spite of having been glaciated as long as recently, these side valleys show V-shaped profiles in their junction area (Photo 145 ▼). Their meltwaters have transported the late-Late Glacial to Holocene moraine fillings up to the valley exit and laid down in the form of fans on the main valley bottom (Photos 143 △, 144 and 145 △ white). The older ground moraine deposits of the Gar Zangbo main valley have only remained between these side valley inflows (Photo 143 ■ black; 144 ■ left-half of the photo; 145 ■). On the orographic right side of the Gar Zangbo, Late Glacial kame ledges present the geomorphologically specific feature of an already far down-melted Gar Zangbo parent glacier (Photo 143 ■ on the very left; 190 ■ left half of the photo; 191 ■ large).

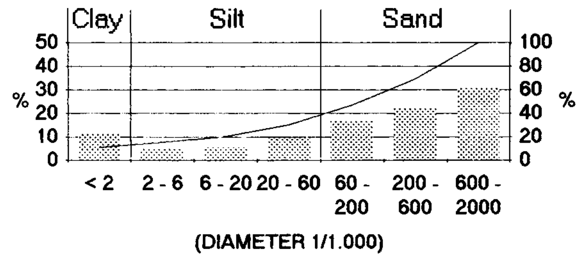
In comparison with the dislocated moraine materials which have been glaciofluvially and fluvially transported down through the side valleys of the Gar Zangbo and sedimentated out of the valley exit in the form of fans (Photo 188 △), the ground- and ablation moraine covers (Photo 188 ■ small, 187 and 146 ■) preserved *in situ* are particularly expressive with regard to the characteristics of the maximum prehistoric ice sheet. This applies especially in the case of the highest moraine remnants. They mostly lie in a thickness of only decimetres to metres on round-polished bedrock mountain ridges and slope shoulders. In slope positions they show a typical pattern of fine microfluvial rills, which have been formed since deglaciation during the Late Glacial (since Stadia I–III; Table 1) (Photo 188 ↗).

By means of their glacigenic accumulation habit these high-lying remnants of ground- and ablation moraine complete the circumstantial evidence of a prehistoric glacier cover which has also been provided for the glacial erosion forms in the underlying bedrock (☗). In the areas, to which no higher mountains with perennial valley glaciers are connected, but valleys and remnants on the high plateau have nearly simultaneously been deglaciated during the Late Glacial, classic trough valleys as indicators of glaciation are preserved (Photo 188 ᑌ). Triangular slopes – which can be referred to as a characteristic flank polishing form of its own – are to be observed at many places between the valley exits (Figure 2, Nos. 106–109). They have been shaped by the back-polishing of mountain spurs (Photo 145 ☗ right half; 146 ☗; 148 second ☗ from the left, third ☗ from the right). Besides only slightly modified ground- and ablation moraine ridges with overlays of drift-cover-sand (Photo 188 ■ big), undulating gravel fields occur on the main valley bottom, which during deglaciation have experienced a heavier washing and thus got rid of larger portions of the fine material (Photos 146 and 187 □; Figure 2 between Nos. 105 and 109).

Glaciofluvial glacier mouth gravel floors (sanders) have been preserved in the form of a three-stepped terrace in an orographic left side valley junction of the Gar Zangbo (Photo 146). They belong to the Late Glacial; the oldest gravel floor (No. 4) has been deposited as a kame against the orographic left margin of the Gar Zangbo glacier. Evidence was found of a still exisisting Gar Zangbo main glacier by the orographic left ground- or lateral moraine remnant of the Late Glacial Stadium I, shown in Photo 146 (■ I). The kame deposit No. 4 took place at a time, when the side valley glacier tongue had already melted back and thus had no longer contact to the parent glacier (Gar Zangbo glacier). The younger gravel floor terraces of the side valley have the following Numbers 3 and 2 from above to below, i.e., they belong to the local Late Glacial Stadia II and III of the side glaciers (cf. Table 1). Since the Gar Zangbo glacier no longer existed in the main valley, they found no abutment, but have been accumulated as gravel fans on the main valley bottom. These gravel fans have to a great extent been removed by the anastomising meltwaters on the Gar Zangbo main valley bottom (in the area of Photo 146 □). Up the Gar Zangbo a further orographic left side valley is connected (Photo 187), which presents numerous traces of the High Glacial (LGM) ice infilling and complete glacier cover of the relief (▬ ▬). Here, a flank polishing cavetto (◞) is preserved at a height of 250 m above the valley bottom. On the opposite valley side a mountain ridge has been rounded by the ice (☗ left) and mantled by ground and ablation moraine (■). At an already up-lifted snow line (ELA) in the Late Glacial, the valley head, polished by an ice transfluence (☗ right), has been dissected by a subglacial meltwater gorge (↓). The 10 km-broad valley chamber in the area of the settlement of Gar (Figure 2, Nos. 108–110) has been filled by Late Glacial lateral- and end moraines (Photo 148 I, II, III, IV). During the Ghasa-Stadium (Stadium I; cf. Table 1) the Gar Zangbo parent glacier, flowing down from SE (Photo 148 from right to left), has still passed the viewpoint of Photo 148 (Figure 2, No. 110), leaving behind the highest lateral moraines and kame terraces (= glacigenic lateral forms) (■ I) preserved. (▲) is the locality of the accompanying moraine exposure, shown in Photo 147. Besides loose material the densely-packed moraine material contains far-travelled erratic granite boulders. Classic drift-cover-sand lies on the moraine surface (Photo 147 □). At the time of this moraine accumulation, the tongue basin of the Gar Zangbo glacier has left behind the down-valley bank formation mentioned (Photo 146 ■ I), damming up a kame at the terrace level No. 4 (Photo 146; 4) of that side valley (Figure 2, No. 109). During the Taglung Stadium (Stadium II) the next lower lateral moraine terrace has been left behind by the Gar Zangbo glacier which had already melted down (Photo 148 ■ II). The next younger glacier positions, i.e., those of the Late Glacial Dhampu- and Sirkung Stadia (see Table 1, composed according to the nomenclature of the glacier stadia by Kuhle, 1982, pp. 150–169), have already developed their end moraines up-valley of the viewpoint of Photo 148 (■ III and ■ IV) (Figure 2 at Gar below No. 108). On their outer slopes these end moraines show sanders of the 'Bortensander'-type (IMR) and their sub-type 'transition cone' (▽ up to the right □) (Kuhle, 1990a, e). The rounding of the mountain cupolas- and ridges (☗) as well as their ground- and ablation moraine covers and the overlying drift-cover-sands (■) are evidence of a High Glacial inland ice sheet which totally covered the relief on the SE- as well as on the NE side of the Gar Zangbo (Photo 148 ▬ ▬ 0).

Geomorphologically the large-scale High Glacial ground moraine overlay on the slopes is especially evident at the places where the post-High Glacial rill flushing has fissured and exposed the ground moraine cover, as, e.g., on the orographic left flank of the Gar Zangbo, 2–10 km up the valley (Photo 186 ■ and ↗ ■). The Late Glacial end moraines mentioned have been attached to these ground moraine covers in the slope foot area of the valley chamber of the settlement Gar (I and III ■). Also in the region of the orographic left valley flank of the Gar Zangbo, but a further 7–13 km up-valley, glaciolimnic sediments are exposed (Photo 149 □ black and white; 184, 185 □ black) (Figure 2 between Nos. 110–112). Their true locality in the topographic connection of the arrangements of their positions is shown in Photo 148 (↓) and Photo 183 (↑). They lie on morainic material with separate large boulders (Photo 149 ○). Two interpretations are to be suggested: either these are sediments of an end-moraine-dammed lake in the Late Glacial tongue basin at the settlement of Gar of Stadium IV (Figure 2 below No. 108), or it is an ice-, i.e., lateral-moraine-dammed lake in the orographic left lateral valley of the Late Glacial Gar Zangbo glacier of Stadia III–IV. The latter interpretation ought to be favoured because limnic sediments exist only on the very margins, but not in the centre of the tongue basin. To the SE, i.e., the Gar Zangbo up-valley, up to ca. 90–110 m-thick Quaternary loose sediments immediately continue the glaciolimnic sediments (Photo 183 ■ and □ white). They consist in their core from pre-Last Glacial (pre-LGM) washed moraines of Stadium −I (= Riss or pre-last High Glacial maximum; see Table 1) and glaciofluvial gravels of the Riss-Würm interglacial (LGM-pre-LGM interglacial). This chronological classification has been deduced from the fact that these loose rocks have been reshaped, i.e., overflowed by the inland ice during the LGM (Stadium 0). Evidence of this is provided by the overlying ground moraine sheet (Photo 184 ▼) as well as by the glacigenic flank polishing forms (Photo 150 ☗; Figure 2 on the right above No. 116) with their typical flow lineaments, pressed and carved into by the flank pressure of an ice stream into the yielding loose rocks (Photo 184 ▼). Here, the general direction of the ice flow followed the incline of the largest valley, the Gar Zangbo, to the NW. Even back-polished triangular-shaped spurs have been developed between two side valley junctions (Figure 2 between Nos. 112 and 116; Photo 150 ☗ right margin). In the centre of the Gar Zangbo ablation moraines, i.e., drift-cover-sands have been preserved on the cross profile concerned (locality in Photo 150 ■ black). They wear the characteristics of ‘drift-cover- sands’ described by Kopp (1965) for Central Europe, i.e., they correspond to the definition of Hinze et al. (1989) (quoted from Bussemer, 1994): ‘Sand unterschiedlicher Korngrößen, z.T. mit geringem Schluffgehalt und einzelnen Kiesen, Steinen sowie evtl. Blöcken (Geschiebe, Findlinge), meist weniger als 1 m mächtig, gelegentlich mit einer Steinsohle, sonst ungeschichtet und strukturlos, Geschiebe können Windschliff aufweisen.’ Solgers (quoted from Kopp, 1965) has been the first, who interpreted material of that sort as cover moraine, developed from melted surface- or internal moraine, i.e., ablation moraine (ablation till). Figure 31 provides the analysis of the matrix of this ablation moraine (Figure 2, No. 113). Its characteristics are typically morainic, i.e., they show a peak in the clay. It is, however, lower than that of ground moraines. The silt, too, is compared with the sand less than in ground moraines. This is a result of the reshaping through meltwater during the sedimentation process of the ablation moraine. Figure 5, diagram 06.09.96/1, points to a predominance of 60% glacially crushed/freshly weathered quartz grains. The possible alternative of being ‘freshly weathered’ must be ruled out, because the sampling took place many kilometres away from bedrock. Since the outer edges of the quartz grains are at the same time rounded (see Figure 5: remarks), an increasing intake of glaciofluvial gravel material by the last-High Glacial (LGM = Stadium 0) inland ice – probably in the orographic left flank area of the Gar Zangbo – is confirmed (see above). But also from the orographic right valley side glaciofluvial gravels as well as glacier mouth gravel floors (Photo 182 □) and outwash aprons (/ /) have been transported to the still existing Late Glacial Gar Zangbo parent glacier and partly incorporated (Figure 2, No. 114). During the LGM the rather hilly relief of this region was completely covered by the inland ice (▬ ▬ 0 ▬ ▬). This also applies to the at least 120–150 m higher main valley bottom-, i.e., flat upland area of the upper Gar Zangbo, located ca. 20 km to the SE (Figure 2 between Nos. 117–119; Photos 151 and 181 ▬ ▬), though the framing mountain ridges are about 1000 m higher. From this a minimum thickness of the inland ice of over 1000 m can be derived (see also Photos 152 ▬ ▬, 180, 0 ▬ ▬). Besides the omnipresent moraine overlays (■), exaration furrows, gouged into the ground moraine by the inland ice (Photos 151 and 152 ▲) and thus preserving the direction of the ice flow, have been observed. These, as well as the roches moutonnées (Photo 151 the two ☗ on the very left and right; Photo 152 ☗ large) document, that at a certain time the inland ice has overflowed and formed the 4780 m-high transfluence pass (Figure 2, left of No. 118) on the watershed between the Gar Zangbo and the Langqen Zangbo in either a NW- or SE-direction. In the immediate pass area (Photo 152) as well as in the area 10 km to the SE (Photo 180), large erratic boulders, which lie on series of sedimentary bedrock in the underground and ‘swim’ in a fine ground moraine matrix, provide evidence of a High Glacial (LGM = Stadium 0) as well as a Late Glacial (ca. Stadia I–IV) ice cover. They have not been reshaped glaciofluvially. The classic condition of the ground moraine matrix is shown in Figure 29; the morphometry of the quartz grains can be derived from Figure 5, diagram 02.09./1. A portion of 26.5% fluvially polished (lustrous) grains testifies to an important influence of water, which at first appears to be untypically of the pass topography. However, since it can be deduced to the out-thawing of the over 1000 m-thick inland ice, it is in this context a further consistent indication. In the area SE of the 4780 m-transfluence pass, drumlin-like ground moraine ridges, which are relatively rare on the Tibetan plateau (Photo 180 ■, rear on the left) as well as roches moutonnées (☗ on the very right) and accumulative-erosive mixed forms from both of them have been preserved (second ☗ from the right and ■ on the very right; Figure 2, No. 118). This concerns a roche moutonnée (second ☗ from the right), the several metres-thick ground moraine nose of

CUMULATIVE FREQUENCY GRAIN-SIZE CURVE 02.09.1996/1




HUMUS CONTENT: 2,37 %

LIME CONTENT: 0,49 %

*Figure 29.* Locality: Photo 152 foreground; Figure 2, No. 118; at ca. 4780 m asl (aneroid measurement: 4615 m at high pressure). Matrix of ground moraine on the S-Tibetan plateau, bearing erratic granite boulders; sample taken from a depth of 0.15 m. The striking fine grain peak in the clay (11%) is typical of a moraine matrix in the development of which glacigenic trituration has taken part. As for the morphometry see Figure 5, diagram 02.09.96/1. (Sampling: M. Kuhle.)

which (■ on the very right) passes into a decimetres-thick ground moraine cover that clings streamline-like to its flatter luff slope. This arrangement points to a local ice flow direction in the Late Glacial (Stadia I–IV) from NW to SE (in Photo 180 from left to right). The extended, drumlin-like ground moraine ridge running in the same direction (■ rear on the left) consists also of 6–8 m-thick ground moraine. Today it is fluvially patterned by transverse rill-flushing.

Further SE of the 4780 m-pass, down the Langqen Zangbo valley, with decreasing height the valley bottom changes into a glaciofluvial landscape (Figure 2 from No. 118 via 119 up to 121). Near the surface the ground moraine (Photo 153 ■) has been more and more washed (□); a terrace landscape (Photos 154 and 179 □) from Late Glacial glacier mouth gravel floors (Nos. 1 and 2) reflects deglaciation – only interrupted by short glacier advances and -stagnations – and covers the ground moraine landscape which chronologically belongs to the High Glacial glacier level (— — 0 and — —). In the only 4380 m-high valley chamber of the settlement of Menshih, the Late Glacial glaciofluvial gravel covers (sander) pass with increasing terrace-height into a 50 m-high glaciolimnic terrace (Photo 155 □ black; Figure 2, No. 121). During Stadia III–IV an ice-dammed lake existed in this confluence area of the two source valleys of the Langqen Zangbo, dammed-up by an inland ice complex remaining down the main valley. Fifty-five km to the SW the glacial ice stream network of the Himalaya continues with the Nanda Devi- and Kamet massifs (Garhwal Himalaya) and the ca. 5000 m-high transfluence passes – the Tun Jun La (Marphi La) and Shashal La (Figure 2 below Nos. 129 and 128; Figure 12, I3). In the Alaknanda valley at 1100 m asl, near the settlement of Pipalkoti, the author had mapped the lowest ice margin positions of the outlet glacier tongues on the Himalaya S-slope here (Figure 12 below; between Nanda Devi and Kamet) (Kuhle, 1997b, p. 127) during his eight-week investigations in 1993 (Figure 1, No. 16). In the adjacent valleys Gohna and Nandakini (Nanda Ghunti-Trisul-group) the glaciers flowed down to at least 1800 m, i.e., 1200–1400 m (Kuhle, 1998, p. 87).

We follow now the SE source branch of the Langqen Zangbo upwards as far as the Kangrinboqé Feng (Kailash), Mapam Yumco (Manasarowa lake) and Gurla Mandhata (Figure 2, Nos. 126–128). Figure 2, No. 28 shows glacier mouth gravel floors, located approximately 12 km SE of the settlement of Menshih, which have been deposited from the NE-slope of the Gangdise chain – the orographic right flank of this valley (source branch) – onto the valley bottom (Photo 156 □ 3-1). These are Late Glacial gravel floors No. 3-1, i.e., they belong to the glacier ends of Stadia II–IV (Table 1). (■) marks the oldest Late Glacial end moraines preserved, fringing an upstream tongue basin from which the gravel floors have been accumulated. Their upper layers (□ 1 = gravel floor No. 1 in Table 1) have covered the older gravel floors, thus burying the base of the moraines (■) by their aggradation. The large granite boulders of the moraine (●) have been displaced by the 'high energy flow' of the meltwater, bunched together by the glacier mouth, over a distance of several hundred metres. The accompanying Late Glacial glacier tongue – and at the same time many adjacent parallel glaciers – flowed from the trough valley (∪) of the Gangdise Shan WSW-slope down into the mountain foreland. Several of these local ice streams emerged from cirque depressions (○). The gravel floor (□) has mantled the early-Late Glacial (Stadium I) and High Glacial (Stadium 0 = LGM) ground- and ablation moraine at a thickness of over 10 m. This gravel-thickness is documented by the exposures in the fluvially eroded small valleys, which have then dissected the gravel floors during the neoglacial to historic glacier retreatment in the Holocene (∇). During the High Glacial the fjell-like mountain land, too, was completely covered by the Tibetan inland ice (— —). In this valley excavation area a corresponding to equal development of the glacial landscape can be observed 15–16 km further SE (Photo 157).

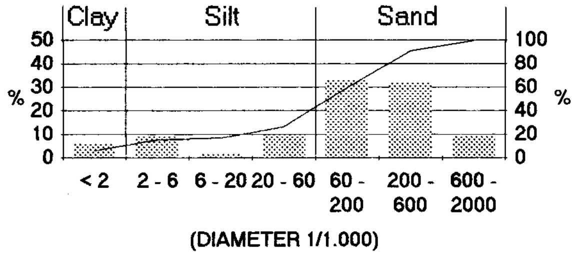
Still ca. 100 m further up this valley (to the SE), Late Glacial glaciofluvial accumulations are nearly completely absent. A landform of ground polishes and roches moutonnées predominates, covered by ground- and ablation moraine (Photos 158 and 159 ■ and ▲; Figure 2, Nos. 122–125). The cause of this change is that up here the Late Glacial ice cover has existed longer, i.e., up to Stadium II (Taglung Stadium; Table 1). Apart from that, the final ice decay with increasing height ought to have been more and more dependent on sublimation ablation instead of melting ablation. Not least the concentration of the meltwater runoff has also decreased with increasing height and thus its geomorphological efficacy has declined. The washing-down of the immediate ablation moraine surface – which has led here to the development of drift-cover-sand (■ foreground) – has only been exceeded by the glaciofluvial effect at the immediate mountain foot of the Kangrinboqé Feng-chain. Here are flatly embedded, late Late Glacial gravel fields (Photo 160 □) which, bundled together by the mountain valleys, emerged into the foreland. Until Stadium III (Dhampu Stadium; Table 1) the persisting glaciers of the higher mountain valleys have reached the level of the Tibetan plateau (Photos 161 △ III; 162 ■ III; Photo 163 ■ black) and accumulated their glacier mouth gravel floors (Photos 160 and 162 □). During Stadium IV (Sirkung Stadium; Table 1) the glacier ends lay in the valley exits (Photo 163 IV) and – retreated to a greater extent – in the valleys (Figure 2 right of No. 121), depositing fan-shaped gravel floors of the 'cone sander'-type in and out of the valley exits (Photos 160 and 162 ▲).

In this large valley excavation area or S-Tibetan plateau area S- to SSW of the Kangrinboqé Feng (Kailash)-chain, decakilometres-extended central hills are striking (Photo 161 ■ white, centre). They are located N and between the two lakes Langa Co and Mampa Yumco (Manasarowa) (Photo 164). During the Late Glacial Stadium II these hills have been accumulated as a medial moraine-, i.e., kame complex-fringed on all sides by glacier ice-between the ice lobes, which flowed down from the mountain systems of the Gurla Mandhata (No. 1: 7739 m) from the S and the Kangrinboqé (Kailash, No. 2: 6660 m) from the N into the foreland (Photos 164 and 165 ■ II). Before that, a completely covering glaciation had existed (Stadium 0 – I) (Photos 158–164: — — 0, 0 — — and — —). Figure 30 (locality: Figure 2, No. 124) shows the condition of the material of this ice margin deposition (medial moraine, i.e., glacigenic to glaciofluvial glacier margin- to bank formation of the 'kame'-type), which at least near to the surface has been glaciofluvially washed. The fine grain peak, shifted towards the silt (10% fine silt) shows the meltwater activity as well as the content of ca. 30% fine- and medium sand. Eighty-three % of the quartz grains are either dull-eolian or fluvially polished (lustrous); only 17% are glacially crushed, i.e., freshly weathered (*in situ*). This also confirms the displacement or/and reworking of the glacigenic depositions (Figure 5, diagram 02.09./2). In the later Late Glacial during Stadium III, the lake basins of Langa Co (Photo 169) and Mapam Yumco (Photos 164 and 167 □) have been eroded as adjacent glacier tongue basins by two piedmont glacier lobes, flowing down from the Gurla Mandhata from the S (Figure 2, No. 125).

During this decay of the Late Glacial inland ice, i.e., later ice stream network and piedmont glaciers – accompanied by an increasing ELA – the ice streams from the Gurla Mandhata massif S of the lakes obtained a rising glacio-geomorphological influence. The reason for this are the important glacier feeding areas at over 7000 m of this massif, which shows several summits and a width of 50 km at its base. Originally, during the High Glacial (LGM = Stadium 0), when the ELA ran 400–500 m lower and a largely connected Tibetan ice existed, the direction of the main ice flow was approximately reverse, i.e., out of the centre of Tibet and therefore from NE to SW.

The end moraine trains, bordering the two lake basins, and the ground- and ablation moraine covers which have been flattened out in the basins, are evident (Photos 164, 166, 167 ■ III). During a youngest Late Glacial glacier advance, geomorphologically and thus relatively classified as belonging to Stadium IV, the foreland glacier tongues

CUMULATIVE FREQUENCY GRAIN-SIZE CURVE 02.09.1996/2

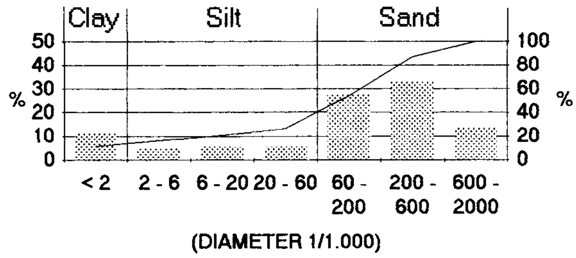



HUMUS CONTENT: 4,81 %

LIME CONTENT: 14,43 %

*Figure 30.* At ca. 4840 m (aneroid measurement: 4570 m asl at high pressure), ca. 110 m above the Mampa Yumco level (Manasarowa Lake) at 30°46′ N/81°21′ E; Figure 2, No. 124, between Langa Co and Mapam Yumco. Ground- or end moraine matrix of the S-Tibetan plateau area visible in Photos 164 (■, ■ II and III), 166 ■, ■ III and 167 ■, ■ III), which is completely covered with moraines. Sample taken from an exposure wall from a depth of 1.00 m beneath the surface. The bimodal course of the curve with two fine grain peaks – typical of ground moraine – is obvious. Compared with characteristic ground moraine, the finer fine grain peak (left) has been shifted from the clay to the fine silt. This points to a washing of clay portions which took place by Late Glacial (Stadia II–III, Table 1) meltwaters during the down-thawing of the inland ice, i.e., later ice stream network. As for the morphometry see Figure 5, diagram 02.09.96/2. (Sampling: M. Kuhle.)

CUMULATIVE FREQUENCY GRAIN-SIZE CURVE 06.09.1996/1




HUMUS CONTENT: 3,11 %

LIME CONTENT: 12,59 %

*Figure 31.* At ca. 4510 m (aneroid measurement: 4365 m asl), matrix of ablation moraine- to 'drift-cover-sand', taken in the southern area of the Tibetan plateau from a depth of 0.2 m. Locality: Gar Zangbo, i.e., upper Indus valley (Kaerh Ho according to ONC 1:1 million H-9) (31°38'30″ N/80°21′ E; Figure 2, No. 113). The clay content (11%) shows the characteristics of ground moraine. The pronounced bimodal course of the columnar diagram is also typical of moraines. The important medium- and fine sand portions (ca. 32% and 28%) are characteristic of ablation moraine or 'drift-cover-sand', which in comparison to ground moraine is coarser. As for the morphometry see Figure 5, diagram 06.09./1. (Sampling: M. Kuhle.)

from the Gurla Mandhata have newly reached the southern regions of the two lake basins. They have overthrust several end moraine hills and roches moutonnées, mantled by older ground- and ablation moraine (Photo 167 ■ black on the very right; 168 ■ III–IV; 169 ↗, ■ ☁). At the same time ground- and lateral moraine remnants of Stadium IV have been preserved in the immediate valley exits of the Gurla Mandhata massif (Photo 168 IV ↙). Still today the valley exits, i.e., highest cross profiles of the typically glacigenic trough valleys (Photos 168 and 169 ∪) are reached by glacier tongues.

Owing to the important dimensions of these tongue basin lakes (ca. 30 km longitudinal extension), storms create a heavy surge. This resulted in an undercutting of the end moraine fringing the shore, so that a fresh cliff with a secondarily (limnical) steepened inner slope of moraine has developed (Photo 166 ▲).

In this study the High Glacial inland ice level – reconstructed here only with its minimum height (– –) – is a focus of interest. On the Gurla Mandhata side of the area treated, this level has been deduced from classic glacially triangular-shaped slopes, which have developed on ‘glacially truncated spurs’ (Figure 2, No. 126; Photos 168 and 169 ◒ ◥ background). The same, i.e., synchronically highest minimum ice level (Photos 168 and 169 – –) was found on the Kangrinboqé (Kailash-) side of this valley excavation area at also 5700–5900 m asl (Photos 163–165 – –). It is documented by ground- and ablation moraine overlays with erratic material on the slopes (Photos 159, 160, 162, 165, 170 ■ black in the background) as well as by mountain spurs, rounded by flank polishing (Photos 159, 160, 162, 163, 170 ◒) and mountain cupolas. The Gurla Mandhata peak (Photos 168 and 169: No. 1) has towered above the inland ice level by ca. 1800 m; the Kangrinboqé (Kailash) (Photos 163–165: No. 2) by ca. 700 m. These findings argue for a local inland ice thickness of ca. 1000–1200 m.

The field observations introduced here, can be seen in a large-scale connection with the ice cover reconstructions and ice margin determinations carried out by the author during his field expeditions in 1976 and 1977 as well as in 1994–1995 (Figure 1, Nos. 1 and 18) in the Dolpo and Kanjiroba massif NW of the Dhaulagiri Himalaya, i.e., likewise on the S margin of Tibet and through the Himalaya-main-ridge to the S. Here, 150–170 km SE of the Gurla Mandhata, a connected High Glacial ice stream network has been reconstructed (Figure 12 left above the Dhaulagiri) which as I3 was directly linked with the Tibetan inland ice (I2) (e.g., Kuhle, 1982 (figures), Figure 8, 1983). Its outlet glaciers flowed into a large Bheri Khola glacier, discharging W of the Dhaulagiri through the Himalaya-main-ridge far down into the Bheri gorge. This lowest parent- and outlet glacier still had a thickness of at least 400 m at 1900 m asl – as could be evidenced by erratics found at the settlement of Tripurakot (Kuhle, 1997b, p. 127; 1998a, p. 224). Accordingly, during the LGM (Stadium 0) a connected inland ice surface – and further S and SE an ice stream network pierced by the relief – has existed from the Kangrinboqé- (Kailash-) chain and the Gurla Mandhata as far as the Himalaya. Owing to a joint main run-off of the ice towards the Himalaya and through the Himalaya main ridge, the different surface levels have communicated with each other.

### *6.1. Reconstruction of the High Glacial maximum glaciation of the Kangrinboqé- (Kailash-)massif in the S Tibetan Gangdise Shan system (Figure 2, Nos. 120–123, 127) and its embedding into the Tibetan inland ice*

On the NE flank of the large excavation area, formed by the 6660 m-high Kangrinboqé- (Kailash-) massif, late Late Glacial glaciers (Stadia III and IV) have upthrust local end moraines, which interrupt the fine-grained High Glacial (LGM = Stadium 0) ground- and ablation material on this valley slope (Photo 165 ■ black, background) with their coarse-blocky composition (Photo 163 ■ black; 168 ○; 169 ■ III–IV). This spatial distribution pattern of the preservation of moraines occurs in particular clear at the exit of one of the large orographic right side valleys, the ‘Kailash-NW-valley’ (Photo 170). The late Late Glacial (Stadium IV) Kailash-NW-valley glacier has only just left its side valley with the tongue end, pushing its end moraine (■ IV) into the foreland. At the same time High- to early-Late Glacial (Stadia 0 to I, perhaps also II) ground- and ablation moraine (the left ■ black) has been overthrust and remoulded. During the LGM the glacigenically rounded montain ridges fringing the main- as well as the side valley (◒; Figure 2, Nos. 121–123) were covered by the inland ice (– –). Thus, the ‘Kailash-NW-valley’ received its classic trough form (Photos 170 and 171 U; Figure 2 below No. 127) during the High Glacial and still in the Late Glacial by the decreasing ice filling of a valley glacier. During the Late Glacial as well as during the inland ice phase – when the ice filled the entire trough valley – the ice flow followed the valley incline. As a result, varying ice levels and ice thicknesses from the High- to Late Glacial (Photos 172 and 173 – – 0 and – – I) can be differentiated in this mountain system, but the glacigenic shaping of the valley bottoms at a reduced ice thickness remained largely unchanged with regard to all connected side valleys and source basins of the 2nd and 4th degree (Photos 171–178). Nevertheless, a remarkable inversion of the preservation of glacial forms in these valleys can be observed. This concerns the valley sections as far up as to the glaciers still existing postglacially, i.e., during the Holocene up to the present (Photos 174 and 175), which are located at a shorter and shorter distance from the valley head: the trough valley forms and their elements as, e.g., flanks, polished concavely below and convexly above (Photos 171–173 ◒ ◥), are preserved more and more poorly towards the up-valley younger glacier positions (Photos 177 and 176 ◥◒). In places where glaciers still exist, i.e., in most upper valley chambers, the purely glacigenic valley- and flank form type occurs in the least classical and clear (i.e., the most degraded) form (Photos 174 and 175). This spatial-chronological form sequence makes obvious that the late Late Glacial to postglacial valley glaciation has reworked the older, i.e., early-Late Glacial to High Glacial features by undercuttings, so that they have been more destroyed than preserved. The same applies for the sharpening of the intermediate valley ridges – being relatively round in the High Glacial (Photo 174 ◒): these roundings, too, have been increasingly destroyed and shaped into sharp ridges of solid rock and blocks during the late Late Glacial (Photos 174 and 176 between the roundings ◒). A corresponding glacigenic reworking with regard to a destruction of the roundings and roughening becomes evident in the area of the cirque glaciation, effective as far as recently. Small cirques and nivation niches have very quickly destroyed the roundings of intermediate valley ridges as well as the polishings of the upper slopes of trough valleys (within a few millennia) (Photos 176 and 178 ○). The transition from a good trough valley preservation to an extreme glacigenic destruction of older glacial features can be evidenced between Stadium I (early-Late Glacial) and Stadium III with glacier levels already heavily lowered towards the valleys. This transition becomes obvious in the background of Photo 178, where the bottom of the 'Kailash-NW-valley' at the level where it falls below the 4750 m isoline, has best preserved the trough form (the three ▲ in the centre) eroded during the High Glacial (pertinent minimum inland ice surface – – 0). This valley profile is also shown in Photo 171. Above 4800 m asl the destruction of the glacigenic valley relief through younger ice fillings and periglacial weathering is dominant. The phenomenon of a better preservation of glacigenic old forms at a minor sea level has been described by the author for the first time with regard to the Dhaulagiri Himalaya S slope. There he has documented a lower altitudinal level at which glacial features, in relation to their higher age, are strikingly better preserved (Kuhle, 1982, pp. 59–61; 1983, pp. 156–162).

During the High Glacial (LGM) such rock sharpenings by undercuttings can only be found over small areas, that is to say at places at which high summits have towered above the Ice Age inland ice sheet. This applies for the main peak of the mountain group concerned, the 6660 m-high Kangrinboqé Feng (Kailash). Therefore the upper 700 m of its summit show especially sharp crests (Photos 163 and 165: No. 2 above – –). With the exception of this high summit, there was no great difference between the inland ice surface in the area of this mountain group and the inland ice surfaces of the main valley excavation area connected to the SW as far as the Gurla Mandhata. However, for theoretical reasons a slightly cupola-shaped up-doming is to be suggested, because: (1) the valley structure of this mountain group occurring on the underground of the inland ice (Photos 171–178) has impeded the ice discharge and generally enhanced the friction, and (2) the valley bottoms are located about and over 5000 m asl, i.e., 300–500 m higher than the main valley bottom in the foreland, so that the inland ice bottom – lying here several 100 m above the High Glacial ELA (running at 4600–4700 m asl) – might have been frozen to the valley bottoms over large parts.

### *6.2. Summary of Section 6*

In the 300 km-long SE–NW extent of the Mapam Yumco test area (Manasarowa lake; Figure 2, No. 125) down the upper SE Langqén Zangbo (up to Figure 2, No. 121), across the 4780 m-pass (No. 118) and the upper Gar Zangbo (S source branch of the Indus) as far as a valley chamber 250 km up-valley from the settlement of Leh (Figure 2, No. 131), field- and laboratory findings provide evidence for a High Glacial (LGM = Stadium 0; Table 1) cover of an inland ice and ice stream network with a glacier ice thickness of over 1000–1200 m. The arrangement of the positions of the indicators in this investigation area, as well as their arrangement with regard to those of the neighbouring and immediately adjacent research areas (Section 5), indicates the connection and large-scale relief-covering linkage of the ice complex reconstructed in this section, with the inland ice deduced from the observations in other areas (Figure 12 between the line of I2 right, up to left above Kamet). In the test area of Section 6 the ice has been drained by the valley courses of the Langqén Zangbo and Gar Zangbo to the W, i.e., WNW. Channelized by the Langqén Zangbo, it flowed down towards the Himalaya main ridge, following the incline of this antecedent transverse valley through the W Himalaya chain between the 7775 m-high Kamet and the 7029 m-high Deo Tiba-massif (Figure 2) in the direction of the settlement of Simla. The steep incline of this last stretch and the only low altitude of sea-level, resulted in a markedly decreasing thickness of this outlet glacier of the Himalaya ice stream network (I3). Here (Figure 2 left of Kamet), the glacier surfaces of the main valley were already located below the climatic snow line (ELA), which the author in this Himalaya section has calculated and interpolated as running at 4100 m asl during the LGM (cf. Figure 2). The Gar Zangbo- or uppermost Indus-outlet glacier followed the incline of the valley bottom as far as at least 50 km SE up-valley of the settlement of Leh, where it might have calved into the High Glacial ice-dammed lake of Leh at 3100–3300 m asl (Figure 2). Up to there the outlet ice flow has been supplied by steep glacier branches of mountain valleys from the inland ice of Central Tibet, i.e., from the Gangdise Shan (Figure 2 between Nos. 105 and 115; cf. Section 5) as well as from the Ladakh Range in the NE and the Zaskar Mountains in the SW of the upper Indus valley furrow. As is documented by the upper polish line of the lowest valley trough profile investigated here (Figure 2, No. 106), the ice thickness had still not significantly decreased at a distance of ca. 200 km from the glacier end.

## 7. Reconstruction of the maximum Pleistocene glaciation of Central W-Tibet with the Aksai Chin and E Lingzi Thang between the Basin of Shiquanha (Ali) in the S and Haji Langar (Kuen Lun) in the N (Figure 1, No. 20 Aksai Chin; Figure 2, Nos. 132–168; Figure 12 above Kamet up to Kuen Lun)

The immediate E connection to the area treated here – and this is of importance for the large-scale arrangement of glacial indicators – is provided by the findings introduced in Section 5 (Figure 1, No. 20 SE of the Aksai Chin). The immediate S connection is established by the field- and laboratory data and their interpretation recorded in Section 6 (Figure 1, No. 20, area NW of the Kailash (see above). Though a consistently recorded field profile exists for this section, the spatially complete implementation of the two previous sections permits one to describe only two representative main areas here: (1) the Nako Tso area (Kingdom of Rutog) (Figure 20 below Aksai Chin; Figure 32 Na-K'ot Ts'o; Figure 2, Nos. 140–147) and (2) the Aksai Chin (Figure 1, No. 20) (Figure 2, E Lingzi Thang, Nos. 155–163). The glaciogeomorphologically detailed observations of the 100 km between the Basin of Shiquanha and the basin of the Nako Tso (Basin of Rutog) are completely presented with regard to their arrangements of the positions in Figure 2 (Nos. 132–139). This applies also to the 85 km between the Basin of Rutog and the SE Lingzi Thang (Aksai Chin), which are spatially completely mapped with Nos. 146–154. As a result, connected ice stream network- and inland ice covers could be reconstructed for these two intermediate areas, the overall expansion of which amounts to ca. 200 km (cf. Figure 32 for the areas adjacent to the depression of Na-K'ot Ts'o).

### *7.1. The prehistoric maximum glaciation of the Nako Tso Basin as the lowest region in W Tibet (Figure 1, No. 20 below Aksai Chin; Figure 2, Nos. 140–147)*

In the sense of a classic key locality, findings from the arid region of the Nako Tso in Central W Tibet are exemplarily important for the evidence of a total prehistoric glaciation of Tibet. Therefore they are introduced in a somewhat more detailed manner: this lake (Photo 192) is located far away from every presently glaciated mountain group at only 4220 m asl (4218 m = lake level) – that is to say in a basin with the topographically lowest position of the whole of Central Tibet. The shore line undercuts the slopes of the surrounding hill chains, fringing the lake basin, so that fresh cliffs with wave-cut notches (Figure 2, No. 141) have been developed. This evidences the Nako Tso as being a young lake, later filled into a relief of a different, i.e., non-limnical origin. The undercut slope profiles are not solely solifluction slopes. At many places there are ground- and ablation moraine covers (Photos 192 and 193 ■) undercut by the lake level. Additionally, even glacially rounded mountain ridges (streamlined hills) and perfectly preserved, i.e., very young roches moutonnées, the slopes of which have been limnically undercut, occur quite often (Photo 192 ⇧). This documents, that the Nako Tso – despite its most arid and topographically lowest position – occupies a plateau area which in the last glaciation (LGM to Late Glacial: Stadia 0 to ca. II; cf. Table 1) must have been covered by the inland ice (Photos 192 and 193 ‒ ‒0‒ ‒; Figure 34). At widely scattered positions erratic granite boulders have been found, which confirm this observation (Figure 2, Nos. 142 and 143). Several indicators are shown in Photos 192 (↗) and 193 (○ ↗ ↙). They are erratic boulders lying at the E end of the lake, i.e., in a position towards the centre of Tibet. Metre- to room-sized (Photo 193 ○), they either lie on a relief-covering ground- and ablation moraine overlay (■) or they are incorporated into the moraine, i.e., 'swim' in the fine groundmass – this concerns mainly the small granite boulders (Photos 192 and 193 ↗). The ground moraine (■) and the light erratic granite boulders (↗ ○) lie on dark metamorphic sedimentary bedrocks (▼). Erratic granite boulders as these have been found up to approximately the culminations of hill- and mountain ridges (Photo 193 ↗). But also at the places, where they have been deposited on lower slopes (Photo 192 ↗; Photo 193 ○), granite bedrock is absent on the upper slopes (Photo 192 ☁ left; Photo 193 ▼), so that a sheer down-slope transport of the boulders can be ruled out. Thus, the long-distance transport by glacier ice is unambiguously documented. At a distance of ca. 50 km the author has mapped granite bedrocks in a valley S of the settlement of Rutog, which he considers to be a possible area of origin (Figure 2, Nos. 136 and 137; 33°11′ N/79°50′ E). However, this valley does not lead down from a high mountain group to the Nako Tso basin. On the contrary, its catchment area with its elevations and dimensions corresponds to all neighbouring catchment areas of the Nako Tso basin, which in their hill- and mountain topography are very similar to each other and thus as glacial catchment areas are equivalent. This leads to the assumption that at a same and therefore large-scale simultaneous ELA-depression (during Stadia 0 to II at = maximum ca. 1300–1000 m; cf. Table 1) by necessarily the same amount, the glacier ice supply from all surrounding areas into the Nako Tso basin must have been equally rich and intensive. On the other hand, this also suggests the glacigenic transport of those granite boulders from other valleys, in which granite bedrock might occur. At the same time these considerations make clear, that the erratic boulders provide evidence for a completely covering ice in this area (‒ ‒0‒ ‒). In Figure 2 a snow line depression to ca. 4400 m asl, i.e., to 200 m above the lake level of the Nako Tso and – according to the depth of the lake which has to be added – still somewhat more above the Nako Tso basin bottom (see Figure 34, Na-K'ot Ts'o) is indicated. So, this was one of the few basin- and valley bottom areas of Tibet located below the High Glacial climatic snow line.

#### *7.1.1. Insertion concerning large-scale granulometric and morphometric analyses of moraine matrix*

On a 4800 m-pass (Figure 2, No. 147) 50–60 km E of the eastern end of the Nako Tso, a further expressive sample of ablation moraine matrix has been taken, testifying to a prehistoric ice transfluence and the inland ice contact from the Nako Tso- to the Aksai Chin area (Figure 33). There is no fluvial catchment area on this pass culmination, so that water can neither have caused any transport recently nor since deglaciation. This means, that the reduction of the clay peaks close to the surface to merely 4–5%, which is characteristic of ground moraine, can only be explained by the Late Glacial down-thawing of the inland ice. Accordingly, the ablation moraine character is documented. This observation is supported by 75% quartz grains with a dull(eolian)/lustrous (fluvial) forming and only 25% glacially crushed/freshly weathered quartz grains (Figure 5 diagram 07.09.96). Eolian accumulation has to be ruled out on this wind-exposed pass saddle, lacking wind-shadow. Because of the only small lime content (16.72%) of the sample (Figure 33), a fresh weathering from the surface of the limestone bedrock in the underlying bed is out of question. Owing to these laboratory analyses only the indication of an ablation moraine is topographically acceptable.

Figures 4–34 show a selection of sedimentation analyses of ground- and ablation moraine ground masses found on the glaciogemorphological profiles, which is representative for the S- and Central Tibetan area as far as W Tibet treated in this study. According to the comparative method, significant cases have been placed next to corresponding samples of the Laurentide Ice Sheet in N-America. With their bimodal course of the curves and more or less marked peaks in the clay or fine silt, the laboratory results confirm the field

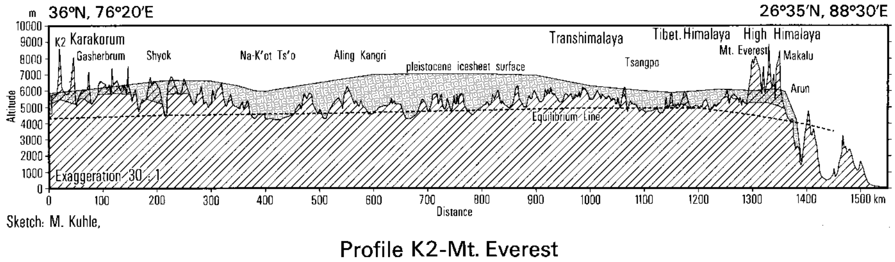



*Figure 32.* Cross-profile through the Tibetan plateau covered by the reconstructed inland ice, from the Karakorum as far as the Himalaya; cf. Figure 12; Nos. 1, 2 and 3.

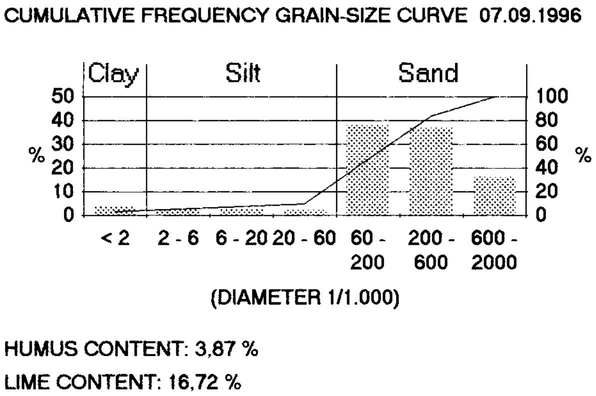



*Figure 33.* At ca. 4800 m (aneroid measurement: 4750 m asl) ablation moraine matrix in Central W-Tibet taken from a depth of 0.2 m in an area with limestone bedrock in the underground. Locality: 55 km away (to the E) from the E-end of the Nako Tso (Photo 193) on the caravan route from Rutog to Haji Langar over the Aksai Chin; 33°43′10″ N/80°27′ E; Figure 2, No. 147; cf. Figure 5, diagram 07.09.96. (Sampling: M. Kuhle.)

analyses and the morainic character of the material after the significance criteria of Dreimanis (1979,1982), Dreimanis and Vagners (1971), Lundqvist (1984, 1989), and others. The samples have been taken in the order of their numbering in Figures 4–34 at the following localities shown in Figure 2, Nos. 5, 7, 10, 11, 12, 13 (as far as here see also Figure 3) 23, 33, 41, 59, 61, 75, 83, 95, 118, 125, 133, 147, 157.

### *7.2. The geomorphologically and Quaternary-geologically verifiable maximum glaciation of the Aksai Chin (Akhsai Tshin) (Figure 1, No. 20; Figure 2, Nos. 154–167)*

The Aksai Chin region is a test area in Central W Tibet connected to the N, which is located E of the high plains of the Lingzi Thang. Trinkler (1932, pp. 20 and 75) was the first researcher, who determined an extended Ice Age glacier cover for the adjacent Lingzi Thang area. He was contradictory to De Terra (1934, note 32). As for the Lingzi Thang the latter stated: ‘The ice cover must have been sporadic, and quite unlike that of the neighbouring ranges’. According to his investigations being the basis of this statement, the snow line depressions amounted to at most 250 to 500 m (De Terra, 1934, p. 28, Figure 16) during the two last High Glacials (Riß and Würm, i.e., LGM). According to De Terra this means as far as the Panggong Tso area (Figure 2, left of Nos. 139–141), located only 100 km W of the Nako Tso basin, which the author (Section 7.1) has evidenced as having been completely covered with ice (Figure 2, Nos. 141–143). The interpretation of Huntington (1906) is more consistent with the research results presented here. He considered the neighbouring Panggong Tso to be a glacigenic lake.

The Aksai Chin area concerned, which continues our profile (Figure 1, No. 20) to the N, consistently lies at a height of over 5000 m asl (Figure 2, Nos. 154–167; Figure 12 left of Mawang Kangri). It is made up from more or less metamorphic sedimentary rocks as, e.g., clay-, silt- and sandstones, i.e., phyllites (Photos 194–200). Today it is experiencing a heavy weathering on the surface, caused by the freezing and thawing of the continental upland climate (Kuhle, 1990c). However, a frost debris veil is largely absent. At the few places at which it exists, it is at most several decimetres-thick. During the Holocene it has been in part accumulated by the snow meltwater to flat alluvial debris fans a few metres thick. Instead of a debris mantle developed by frost weathering *in situ*, a covering ground moraine overlay is dominant (Figure 2, Nos. 155, 157, 159, 163, 166; Photos 194–200 ■). The features which determine the actual picture are prehistorically glacigenic, too. They are forms of perfectly rounded roches moutonnées and mountain ridges, partly streamlined lengthwise (Figure 2, Nos. 150, 153, 156, 160–165; Photos 194–200 ▲), of transfluence passes with flat, trough-shaped cross profiles (Figure 2, between Nos. 154 and 159; Photos 194 and 198 in the fore- and middleground; 199 ∪) and also of glacial horns sharpened by the Late Glacial ice sheet (Stadia I or II to IV) (Figure 2 between Nos. 160 and 156 and on the right of 162; Photo 195 No. 8; 199 No. 9). Almost all these features – with the exception of the glacial horns and the high-lying ridges of the glacially streamlined hills – are mantled by ground and ablation moraine decimetres- to several metres in thickness (Figure 2, Nos. 157, 158, 163, 166, 168). Figure 34 shows the typical grain size composition of its matrix in pass- and saddle positions, as well as on flat mountain-, i.e., high plateau ridges, from which the meltwater flowed down to all sides during deglaciation. The clay peak, typical of ground moraine, is still clearly developed, but (with a portion of only 6%) has undergone a loss in height – obviously because of washing and flushing. This is already an indication of ablation moraine. The high portion of 66% dull/lustrous quartz grains (Figure 5, diagram 08.09./1) point to a morphoscopic vergency to glaciofluvial and later eolian shifting during the process of down-thawing. Accordingly, there are also some indications of ‘glacial drift-cover-sand’ (see above). This moraine contains ‘swimming’ erratic granite boulders (Fig-

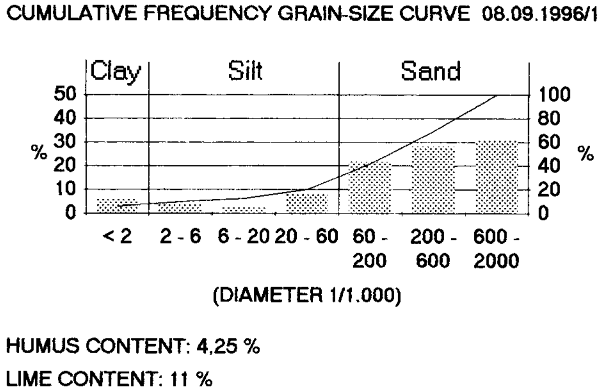



*Figure 34.* At ca. 5200 m (aneroid measurement: 5055 m asl) in W Central Tibet on the Aksai Chin, in the area of the E Lingzi Thang plateau, ablation moraine matrix (drift-cover-sand?) taken from a depth of 0.2 m. The ground- and ablation moraine cover, which has been somewhat solifluidally dislocated, i.e., secondarily moved by cryoturbation, contains several large granite boulders (see Figure 2, No.157). The concentration of sand of the sampling- layer on this culmination topography (flat slopes fall away on all sides) becomes only understandable by reference to the short glaciofluvial washing during the thawing-process of the inland ice. Locality: caravan route over the Aksai Chin from Rutog (settlement of the kingdom of Rutog) to the caravan settlement of Haji Langar on a pass ridge between the localities of Photo 195, located 5 km S, and Photo 196, located 5 km N of this digging; 34°29′30″ N/80°24′40″ E; cf. Figure 5 diagram 08.09.96/1. (Sampling: M. Kuhle.)

ure 2, No. 157). In addition, the 11%-lime content points to a long-distance transport, because limestone is absent in the siltstone underground. During the High Glacial (Würm, LGM, Stadium 0) and as far as into the older (early) Late Glacial (Stadium I), the relief concerned was completely covered by the inland ice up to beyond the summit No. 8 (ca. 6100 m, Photo 195) and No. 9 (6480 m, Photo 199). Thus, the ice must have been at least 1300–1400 m thick (Photos 194–200 ▬ ▬ 0, ▬ ▬ 0, ▬ ▬; Figure 12, I2 on the left above the Kamet). Later, between Stadia I and III (cf. Table 1), the glacial horns (Photo 195 No. 8; Photo 199 No. 9) have increasingly pierced the inland ice surface. Only during the youngest (= late) Late Glacial (ca. Stadium IV) has the ice cover partly melted down as far as the rock and its ground moraine overlay and was full of holes, so that meltwater lakes could develop. At many places of the Aksai Chin the basin-, i.e., high valley bottoms or the excavation areas are covered by stillwater sediments or limnically remoulded ground- and ablation moraines (Photos 196 and 197 □ white; 199 □ black on the left).

These late Late Glacial primary meltwater lakes, developed as relatively persevering ice- or glacier-dammed lakes in an ice stream network full of holes, were approximately located at the places where the current residual lakes, now largely containing salt- and brackish water (Photos 196, 197, 199 □ black), i.e., the already silted-up bottoms of lacrustine clays or -marls (Figure 2, No. 150 below 161) do still exist. The prehistoric lake level positions of these glacier-dammed lakes are preserved decametres above the levels of the present-day lakes lacking an outlet. They are indicated by lake terraces several hundred metres in length, which in many places rise like stairs, showing water lines (Figure 2, No. 160; Photo 196 ▼) and wave-cut notches (cliffs) (Figure 2, No. 159, on the right of 160; Photos 197 ▲; 199 ↿). Their reshaping caused by periglacial frost weathering is only insignificant. These lakes could not have been developed without the up-damming by the glacier ice, i.e., according to the topography they would have run off up to much lower level positions. The ice, melted down from the High Glacial Stadium (0 = LGM) of the inland ice to the late Late Glacial ice stream network, consisted at the same time of more or less large and small dead ice complexes- and blocks. This can immediately be deduced from the upland topography of the Aksai Chin, being on a large scale only little declined, but showing numerous small-scale depressions and thus counter-slopes (cf. Photos 197, 198, 200). The dead ice bodies which took part in the damming-up of the lakes, remained the longest on the hill ridges and rock thresholds – raising them to higher barriers –, because the minor albedo of the ice-dammed lakes must have led mainly to an enlargement of the ice-free areas in the depressions. A geomorphological indication for this glaciological explanation of the formation of ice-dammed lakes on undulating upland plains is the fact, that no overspill breaches have been developed there (cf. the saddles in Photos 197 and 198). In normal lake landscapes the spill-overs connect the several lake basins by fluvial forms, thus showing a consistent thalweg down from one lake to the other. Accordingly, the following deduction is suggested: because fluvial spill-overs are largely absent in the saddles between the glacigenic polish depressions, one can infer a discharge of this ice-dammed lakes, which took place syngenetically to the thawing of the ice as far as somewhat above the level of the currently remaining lakes. This discharge, which happened suddenly upon the raising of the ice-dammed lake levels by the upwelling and following breaking away of the ice barriers, is evidenced by the development of classic ‘spillways’ (Photos 194 ⇓; 200 ↓). It concerns concise V-shapes, that have been abruptly fluvially cut into the glacigenically-rounded hill landscape. Their major characteristic is, that they cut the High Glacial ground polishing thresholds only up to a certain depth, but not totally. After a local break of an ice barrier, the water of the ice-dammed lake suddenly – within minutes and up to a quarter of an hour – gushed into the basin of a neighbouring ice-dammed lake, until the new mutual lake level was reached. At this level, high above the present-day basin bottoms and the base of the dissected rock thresholds, the cutting of the V-shapes has come to an end. Spillways of that sort have no a fluvial connection to the present-day relief, i.e., their strikingly fresh features cannot be explained by the current drainage and thalweg development, always following the large-scale direction of incline.

The glaciogeomorphological observations introduced here are confirmed by the limnological study of Van Campo and Gasse (1993) by means of the Tso Kaerh Hu (Longmu Co; Photo 196) and the W adjacent Sumxi Co, which attains only a quarter of its extension. A 10.50 m-deep drilling of the latter one indicated a basal C14 age of ca. 12 700–10 000 yr BP. Accordingly, it has to be classified as belonging to the ‘Late Glacial period’ (Van Campo and Gasse, 1993, p. 306). This corresponds to an initial lake development

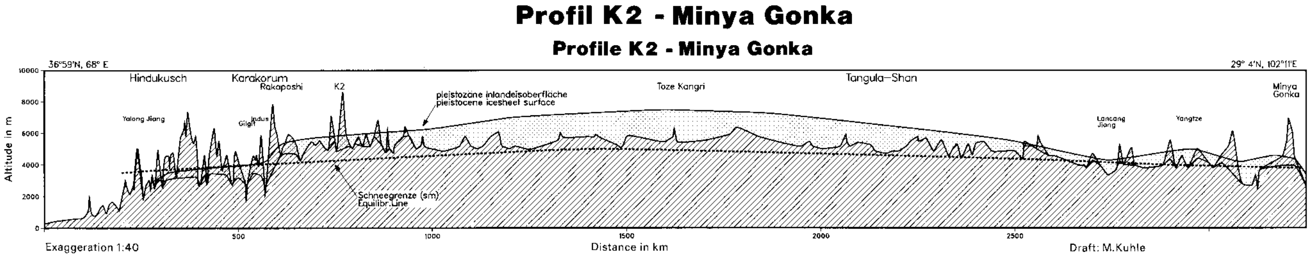



*Figure 35.* Longitudinal profile through the prehistoric Tibetan inland Ice, reconstructed according to the author's field investigations in the test areas (from W to E) Nos. 19, 6, 21, 5, 20, 9 and 12 (Figure 1) (cf. Figure 12).

about 13 500–13 000 yr BP, i.e., – according to the author – during Stadium IV (cf. Table 1). Lake terraces of the Tso Kaerh Hu (Longmu Co) have been dated as being ca. 7290, 7520 and younger as ca. 6000 yr BP (Van Campo and Gasse, 1993, p. 302) (cf. Photo 196). Thus, postglacial (Holocene; probably also neoglacial) lake levels have already been recorded (ca. Stadium V; cf. Table 1).

Considering the cold-arid marginal areas of the Antarctic or N-Greenland, which are supposed to have been prehistorically glaciated, though preserved moraines and traces of polishing, i.e., severe indicators, are lacking, a high-glacially and very cold glacier cover ought to be deduced for the large-scale and very elevated, cold-arid Central W-Tibetan Aksai Chin area as well. Here, too, the ice would have been frozen to the rock underground, preserving rather than polishing it. According to the author, the occurrence of classically round-polished hills, which nevertheless have been developed (Photos 194–200 ☗), cannot be explained as a work of the High Glacial inland ice (LGM = Stadium 0), but by the polishing of the Late Glacial ice cover (Stadia I–III), which at an already 200–500 m uplifted snow line (see Table 1) had become warmer.

A further aspect of general importance should also be called to mind: in all areas of S and Central Tibet investigated for this study, the macrosolifluction- and frost-pattern bottoms, typical of the permafrost zones of the earth, are nearly totally absent. Merely isolated forms of a solifluction lacking vegetation (Photo 200 ▽) or impeded by it (Photo 194 ▼), and only small frost-patterned bottoms (Photo 198 ◇) have been observed. However, the permafrost climate would absolutely permit macroforms (An Zhongyuan, 1980; Zhou Youwu and Guo Dongxin, 1982; Kuhle, 1987a). This can be considered as being a further indicator of an extended Late Pleistocene ice sheet in Tibet.

### *7.3. Summary of Section 7*

The glaciogemorphological field investigations in connection with the sedimentological analyses of the currently – even under Tibetan conditions – strikingly arid Nako Tso basin (precipitation less than 200 mm/yr or perhaps only 100 mm/yr), attaining the lowest sea-level of Central W Tibet, as well as of the connected Aksai Chin being just as dry, have led to a High Glacial (LGM) complete inland ice cover (Figure 12, I2 on the left above Kamet). Its minimum thickness testified to in the field, amounted to 1300–1400 m. Owing to the ice confluences in the Nako Tso basin, an ice thickness of about 2000 m or even more at the greatest can be suggested (Figure 32).

The Late Glacial deglaciation has first reshaped the highest mountains into glacial horns; later expanding ice-dammed lakes have been created. The still existing lakes are residual lakes of late Late Glacial lakes, which were ca. 130 m deeper at that time than at present as, e.g., the Tso Kaerh Hu (Longmu Co). The Late Glacial to postglacial age of these lakes has already been documented by the limnological study of Van Campo and Gasse (1993) and thus does not form a contrast to the High (LGM)- to early Late Glacial inland ice cover of the relief suggested by the author.

It is not the High Glacial, but the Late Glacial ice cover, already reduced by raising temperatures, which has led to the classically-glacially rounded erosion landform preserved in the Aksai Chin. During the LGM (Stadium 0) the inland ice was frozen to the underground here.

## 8. Traces of northwestern outlet glaciers of the Tibetan inland ice through the western Kuen Lun (Figure 1, No. 20 from the Aksai Chin up to No. 5; Figure 2, Nos. 165–189)

Finally, some results are presented from the area of the NW outlet glaciers, which flowed down from the High Glacial inland ice through the valleys leading from the Tibetan plateau as far as into the Tarim basin (Figure 12, I2 on the right above Nun Kun). This W Tibetan area is adjacent to the area N of the Karakorum system, which the author has investigated in detail in 1986 (Figure 1, No. 5) (Kuhle, 1988f, 1994b). Research work with concern for the prehistoric glaciation of the contiguous Kuen Lun N-slope has been carried out by De Terra (1932), Norin (1932), Hövermann and Hövermann (1991) and Jäkel and Hofmann (1991). With the help of moraines and roches moutonnées in the Sanesch- and Kilyang valleys of the Tisnab chain, De Terra (1932, pp. 23, 29, 66; Table III, Figure 3 and Map 2) has reconstructed an Ice Age snow line depression of 1000 m, i.e., a snow line (ELA) running at ca. 4000 m asl. In the Duwa valley, W of Khotan, Norin (1932, p. 596 and Figures 6 and 7) described the lateral moraines of a Tschunak Stadium, located lower than 3150 m asl, thus evidencing a snow line depression of 1200 m and a snow line altitude at only 3800 m asl. Hövermann et al. (1991, p. 51 and pp. 56–67) indicate for the E adjacent N Kuenlun foreland along the Keriya a lowest glacier margin at 1450 m asl for the penultimate Ice Age and

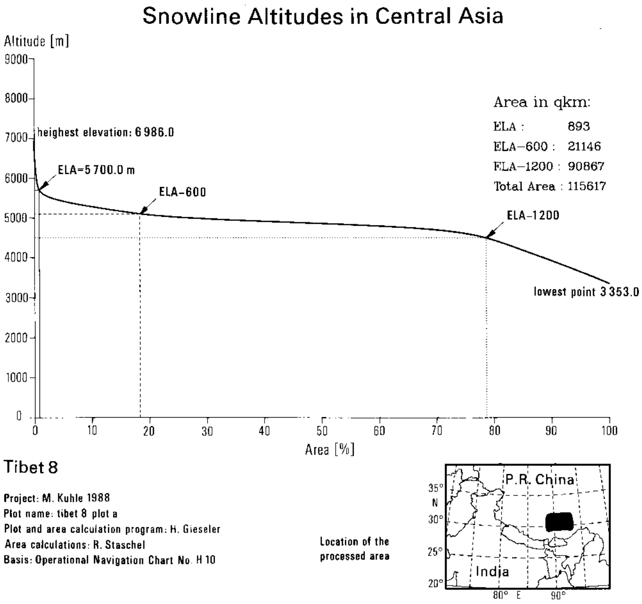



*Figure 36.* Indicates the increase in glacier feeding area from the current snow line altitude (ELA = 5700,0 m) in relation to the altitude of the relief above the ELA at an uplift of the relief by 600 m against the present-day snow line (ELA-600) up to an uplift of the relief surface by 1200 above the current ELA (ELA-1200) This corresponds in its efficiency with a lowering of the snow line by 600 m, i.e., 1200 m compared with the present relief surface. This Figure shows the test area in the research area Nos. 4 and 9 in Figure 1.

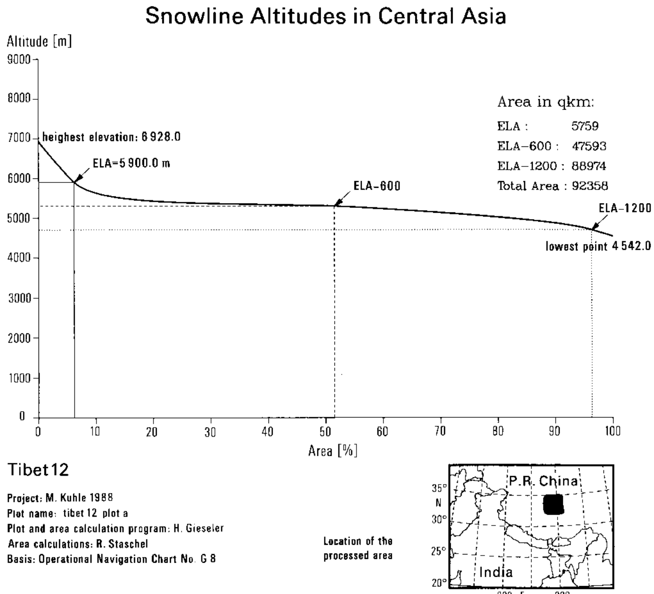



*Figure 37.* Indicates the increase in glacier feeding area in the same way as in Figure 36 (see text of Figure 36). Figure 37 presents a test area in the N of research area No. 9 and research area No. 11 shown in Figure 1.

for the Last Ice Age a glacier margin somewhat lower than 2000 m asl. This points to a lowering of the snow line to ca. 4000 m asl. In the same area, in the valley of Kurab He, Jäkel and Hofmann (1991, p. 35 and pp. 44–48) have found strikingly lowest end moraines and stages of ice retreat at 1900, 2600, 2850, 3250, 3560 and 3800 m asl, which belong to the last High- to Late Glacial. All the High- to Late Glacial snow line depressions and snow line altitudes resulting from these observations roughly correspond to those reconstructed by the author in the nearer and farther neighbourhood of W-Tibet (Kuhle, 1988f, 1994b, Figure 138). Due to the position of their test areas, they could not be claimed for W-Tibet or even Central W-Tibet, but only for the N slope of the Kuen Lun. Nevertheless, from the perspective of the paper presented here, J–Kel and Hofmann (1991, p. 35) state correctly: ‘At this time ice streams of the northern Tibetan plateau may have taken part in the feeding of the Kurab ice stream’.

Summing up, it ought to be realized that all the authors who have investigated the traces of glaciation on the Kuen Lun N slope, either have contradicted the inland ice glaciation of Tibet, or did not draw any conclusion from their observations only located on the periphery with regard to the Ice Age glaciation of the Tibetan plateau.

The findings introduced now continue the glaciogemorphological profile of Figure 2 in Section 7, presenting results from the area of the northwestern outlet glaciers. These glaciers flowed down from the High Glacial inland ice into the Tarim basin, following the valleys leading down from Tibet (Figure 12, I2 on the right above the Nun Kun; Figure 19, Kuen Lun to Takla-Makan). This W Tibetan area is adjacent to the region N of the Karakorum system (Figure 1, No. 5) which the author visited in 1986 (Kuhle, 1994b). The observations are shown in detail in Figure 2. In particular the complete lining of the valley cross-profiles, leading down W of Haji Langar from the passes which are located on the edge of Tibet, is remarkable. One ought to mention for exemplification the lining by moraine of the large longitudinal valley N of the Kuenlun, the Kolakoshih Ho, and its most important side valleys (Figure 2, Nos. 170–183). Besides these linings with ground moraine, nearly all the other key forms of glacigenic development of valley landforms do occur, as for instance trough valley cross-profiles (No. 172), flank polishings (Nos. 174 and 182), glacigenically triangular-shaped slopes (truncated spurs) (Nos. 177, 178, 182), roches moutonnées, developed from fluvial cut-off meander spurs (No. 182), local Late Glacial (Stadia II–IV; Table 1) pedestal moraines from steeply-connected hanging valleys (No. 179) and also kame-terraces (Nos. 176 and 181), some hundred metres above the valley bottom, which is covered by Late Glacial to Holocene (neoglacial) gravel fields (Stadia II–IV and V–’VII; Table 1) with small terrace steps. The High Glacial (LGM) ground moraine cover reaches up the valley flanks as far as 800 or even 1000 m above the valley floor (Figure 2, Nos. 180 and 183). It cloaks the debris- and rock slopes with its yellow fine material matrix, visible from afar. Owing to the very heavy trituration through an important thickness of the ice, the portions of coarse blocks, left behind by the outlet glaciers, are rather insignificant in comparison with the local and pedestal moraines. Thus, in some places, one even has the convergent impression of an eolian loess cover. However, such a mistake can easily be removed by the detailed analysis of the material, but also by the approximately horizontal upper limit, drawn sharply as with a ruler. In many places the ground moraine has been rinsed line- like below the onset of gullies and cirque-exits, and secondarily

↑*Photo 1*. The Sun Kosi or Bote Chu Himalaya-cross-valley, taken up-valley from 2 km N of the settlement of Bahrabise below the hamlet of Palati (27°48′ N/85°50′ E, 1110 m asl), 65 m above the thalweg (i.e. the river). Flank polishings occur on both sides of the steep-sloping glacigenic V-shaped valley (◥ ◓ ◤). The steep and thus shady niches and slope steps within the surface of the flank abrasion are spallings, which have taken place after deglaciation. With the help of the polish line the minimum level of the outlet glacier tongue, flowing down from Tibet, is recognizable (– –). (□) mark bodies of slope debris, which, due to the undercutting by the river, are sliding steeply downwards. They contain dislocated ground moraine and erratic boulders of augen-gneiss from N of the Himalaya, i.e., from S Tibet. (◁ ) are waterlogged flows, slope slides and mudflows in the debris of the autochthonous schist rock of the Kathmandu- and Navakot covers with a deep-reaching moisture deposition, as a result of the heavy monsoon rains of the Himalaya S slope. (Photo M. Kuhle.)

← *Photo 2.* View from below the hamlet of Kukhre (27°48′ N/85°50′ E, 1125 m asl), 70 m above the river, seen down-valley into the orographic right-hand flank of the Sun Kosi (Bote Chu). (□) mark covers of slope debris, undercut by the river, into which the crumbled glacial ground moraine material has been incorporated. The bedrock metamorphites are round-polished by the prehistoric valley glacier up to at least 250 m above the thalweg (◓). (– –) indicates the minimum height of its ice level (cf. Figure 1). (Photo M. Kuhle.)

↑ *Photo 3.* View from above the junction of the Chaku Khola (river on the left in the photo) with the Sun Kosi valley, seen from the inset between the two valleys (foreground; 27°50′ N/85°51′ E, 1200 m asl) to the S down the Sun Kosi. (◥ ◤) mark the glacial flank smoothings of this glacigenic V-shaped valley. On the two slopes of this – from the structural-geomorphological point of view – consequent valley course, there are outcropping edges of the phyllite-covers strata (◤), which have a vergency of movement (gravity gliding movement) towards the Himalaya fore-chains, and are overlapping to the S. In the area of the vaguely signified polish line, the Ice Age glacier level has been marked (– –). (△) indicates one of the many postglacial rock crumblings which confirm, that the prehistorically glacigenic valley cross-profiles do not correspond with the recently different, i.e. fluvial, morphodynamics. (Photo M. Kuhle.)

↑*Photo 5.* Taken from the same viewpoint as Photo 4, but with a shift of 100 m up-valley (to the N). (◓ ◥ ◤) signify the outcropping edges of the strata of the valley flanks, which have been round-polished and abraded by the High- to early-Late Glacial (LGM = 0 to Stadium I, see Table 1) Bote Chu outlet glacier of the Tibetan Ice. (– –) indicate the pertinent glacier level on the right, seen up-valley to the N, and at a corresponding height on the right-hand western valley flank (– – left third of the panorama). (▼) is an exemplarily clear rock spalling, which happened after deglaciation in the area of the Ice Age flank polishing. It orientated itself according to the ac- and bc-clefts of the stratified bedrock, i.e., under the control of the clefts. (▷) shows a talus cone, made up from the detritus of such spallings (Holocene rock slides). (□) are diamictic bodies of slope debris, containing portions of ground moraine, which have been exposed by fluvial undercutting. (○) marks one of the few preserved remnants of glacier-mouth-gravel-floor terraces of the Late Glacial and Holocene (cf. Table 1 probably No. 1 to youngest No.-3). Presumably (◇) is also a Late Glacial lateral moraine terrace, but this could not be evidenced quite clearly until now. (↘) shows the mouth of the Jangbo Khola, where the huge damaging mudflow came down in 1996. At the same time it marks the site of Lartzu, which was completely destroyed by the mudflow. (Photo M. Kuhle.)

← *Photo 4.* 5 km further to the N than Photo 3, N of Jhirpu (27°53′ N/85°52′ E, 1350 m asl), looking up-valley the Sun Kosi to the S (cf. also Photo 5, seen from a view point which has been shifted by 100 m up-valley to the N). (◥ ◓ ◤) indicate the valley shoulders, polished round by the Ice Age (LGM) glacier; their polish lines (– –) show the minimum height of the former ice level. (□) are debris slopes, undercut by the river and thus increasingly breaking away. They consist of talus deposits and dislocated ground moraine. (↘) marks a mudflow, which had become active just some days before the photo was taken. It has destroyed the jeep-road. (Photo M. Kuhle.)

↖ *Photo 6.* On the orographic right-hand flank of the Bote Chu, several decametres above the valley thalweg, near the settlement of Linding (27°57′30″ N/85°57′ E, 1620 m asl), there is loose diamictic rock with a pelitic matrix, rich in clay, which has been exposed by the road construction (□). (▼) shows the outcropping edges of the strata, smoothed by the subglacial and marginal meltwater run-offs of the prehistoric valley glacier. The still light rock surface shed the loose rock cover only a few months ago, so that the polishings and smoothings have been preserved. (○) are far-travelled gneiss boulders, 'swimming' in a matrix of fine material. These, in the most general sense 'erratic boulders', are dislocated components of High-(LGM) to Late Glacial moraines, integrated into the slope debris and at the same time reworked. They cannot be applied to the evidence of glaciation, because they could have been transported by the ice as well as by mudflows and also by both of them. (Photo M. Kuhle.)

↑ *Photo 7.* Looking from 2250 m asl from the orographic left-hand valley flank of the Bote Chu from the settlement Dram (or Zhangmu) (27°59′ N/85°59′ E) towards the western rock flank of the valley, polished by the glacier ice (◤ ◓). (◓ white) is situated between two back-polished rock spurs, which have been shaped by neighbouring small hanging valleys up to wall gorges during the preceding interglacial period. Since deglaciation there have taken place rock spallings (▼) at the polish surfaces of these 'truncated spurs'. (– –) marks the termination of the fresh flank polishes and thus the minimum height of the High- (Stadium 0 = LGM) or Late Glacial (Stadium I, cf.Table 1) valley glacier level. (Photo M. Kuhle.)

← *Photo 8.* From the confluence area of the Fuqu Chu (28°09′30″ N/ 85°59′ E; Figure 3 No. 6) at 3680 m asl (aneroid measurement) looking down the Bo Chu. The valley flanks are covered with High Glacial (LGM) ground- and Late Glacial end moraine material reaching down to the valley bottom (■). In places features of the High Glacial glacier ground scouring remained – here as a roche moutonnée (◓ white), which is preserved in the outcropping edges of the strata of vertical-standing, very resistant metamorphic rocks. (Photo M. Kuhle.)

← *Photo 9***.** Looking up the Bo Chu, from a viewpoint 50 m N from that of Photo 8. (■ white) marks Late Glacial end moraine material (Taglung Stadium II; Figure 3, No. 7), transported out of the Fuqu Chu by the Shisha Pangma SE glacier. On the left-hand side above there is the settlement of Nylamu. (■ black) indicates a metre-thick ground moraine overlay on the orographic left-hand valley flank (Figure 3, No. 8). The mountain ridges and saddles, lying in between, have been rounded glacigenically (◓ black) and then reshaped periglacially (by frost weathering and solifluction) during the Postglacial and Holocene. (◤◤ white) shows outcropping edges of the strata of the vertical-standing, more or less metamorphic sedimentary rocks, polished and smoothed by the High Glacial (LGM) Bo Chu glacier. (Photo M. Kuhle.)


← *Photo 10.* The valley bottom of the upper Bo Chu, leading down half-right to the S to the Himalaya S slope, here at 3700–3800 m asl (viewpoint at 3925 m, 28°14′ N/86°02′ E, N of Kum Thang, Figure 3, Nos. 11,12). It consists of washed High- to Late Glacial moraine material (☐) (Stadium 0 = LGM to stadium IV, Table 1) with large far-travelled gneiss boulders (●), which has been undercut and fluvially reshaped by the recent meltwater river. In the confluence area of the orographic left-hand side valley, too, the corresponding moraine material has been reworked glaciofluvially, forming a superficial fan (settlement-terrace with plots of the irrigation agriculture in the left half of the photo). (■) mark Late- to High Glacial moraine deposits. (◓) show glacigenically back-polished valley flank spurs, (▽) are small fresh talus cones, deriving from Holocene (interglacial) slope ravines, which lie between the spurs. There is fresh monsoonal snow on the mountains. (Photo M. Kuhle.)


← *Photo 11.* From 4000 m asl (3995 m aneroid measurement) down the Bo Chu, looking to the S and into its right-hand valley flank (28°20′ N/85°02′ E; Figure 2 No. 3; Figure 3 No. 17). (2– –8) mark the Late Glacial to recent glaciofluvial gravel fields in the valley bottom, subdivided in terraces; (▽) indicates a mudflow fan, adjusted to the valley bottom, which derives from glacigenically shaped high depressions (○); (– –) signifies approximately the highest Ice Age level (Stadia 0-II; Table 1) of the Bo Chu outlet glacier in this northernmost section of the Himalaya transverse valley above the flank abrasions (◓); (●) are far-travelled moraine boulders, which have secondarily been transported down the slopes. (Photo M. Kuhle.)


← *Photo 12.* From 4040 m asl, the Bo Chu seen down to the S (Figure 3, No. 18). (←) are the exaration rills, produced by the main valley glacier in the direction of flow and flank polishing. A main problem is the synchronization of the highest preserved polish lines (– – right and left valley side). For those (– –) shown here, it can be accepted at most that they are of Late to High Glacial age (= 0 = LGM to ca. Stadium II, cf. Table 1). (●) mark down-valley transported gneiss boulders lying upon the ground moraine (■ below), which first has been undulated by the influence of the prehistoric main valley glacier and then by solifluction. (–3) and (–8) indicate the partial fields of the gravel floor of the historic to present glacier positions of Stadia VII–XII (Table 1). In this valley chamber the meltwater of rather large hanging- to valley glacier tongues from the Shisha Pangma massif, situated to the W, and from the 7312 m massif, lying eastwards (see Figure 3), have dominantly taken part in the build-up of the glacier mouth gravel floors. (Photo M. Kuhle.)


↑ *Photo 14.* Looking from the Yagru Xiong La (5060 m asl; 28°32′ N/86°12′ E; Figure 3, No. 25) in S Tibet across the S edge of this plateau section – which has not been cut by linear erosion until now – towards the S up to the W as far as the Himalaya (No. 4 Rolwaling Himal with Gaurisankar 7146 m; No. 2 Shisha Pangma group, 8046 m). The area of the Shisha Pangma N slope, lying on the right-hand in the background, has been investigated with regard to prehistoric traces of glaciation during the Chinese/German Joint Expedition 1984 (Kuhle and Wang Wenjing 1988). On the left-hand side of the path, leading over the pass culmination, there are prayer flags. The ground moraine cover (■) consists of polymict erratic boulders (granite-, quartzite- and augen-gneiss boulders) (○) in a fine groundmass, the nature of which is introduced in Figure 5 (21.08.96/2) and Figure 6. (– –) marks the minimum height of the Ice Age glacier cover, which has led to this ground moraine overlay. (Photo M. Kuhle.)


← *Photo 16.* Looking from the Yagru Xiong La (same locality as Photo 14 but 300 m further to the N) to the SW towards the High Himalaya with the Shisha Pangma group (No. 2, 8046 m) and further to the W across the High Plateau of Tibet. The plateau section visible here, is covered by a metre-thick ground moraine (■) in which large facetted, erratic gneiss-, granite- and quartzite boulders (○) are ‘swimming’ in a fine matrix (see Figure 5: 21.08.96/2; Figure 6). (– –) marks the minimum height of the accompanying prehistoric ice cover. (Photo M. Kuhle.)

→ *Photo 15.* Exposure of ground moraine (■) at 4530 m asl (28°30′ N/86°10′ E; Figure 3, No. 24): large granite boulders (◇) 'swim' in a fine groundmass (cf. Figure 5: 21.08.96/2, Figure 6). The solid rock in the underlying bed is metamorphic sedimentary rock. Up the slope there is no bedrock granite. The large boulders are facetted and rounded at the edges; the medium-sized components, the petrographic composition of which is mixed (polymict) and thus also partly erratic, are in part better rounded (○). Here, the ground moraine cover reaches a thickness of several metres. Its surface shows slight traces of rinsing processes. A thin, grey weathering horizon is at most 1 decimetre thick (humus content 3.73%). (Photo M. Kuhle.)

→ *Photo 17.* View from 4800 m asl to the NE across the round-polished rock ridges (◓) of metamorphic sedimentary bedrocks (Figure 3, No. 26; 28°33′ N/86°13′ E), cloaked by ground moraine and erratic granite boulders (❙ ❙). These 'glacially streamlined hills' have been polished more or less discordantly (ambygonal or acute) by the overlying glacier ice (– – minimum height of the related High- to Late Glacial ice cover). (○) marks facetted granite erratics of the ground moraine cover in the foreground. (Photo M. Kuhle.)

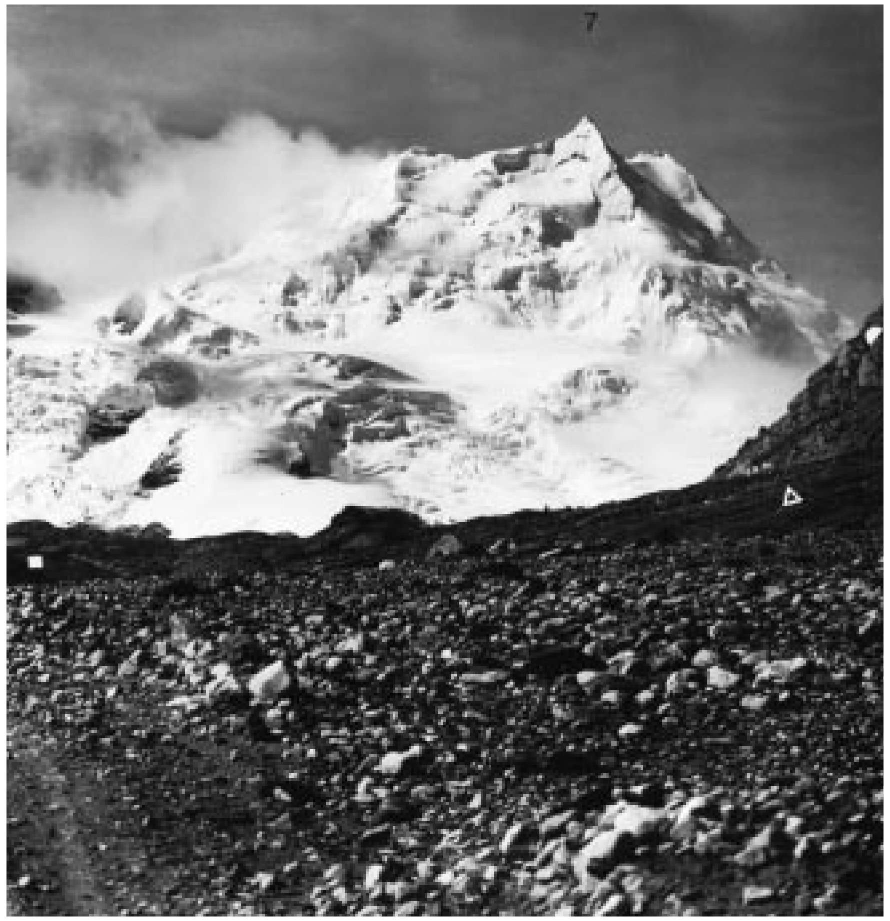


← *Photo 13.* Somewhat down-valley the confluence of its two source branches, from 4310 m asl (Figure 3, No. 23; 28°27′ N/86°11′ E), seen across the upper Bo Chu southwards to the left in the direction of the Himalaya, and to the right, to the N, towards the High Plateau. (◓ ◓) signify glacigenic flank polishings, (■) ground moraine overlays, (– –) minimum heights of High- to Late Glacial glacier-ice surfaces, reconstructed with the help of highest occurrences of ground moraines. (↑) shows exaration rills in the ground moraine. (↓) is dark bedrock under the ground moraine cover. (Photo M. Kuhle.)

← *Photo 18.* View from 4800 m asl ca. 5–7 km N of the Yagru Xiong La (Figure 3, No. 27) facing W (left-hand) via N (centre) to E (right-hand) across a representative, glacigenically shaped high plateau region of S Tibet (28°34′ N/86°13′ E) with mountain ridges, polished round by the ice (glacially streamlined hills) and features, which are related to roches moutonnées (◓) in the granite bedrock. In places the surface of the hills has been roughened to the form of a boulder-scatter-overlay, eroded in situ by postglacial frost weathering (▲). The adjacent ground moraine fields contain granite boulders (□), which have been abraded from the ridges of bedrock granite by exaration and detraction (as a result of regelation). Accordingly this is classic local moraine. The substantial portions of fine to very fine matrix (■) are characteristic of ground moraine. (– –) is the minimum height of the glacier surface pertinent to material and forming. (Photo M. Kuhle.)


← *Photo 19.* Looking from 4435 m asl (Figure 3, No. 28; 28°38′ N/ 86°06′ E) up the upper Xaga Chu to the WNW to the hills near the settlement of Xaga (first two ◓ from left). (– –) indicates the approx. altitude of the High Glacial ice level. (◓) are round-polished mountain ridges. The orographic right-hand flatly-inclined (14-5°) N exposed valley slope is covered by a several metre-thick ground moraine overlay (■). The ground moraine, cut here by a recent slope ravine up to the sedimentary rock, contains polymict boulders the size of a fist or head (○) in its pelitic groundmass; there are also erratic massif-crystalline components among them. In the area of the valley bottom the ground moraine cover plunges under the glaciofluvial gravel body (□ valley sander of the type glacier mouth gravel floor –0 to –5 from the Holocene glacier stadia of the Neoglacial and the historical time, cf. Table 1) of the Xaga river, which today is meandering over a considerable width. (Photo M. Kuhle.)


← *Photo 20.* View from 4245 m asl (aneroid measurement) from the orographic right-hand side (28°46′ N/86°12′ E) of the Xaga Chu across the Holocene glaciofluvial gravel floor (□ –0 to –2) (belonging to the Neoglacial glacier positions V, VI and ′VII) to the NE on to the other valley flank of outcropping edges of the stratum in sedimentary rocks (Figure 3 No. 30). The long mountain ridges making up that valley flank, have been formed into ‘glacially streamlined hills’ (◓) by the overflowing ice. Their surface is cloaked with ground moraine (■). (▼) are morainic slope ledges, having received their features during the last phase of the Late Glacial valley glacier embedment. The post-glacial precipitation has eroded slope ravines, which cut the thin and relatively smooth ground moraine cover as far as the bedrock (⌀). The young stage of this erosion can be ascertained by the round-abraded rock surfaces, which have not been cut until now (○). The talus fans, consisting almost completely of dislocated moraine material (▽) are correspondingly small; (– –) is the minimum height of the High Glacial glacier level, concluded from the ice indicators. (Photo M. Kuhle.)




← *Photo 21.* Seen from ca. 4750 m asl (aneroid measurement) from the upper Kyetrak valley (28°12′ 02″ N/86°36′ E; Figure 3 No. 32) towards the N on to a 6907 m high peak (No. 7) of the Himalaya main ridge W of the Kyetrak glacier. The glaciation of its superstructure reaching more than 1000 m higher than the orographic snow line (ELA), makes the lower end of its glaciation join the tongue of the Kyetrak glacier (■) (Photo 22). Its influx contributes to the fact that the actual Kyetrak glacier end flows down to ca. 4800 m. (■) marks the ice of its tongue end, covered with surface moraine, which is to be classified as belonging to the historical glacier position XI to XII (Table 1). (△) is an orographic left-hand (western) mudflow cone, into which neoglacial to historical lateral- and end moraine material (Stadia V to X; Table 1) has been dislocated. In the foreground the coarse-blocky condition of glaciofluvial washed moraine material is visible. (◤) are young Late Glacial (Stadium IV) glacier flank polishings roughened by the Holocene frost weathering. (Photo M. Kuhle.)




← *Photo 22.* Telephoto of the 7907 m high peak (No. 7) W of the Kyetrak glacier (28°09′ 30″ N/86°34′ E; Figure 2, No. 11). The local tributary glacier tongue from the N-exposed glacier slope of this peak flows together with the tongue of the Kyetrak glacier; (■) indicates the orographic right-hand (eastern) end moraine of Stadium X (Little Ice Age, Table 1) of the main glacier, rising decametres above the present ice level. The Kyetrak parent glacier flows down from the Nangpa La transfluence pass (No. 31; modern glacier surface at 5717 m). (◤◥) mark High- to Late Glacial (Stadium 0 = LGM to II) glacier polishings and abrasions. The accompanying glacier levels indicated above (– –0– –), show the S-sloping, prehistorically counter-surface inclination of the Kyetrak outlet glacier over the edge of Tibet, i.e., over the watershed of the Himalaya. (■ I and ■ II) are Late Glacial lateral moraine remnants. According to their levels, the glacier surface of Stadium I enabled a transfluence to take place over the Himalaya watershed; perhaps that of Stadium II just did not do this any more. (Photo M. Kuhle.)

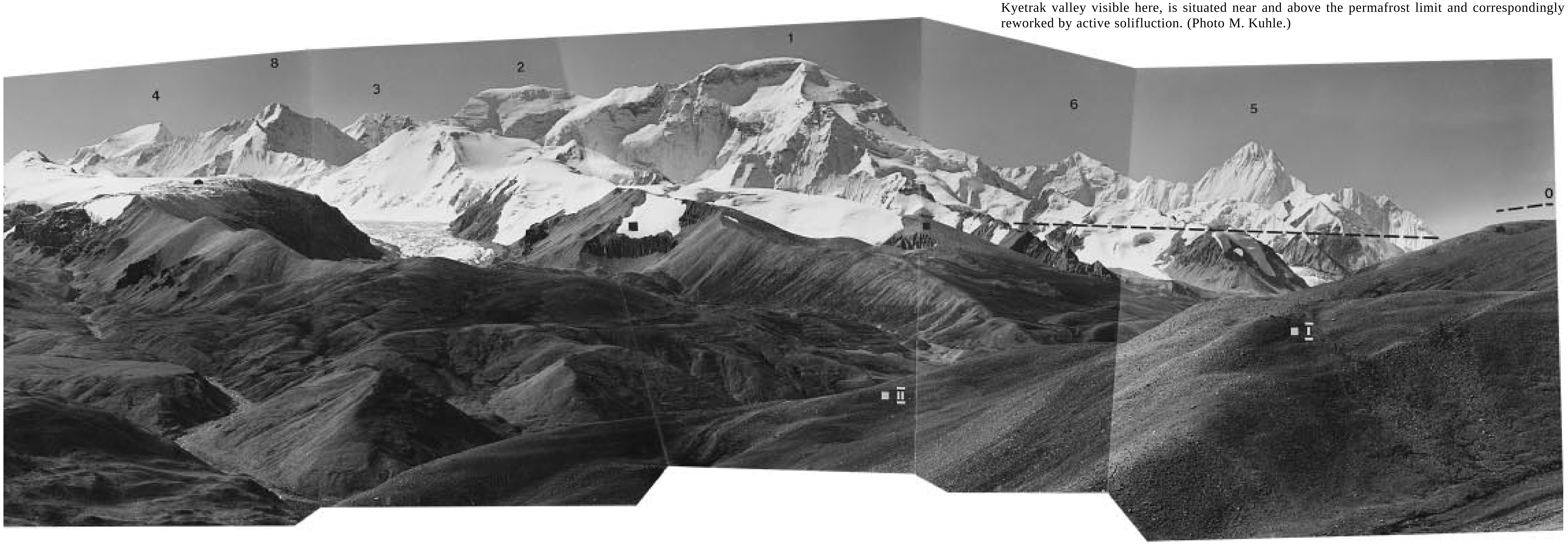
↓ *Photo 23.* View from ca. 4760 m asl seen to the S on to the tongue end of the Kyetrak glacier, which today flows down to the N (■ white) (Figure 3, No. 32; 28°12′ 22″ N/86°36′ E; No. 1: Cho Oyu 8201 m, No. 5: Cho Aui 7352 m, No. 7: 6907 m-peak). The glacier end sedimentates dumped end moraines (■ white), belonging to Stadia XI to XII (Table 1). Sometimes their hills still contain dead ice. Down-valley there follows the modern gravel floor (☐ –8); it is accumulated by braided meltwater streamlets of the glacier discharge. In the foreground a somewhat older gravel floor section continues (☐ –6 to –7) (with a small terrace step towards the modern gravel floor). (▽) mark active alluvial debris- and mudflow cones of older moraine material transported down-slopes (e.g., ■ black). (◓ ◤) are rock faces, which are round-polished and smoothed by the prehistoric glacier infilling of the valley. (– –0– –) indicates the reconstructed approximate altitude of the High (LGM) to early Late Glacial Kyetrak outlet glacier level, flowing down to the S over the watershed of the Himalaya. (Photo M. Kuhle.)


← *Photo 24.* Looking from ca. 4700 m asl at a distance of 3.7 km from the Kyetrak glacier tongue (▲) (Figure 3 above, No. 32 near the pasture of Koyatako; 28°13′ 20″ N/86°36′ E) from Tibet (left-hand) across the right-hand valley flank (to the E) up to the Himalaya, seen in an upward direction; No. 7 = 6907 m peak. (■III) marks Late Glacial lateral moraine ledges preserved on both sides of the thalweg (Table 1). (↙↙) are lateral moraine ledges, which are to classify somewhat younger than Stadium III, or ledges of exaration rills in the ground moraine of Stadium III. (◓) indicate glacigenic flank abrasions, made up in the bedrock far above moraine III. (– –0) shows the level of the High Glacial (LGM) Kyetrak glacier, deduced from that, which inclines to the S (to the right-hand). (–5) is the valley floor with the glacier mouth gravel floor of the ‘Little Ice Age’ (Stadium IX; Table 1). (Photo M. Kuhle.)


← *Photo 25.* From 4725 m asl from the ground moraine cover (■ foreground, Figure 7) on the bottom of the Kyetrak valley (Figure 3, above No. 32) towards the SSW, looking into the orographic left-hand valley flank. There are preserved lateral- or ground-moraine ledges (▼▼) of the young-Late Glacial Stadium IV and Neoglacial Stadium V (Table 1). (◓) indicates the bedrock under the ground moraine cover, smoothed by the glacigenic flank abrasion (■V). (– –IV) = hypothetical young-Late Glacial glacier level. (Photo M. Kuhle.)


← *Photo 27.* View from 5250 m asl seen across the spur ridge between the Kyetrak Chu (valley) (left-hand) and Chomolung Chu (right-hand valley slope; named in accordance with information from Tibetan yak nomads, August 1996) (locality: Photo 28; Figure 3, right-hand of No. 33). In the background there is the Himalaya main ridge with No. 1 = Cho Oyu 8201 m; 2 = Gyachung Kang 7975 m; 5 = Cho Aui 7352 m; 7 = 6907 m-peak. (□) are the bedrock schists (cf. Photo 28 □) on which far-travelled erratic granite boulders have been deposited (○). Further up the erratics are embedded in the ground moraine matrix (■ 0); (cf., Figure 9 and Figure 5, diagram 25.08./1). (\ \) are earth pyramids from High- to Late Glacial moraine material (Stadium 0 to I; possibly even younger?). The erratic granite boulders (■ 0) reach up to a height of 5500-5600 m and thus ca. 700 m above the valley bottom of the Kyetrak Chu (on the left). They are the highest accumulative prehistoric glacier traces and have therefore been marked as 0. Probably, however, they are younger, i.e., their deposition was already committed to a more increased snow line. The High Glacial (LGM = Stadium 0) snow line (ELA), on the other hand, had descended to ca. 5000 m or even some hundred metres lower. (◓) are even significantly higher traces of Ice Age glacial erosion: the mountain ridges are polished and thus rounded by the ground polishing. (0– –, – –) mark the minimal height of the ice surface of the maximum prehistoric glacier cover, belonging here to the Kyetrak outlet glacier, which flowed down from the S Tibetan ice stream network to the S over the watershed of the Himalaya (Figure 10). (Photo M. Kuhle.)

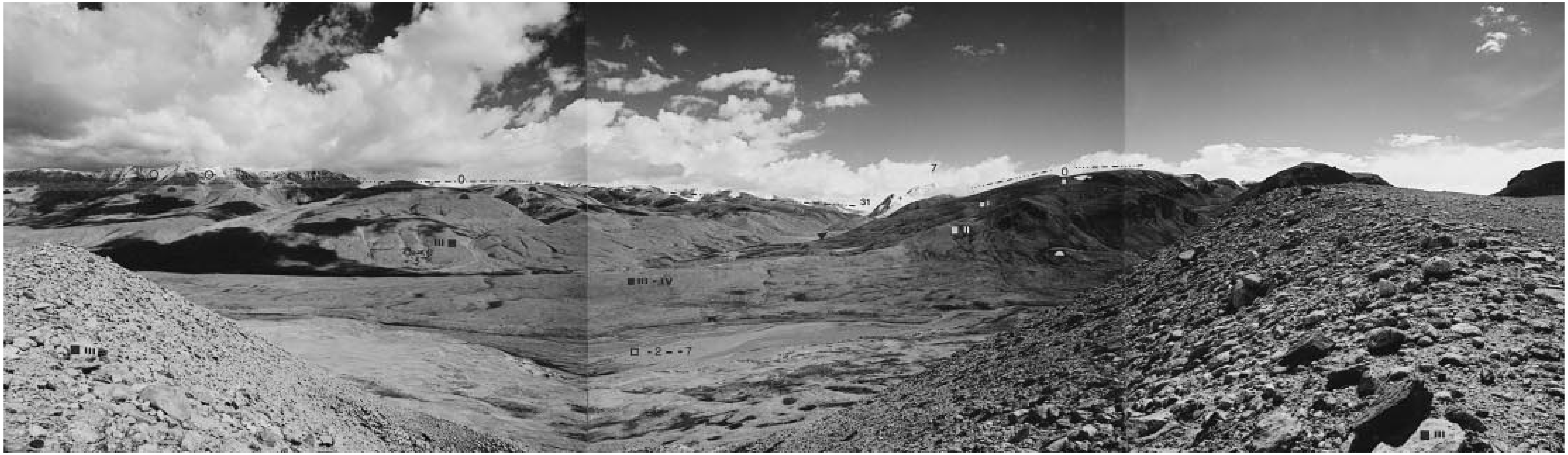
↓ *Photo 26.* Telephoto taken from ca. 5250 m asl (aneroid measurement) from the W flank of the Kyetrak valley (Figure 3, right-hand of No. 33; 28°16′ N/86°36′ E) seen from a direction to the E (left) up to the S across the E flank of the Kyetrak valley (cf. Photo 28). Peak No. 1 = Cho Oyu 8201 m, No. 2 = Gyachung Kang 7975 m, No. 3 = Nuptse 7879 m, No. 4 = Changtse 7580 m, No. 5 = Cho Aui 7352 m, No. 6 = 7296 m-peak. (■ I-III) indicate the early- to middle Late Glacial lateral moraine remnants of the Kyetrak glacier. From Stadium 0 (LGM) up to about Stadium II it was still so thick that it probably flowed down from the left to the right over the watershed of the Himalaya (cf, Figure 10 on the left below High Himalaya). (– –0) shows the surface level of the High Glacial Kyetrak outlet glacier reconstructed with the help of erratic boulders and upper polish lines of the flanks (◓), sloping to the S (to the right) to the Himalaya main ridge. (■ black) are the accompanying huge, over 100 m thick medial- and lateral moraine- and kames insets between the then eastern tributary glaciers and the Kyetrak parent glacier. These deposits of loose rocks are well recognizable from their furrowed spallings of earth pyramids (■ black). The moraine lining of the Kyetrak valley visible here, is situated near and above the permafrost limit and correspondingly reworked by active solifluction. (Photo M. Kuhle.)




↑ *Photo 28.* 360°-panorama at 5250 m asl from the mountain ridge (locality: Photo 30, below ■ 0, Photo 31, below 0 ■; Figure 3, right of No. 33; 28°17′ N/86°36′ E) between Kyetrak Chu (right half) and Chomolung Chu (left half) across the Himalaya and S Tibet. No. 1: Cho Oyu (8201 m); No. 2: Gyachung Kang (7975 m); No. 4: Changtse (7580 m); No. 5: Cho Aui (7352 m); No. 6: 7296 m-peak; No. 7: 6907 m-peak; No. 9: Chomolung Kang (7312 m); No. 10: 6449 m-massif of the Transhimalaya or Gangdise Shan, situated towards the N at a distance of ca. 220 km. (□□) are sedimentary bedrocks; (■ 0) is superimposed ground moraine with erratic granite boulders (see Photo 27) reaching up to heights of 5500- 5600 m asl. (↘↘) are earth pyramids, which have been developed in ground- or lateral moraine. (↑ ↑) are the highest granite erratics, shown in Photo 31, far above the Late Glacial lateral moraines of Stadium III (■ III). The highest Ice Age glacier traces are the mountain ridges, rounded by glacial polishing, and the flank polishings and truncated mountain spurs with their glacigenic triangular-shaped slopes (◥ ◓). They are evidence of the minimum surface height of the S Tibetan glacial inland ice, i.e., ice stream network (– –0– –). This Ice Age glacier surface was sloping down from S Tibet from the N towards the S (from the left to the right), so that the glacial (LGM = 0 up to Stadium I or II, Table 1) glacier discharge has happened over the watershed of the Himalaya in the form of the Kyetrak outlet glacier. The middle- to young Late Glacial valley glacier ice, however, flowed down from Stadium III (■ III) on at the latest according to the present-day interglacial glacier discharge from the Chomolung glacier (below No. 9) (cf. Photo 29) and Kyetrak glacier (below No. 5) (cf. Photos 22 and 30 below No. 31). (▽) indicates a Holocene mudflow- and alluvial debris fan; (▲) a Late Glacial (Stadium IV) dead ice hole ('cattle hole'), situated E of the pasture Pang Tse. (Photo M. Kuhle.)


← *Photo 29.* From 5450 m asl (aneroid measurement) from the glacially polished rock spur of the orographic left-hand flank of the Chomolung Chu (locality: Photo 28 between right of No. 9 and ‒ ‒; Figure 3, No. 34; 28°18′ N/86°33′ E) seen facing WSW towards the Chomolung Kang glacier (○). This ca. 19 km-long glacier flows down from the 7312 m high Chomolung Kang (No. 9) towards the E. In the forefield of the glacier end and covered by surface moraine debris (■), the youngest (present) gravel floor generation can be identified (□ –8). A mudflow cone is adjusted to it (△). (○) shows a tributary stream of the Chomolung Kang glacier of sheer glacier ice, poor in debris. (◥ ◤ ◓) are valley flanks of the Chomolung Chu and the contiguous S Tibetan high plateau to the N, which have been abraded and round-polished by the prehistoric ice infilling and glacier cover. Even the edges of the strata, outcropping obliquely upwards, are preserved abraded and poor in debris (◓ foreground on the right). (I) is the bottom of the Kyetrak Chu, passing into the plain of Tingri, upon which have been deposited the hilly end moraines of the Late Glacial Stadium III (Figure 3, No. 37). These end moraines lie on High- to early Late Glacial ground moraine (Photos 32-34 ■ in the foreground; Figure 3, No. 38). (0‒ ‒) marks the minimum height of the reconstructed Ice Age inland ice- i.e., ice stream network level. (Photo M. Kuhle.)

↓*Photo 33.* Glaciofluvial accumulation of a classic kame (□), taken at 4250 m asl (aneorid measurement) from the ground moraine area of Tingri (cf. Figure 11) in the lower Kyetrak valley (Figure 3, No. 39; Photo 29 left of I) towards the NW at a kilometre-distance from the flanks of the Kyetrak Chu. The photo shows the same accumulation, filled into the hole melted out of the inland ice body, as Photo 32, but this time from the NE. (◀) mark the outcrops of the almost horizontally accumulated gravel layers. Their small steep steps occur in the coarser ones of these somewhat compacted gravel layers. No.1 is the higher kame surface level, resulting from the initially thicker bordering glacier ice. No. 2 indicates the marginally lower kame level, developed in the already larger hole of the meanwhile less thick ice border. (‒ ‒0) shows the hypothetical High Glacial (LGM) surface of the inland ice, i.e., ice stream network that existed before the melting process took place and enabled this kame to be formed. (Photo M. Kuhle.)




↑ *Photo 30.* View from ca. 5150 m asl from the Late Glacial lateral moraine terrace of Stadium III (locality: Photo 31 ■ III on the left, Figure 3, left of No. 34, 28°) seen facing E (on the left margin) across the confluence of the Chomolung Chu (with its gravel floors on the valley bottom ☐ –2 to –7 in the area of the pasture Pang Tse) with the Kyetrak Chu, which leads down from the S from the 6907 m peak (No. 7). No. 31 is the 5717 m high glacier pass Nangpa La on the Kyetrak glacier. (◀) marks the present tongue of the Kyetrak glacier. No. 9 is the 7312 m high Chomolung Kang-massif. (○ ○) are prehistoric cirques, exposed to the W. (■ 0 to IV) indicate High- to Late Glacial moraine deposits. (■ 0 and ■ II ↘) show the highest occurrence of erratics. (■ 0) can be seen in detail in Photos 27 and 28; (■ II ↘) in Photo 31. (◓) are the flank polishings, rounded mountain ridges and 'glacially streamlined hills', reaching up to far above 5600 m. (0– –) are the heights of the course of the early Late Glacial to High Glacial (LGM) inland ice - i.e., ice stream network surface. In the foreground there can be seen the composition of the most striking Late Glacial lateral moraine (■ III), rich in boulders, the matrix of which is analysed more exactly in Figure 8 and Figure 5 diagram 23.08./2 (Figure 3, No. 40). On the inner slope of this lateral moraine (Photo 28 ■ III black) two further lateral moraine terraces or ledges are preserved: in a moraine cross-profile situated 2 km further to the N, there is the highest terrace at 5050 m (Stadium III), the attached next moraine terrace is at 4790 m (sub-Stadium III), the lowest moraine terrace at 4740 m asl (Stadium IV, Table 1). The valley bottom of this Kyetrak valley cross-profile lies at 4665 m. (Photo M. Kuhle.)

↑ *Photo 34.* Seen from 4220 m asl near the N margin of the kame (Photo 33) on the ground moraine area (■ foreground) of Ting-Jih (or Tingri) in an E direction to the S Tibetan upland between Kyetrak- and Rongbuk Chu (Dzakar Chu) N of Mt. Everest (cf. Kuhle, 1988f) (Figure 3, No. 41). The hills and mountain ridges, consisting of more or less metamorphic sedimentary rocks, have been polished and rounded by the covering glacier ice (◓). Over large parts they are overlain by a frost debris sheet, only a few centimetre in thickness, which weathered *in situ* after deglaciation. In many places it is still broken through by the bedrock. But covering ground moraine remnants are also preserved here and there (■). (‒ ‒ 0) indicates the surface of the LGM inland ice, i.e., ice stream network, the exact altitude of which is an inevitably hypothetical one. (Photo M. Kuhle.)

← *Photo 31.* Taken at 5300 m asl from the orographic left-hand flank of the still very wide Kyetrak valley (Figure 3, right of No. 34; Photos 28 ↗↗ ; 30 ■ II ↘) facing N (to the left) via E to S (to the right). There are far-travelled erratic granite boulders, partly well-rounded, in the foreground (○ right half of the panorama; seated person to compare the proportions). They lie on superficially weathered reddish bedrock sandstones. But also angular local moraine boulders from limestone (○ left half of the panorama), moved only a little, are preserved on sandstone. (■, 0 ■ and ■ III) are ground- and lateral moraines of the LGM to Late Glacial. (0 ■) is shown in detail in Photo 27. (◓ ◓) mark mountain ridges, round-polished by the High Glacial glacier ice, which on the orographic left-hand valley side have been formed without exception in the edges of the strata of metamorphic sedimentary rocks (the four ◓ in the left half of the panorama and ◓ to the very right). (‒ ‒) indicate the minimum height of the High Glacial glacier levels, deduced from this geomorphology. (Photo M. Kuhle.)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1
0
2

← *Photo 32.* 7 km N of the settlement of Tingri, looking from 4220 m asl (aneorid measurement) from the ground moraine area of Tingri (■ foreground) facing S (to the left) via W up to NNW to a High- to early Late Glacial (Stadium 0-I or even II) kame (■) (Figure 3, No. 39; Photo 3). (**I**) marks the lowest Late Glacial terminal moraine of the Kyetrak glacier (Figure 3, III on the right-hand side below No. 38), which had already flowed down again from the Himalaya (Nangpa La) to the N. The kame, set upon the High Glacial (LGM=0) ground moraine (■), which has partly been glaciofluvially washed on the surface (see below), came into being during the melting of the High- to Late Glacial inland ice body. At the same time two phases can be evidenced by the clearly visible kame levels (1 and 2): initially, a stationary hole has been developed in the ice body, which – because of the Himalaya threshold – was no longer able to flow down during the Late Glacial. The hole has been filled by the supra-terranean meltwater with glaciofluvially transported surface moraine. Owing to the hole's small outline, the thickness of the ice bordering the hole was at first still substantial (development of level 1). Afterwards, when the outline was more extended, the ice thickness was several decametres less (development of level 2). (○○) signify polymict far-travelled boulders of a similar medium-size and good roundness, which seem to indicate that the ground moraine surface (■) has undergone a glaciofluvial reworking. (◓) is one of the round-polished hills in the area of the orographic right Kyetrak valley flank (Photo 34). (0– –) marks the Ice Age minimum height of the glacier surface, needed to explain the sedimentology and geomorphology shown in this photo. Over large parts the ice must have been far thicker, so that it could flow down over the watershed below the modern glacier pass Nangpa La (Figure 3 No. 31) (cf. Photo 33). (Photo M. Kuhle.)



↑ *Photo 39.* Accumulation of ground moraine (■) on the slope rising N of Lang Tso (ca. 4250 m asl; Figure 2, No. 19). Its surface has been pressed and rounded in a typical way by the overflowing glacier ice (◓ black). The upper slope shows a characteristic flank polishing (◓ white) on the bedrock limestone. (– –) is the prehistoric minimum ice level. The picture was taken towards the N. (Photo M. Kuhle.)

← *Photo 35.* Valley leading down from the Lhagoi Kangri massif (also Ladake Shan or 'Latzu massif'; 6392 m or 6404 m) (Figure 2, No. 16; ca. 29°N/87°30′ E; cf. Kuhle, 1988f, Figure 2, No. 16, pp.466–467 and Kuhle, 1991d, Figure 43, No. 52, pp. 199–200), taken from 3910 m asl (aneorid measurement) facing NW by way of N up to E (into the orographic right-hand valley flank). The valley runs down in a N direction to the Tsangpo valley (◇) in the area of the settlement of Quxan or Latzu (Latze) (Figure 2, Nos.16–17). An outlet glacier flowed through this box-shaped side valley from the Latzu- or Lhagoi plateau as far as the Tsangpo valley. This is proved by a ground moraine cover (■ white) on steeply to vertically layered edges of the strata of the bedrock and granite boulders metres in size (↓ ↓), lying as erratics on the subjacent metamorphic schists. The actual and holocene geomorphodynamics is signified by linear erosion (▼), cutting the round forms (◓) created by the Ice Age glacier overlay. The alluvial debris fan (▽ white), deposited through the small V-shaped valley (▼), contains portions of dislocated fine material of moraine. Due to the water-retaining moraine clay this substrate is suitable for the construction of an irrigation channel (○○). In the area between (↓ ↓) on the very right, exaration rills are preserved in an almost horizontal arrrangement. They originate from the outlet glacier ice, flowing down from the right to the left side. The valley bottom consists of glaciofluvial gravels (□) of the Late Glacial glaciers of the Lhagoi plateau in the S. The modern river (⇓), discharging the present-day glaciers, has cut several metres deep into these gravels. The orographic left-hand valley flank (◥), polished by the Ice Age outlet glacier, shows remnants of the ground moraine sheet (■ black), partly removed and deposited secondarily at the slope foot in the form of debris cones (△ black). (– –) marks the High Glacial (LGM) minimum ice thickness. (Photo M. Kuhle.)

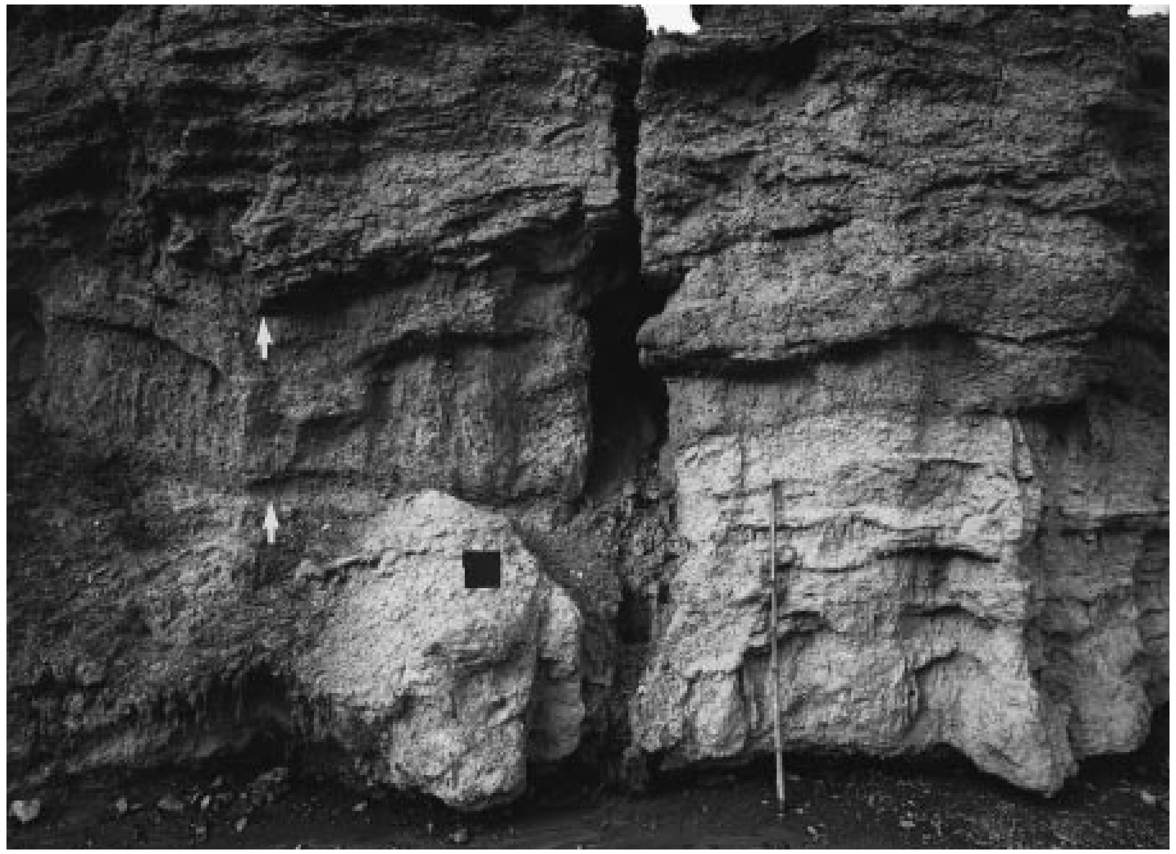
← *Photo 36.* Looking from ca. 3920 m (aneorid measurement; 4100 m according to the map) from the junction with the Tsangpo valley 1 km down-valley of the settlement of Napshi, facing N into the 'valley of Napshi' (Figure 2, Nos. 17–18). (□) marks the valley bottom, which has been accumulated by sand and outwash loess (secondary loess) and - in the underlying bed - by a Late Glacial glaciofluvial gravel body. (◓) are the hills and mountain ridges of thinly stratified metamorphic rocks and schists, rounded by the glacier ice and somewhat roughened by Late Glacial frost weathering. The slope, which has been undercut by the river, shows crumbling in the edges of the bedrock phyllite stratum (▽). During the Late Glacial the high-lying depressions and cirques (○) were still filled with ice. On the orographic right slope the High Glacial (LGM) lighter- coloured ground moraine (■) is preserved, reaching some hundred metres above the valley bottom. (– –) indicates the minimum altitude of the Ice Age level of the inland ice. (Photo M. Kuhle.)


← *Photo 37.* View from 4200 m asl into the orographic right-hand flank of the valley of Napshi looking on decametre-thick remnants of ground moraine (■) (29°10′ N/87°30′ 30″ E; Figure 2, No. 19). They have been deposited into a slope depression in the flow shadow of ridges of bedrock schists (◓ black), rounded by glacigenic flank polishing. Part of the ground moraine has been eroded and deposited as a debris fan at the foot of the slope (▽). It is adjusted to the actually accumulated gravel floor (□). In addition to precipitation this youngest and thus actual gravel accumulation is built up by the glacier meltwater of the connected massifs of the Transhimalaya. It can be classified as a gravel floor of Stadium No. –8 (Table 1). (↙) marks a further light-coloured moraine remnant, lying on the bedrock as a thin sheet and cut by small slope ravines, characteristic of ground moraine. The striping of the mountain ridges, round-polished by the prehistoric glacier ice (◓) is caused by the edges of the stratum of the bedrock schist. (– –) is the minimum altitude of the High- (LGM) to Late Glacial glacier level needed to form this relief. (Photo M. Kuhle.)

← *Photo 38.* Lang Tso with its eastern end (Figure 2, No. 20) is situated 9 km upwards the Napshi valley from the locality of Photo 37. It lies about 4200 m asl (seen from ca. 4250 m) in a landscape, which has been rounded (◓ ◓) by a prehistorically thick ice cover (– – = prehistoric minimum ice level). It concerns a lake basin, over-deepened by ground scouring, which has been dammed up by a Late Glacial end moraine. On the shoreline the down-valley end moraine has been reshaped by the surf (□) and washed. The slowly dropping level of the lake is controlled by a spill-over. Evidence of the post-Late Glacial age of the lake is the undercutting of the rounded glacial relief with its soft lower slopes by the lake level with its surf (◀ ▶). (▶ on the right): here, the lake level has undercut moraine material (■ on the very right); correlative moraine material is visible in the foreground (■ on the very left) (cf. Photo 39). (■ ■ centre) are moraine deposits on the southeastern shore of Lang Tso. (↙) marks the typical lineation of the glacially eroded landscape on the luff slope of a 'glacially streamlined hill' as it can be observed in many places in the Scandinavian mountains and in Greenland. (Photo M. Kuhle.)

↑ Photo 40: View from ca. 7 km E of the 4550 m–high Doka La (pass) facing N to a hilly landscape at 4300–4600 m, which has been abraded by the glacier ice (Figure 2, No. 22). The mountain ridges consist of easily weathering sedimentary rocks. They received their round forms through the ground scouring of the inland ice (◓ ◤). In many places they are still covered by ground moraine (■). The flow direction of the ice (– – = minimum level of the inland ice) can be recognized by the lineation of the relief surface (↑). Here, it points from the left (WNW) to the right (ESE) down to the Tsangpo valley, situated at a distance of ca. 70 km. The ground moraine on the slopes (in places marginally overhanging ❙ ❙) has been cut by ravines as far as to the bedrock. At the same time numerous small Holocene (post-Late Glacial) alluvial fans (△△) have been heaped up by the removed moraine material. On some of them pasture settlements of nomads (△ on the right) have been raised. In the foreground (□) a Late Glacial glaciofluvial gravel floor (sander) occurs, some hundred metres in width, which has been reshaped fluvially during the Holocene. This process still continues. (Photo M. Kuhle.)

← *Photo 41.* From 4315 m asl (aneroid measurement; according to the map ca. 4500 m asl) looking NW across the head of a source branch of the valley of Napshi, leading upwards to the Doka La (pass) (Figure 2, No. 23; 29° 18′ N/87°12′ 30″ E). (◓ ◓) are ridges of sedimentary rock in the immediate environment of the Doka La. They have been abraded and polished round by the inland ice (◓ ◓). Near their culminations they are covered by a merely decimetre- to centimetre-thick ground moraine sheet. Further down the thickness of the ground moraine (■ black) increases by several metres, reaching more than 10 m. An inn for yak drivers, constructed from clay (above ↑) on top of the moraine, gives an impression of the proportions. Gravel complexes, i.e., gravel imbrications (□), are compressed into the ground moraine (■). Probably the exposed gravel body (□) has been deposited by the subglacial meltwater on the lighter ground moraine layer in the underlying bed (■ black, below □). A somewhat darker, 2.5- to 5-m thick ablation moraine (■ above □) covers the gravel body in the hanging layer. The limit line between the subjacent, lighter, finer ground moraine (■ black) and the hanging (overlying) ablation moraine is clearly reconizable (↗); the dark-grey ablation moraine is also visible in the foreground (■ white on the right below). (▽▽) mark the bottom of the post Late Glacial fluvial forms of erosion, set into the ground moraine from the Holocene up to the present, which have been developed since deglaciation. It consists of slightly washed ground moraine. (○) indicates the sampling locality of Figures 13 and 5: 27.08.96/1 and the locality where Photo 42 was taken. (Photo M. Kuhle.)



↑*Photo 42.* Ground moraine exposure (locality see Photo 41 ○); 1.5-m long bamboo cane to compare the size. Polymict pebble-sized stones (drift) 'swim' in isolation from each other in the high portion of charcoal-grey fine material matrix (Figure 13; Figure 5, 27.08.96/1). Almost all of them are rounded at the edges. Evidence of a far-travelled moraine is provided by the stone material contained in the ground moraine (■) which does not originate from the local rocks of this valley head. This concerns for instance very resistant granite- and quartzite stones with a hardness degree about 6–7. The ground moraine has been sedimentated in light and dark layers. (↑ ↑) are the pertinent boundaries of the bed. Traces of fluvial washing do not occur. (Photo M. Kuhle.)

↑ *Photo 44.* About 14 km W of the Doka La this roche moutonnée slope is located in the outcropping edges of the stratum of metamorphic sedimentary rocks (centre of Figure 2, between Nos. 23, 24 and 25; aneroid measurement 4195 m asl), the layers of which are arranged horizontally from this perspective. A few metres thick ground moraine is preserved on top of the roche moutonnée (■ above). On the steeper rock faces of the slope (◓) the ground moraine has already been rinsed out as far as the bedrock and deposited secondarily at the foot of the slope (▼). This deposition took place on ground moraine remnants, which had remained in a primary position in the underlying bed (■ below). Simultaneously or before the deposition of the ground moraine – the thickness of which probably had increased during the Late Glacial and towards the phase of deglaciation – the outcropping edges of the stratum have been polished (outcrop strip polishing: ◓). Ravines, only a few decimetre-thick (▽), have been cut slope-downwards, i.e., vertically to the inland ice polishing, which took an approximately horizontal course. Their cutting continues in the moraine material at the foot of the slope (■ below). This points to the fact, that the work of the precipitation-water, continuing over at most some thousands of years, still has not been able to destroy or just blur the glacial smoothing of the slope. Even if one should doubt the glacial ground moraine character of the loose material in the culmination area of this hill, there is no other possibility of interpretation, since the alternative of a frost debris sheet, developed *in situ*, contradicts its selective preservation on top of the hill and the actual steep and step-like working edge of the current erosion below. At present we have a frost debris climate in the climax stadium, which here – at the level of the lower limit of the permafrost – concedes to the fluvial rinsing no greater intensity than at prehistoric times. (Photo M. Kuhle.)


← *Photo 43.* Panorama taken from the 4550 m high Doka La (pass) (Figure 2, No. 24; 29°14′ N/87°13′ 30″ E) facing NE (ghost-trap and prayer-flags on the left margin) via E (locality of Photo 41) (▼ black) via S, NW (course of the route) and NNW (sharpened summits of the Transhimalaya (2), up to N (right margin of the panorama). The surrounding hills and high plateau remnants, which consist of only little metamorphosed sedimentary rocks and do not rise over 5400 m, have been rounded and polished by the inland ice (◓ ◓). Like the pass (Doka La ■ in the foreground), the hills are covered by a decimetre to several metre-thick ground and ablation moraine (▽). It contains only few and not too large erratic boulders (○ black). (▽) mark slope positions with the most important moraine thicknesses in this area. Only here, some fresh (Holocene to historic, i.e., post-Late Glacial) sharp-edged, metre-deep ravines have been cut fluvially into the slope (▼ ▼). In the small areas without a moraine cover, the only superficially frost-weathered bedrock is visible (○ white). A complete frost debris sheet from loose rocks has not yet been developed *in situ*. Some of the round-polished hills show the lineations and exaration rills typical of overthrusting inland ice (↓) on their rock- and moraine faces, deriving from the ground scouring of very thick ices. (– –) marks the hypothetical inland ice surface (LGM). Towards the NNW, 5800–6300 m high summits of the Transhimalaya (2), sharpened like nunataks, can be seen at a distance of 40–50 km. They still show cirque- and hanging glaciers. (Photo M. Kuhle.)

↑*Photo 48.* About 32 km W of Sang Sang, S of the Dogxung Tsangpo (Figure 2, No. 29; 29°29′ 45″ N/ 86°27′ E; 4440 m), is situated this nearly 5000 m high hilly country from steeply layered strata of metamorphic rocks. Despite their rock structure, which favours a deep-reaching linear erosion, the hills are totally rounded. At this locality this ought to be considered as an especially clear evidence of glacial rounding (◓). This applies the more, as the climate-genetic tendency for linear erosion on the glacier-free slopes is equally proved by the development of gullies (▼). However, this concerns overlying loose rocks of ground- and ablation moraine covers (■), which after deglaciation in the Post Glacial, i.e., during the Holocene, have been furrowed by the precipitation-water as far as the subjacent bedrock - and in places even somewhat into it. The seemingly alluvial fan at the foot of the slope (■ black) is no accumulation form, but a 'transformation debris body' in the sense of Iturrizaga (1998), eroded from the moraine cover. This becomes clear by the fan root, which as a full form (△) stretches up-slope, instead of a gully, ending there (i.e., a hollow mould, out of which an accumulation could have taken place). 6–8 m-high telegraph poles as scale. (– –) is the hypothetical altitude of the Ice Age glacier area (LGM). (Photo M. Kuhle.)

↓*Photo 46.* Ca. 3 km W of the locality in Photo 45, taken from ca. 4260 m asl (Figure 2, Nos. 24–26) facing N. In the upper parts of the ridges from metamorphic rocks, which are round-polished by the inland ice (◓), remnants of ground moraine have been preserved at a small-scale or just in a punctiform manner (▼). On the lower slopes part of the moraine material rinsed from above, has been deposited secondarily and in the form of minor thick small alluvial fans (□) on the ground moraine (■), which the glacier had laid down *in situ*. The development of earth pyramids (↗) indicates some of the moraine localities. The sedimentary rocks, dipping with 40° to the NNE, consist of very resistant layers (○) alternating with soft rock. Thus, in a prehistorically periglacial-fluvial geomorphological environment sharp-edged crests with structure-orientated small valleys would have been developed. The realized, strongly rounded forms give evidence of a totally covering glaciation just a short time ago (LGM). Owing to backward erosion, the ravines, cut deeply into the moraine cover of the lower slopes, meanwhile continue as far as the rock slopes, lying above (▽). Formed during the Holocene they are only metre-deep. (– –) marks the minimum ice level (LGM). (Photo M. Kuhle.)



↑*Photo 45.* Eighteen km W of the Doka La (4 km W of Photo 44; Figure 2, No. 24; about 4240 m asl) seen northwards: a glacigenically abraded and round-polished landscape formed by the ground scouring of the inland ice in bedrock layers of different resistance. The roches moutonnées and glacially streamlined hills (◓◓) have been completely covered by the polishing glacier ice (– – : minimum height of the prehistoric glacier level, deduced from the typical shaping of the area). In places, perfect band polishings of the outcropping edges of the stratum are preserved (▾). Here and there light-yellow, far-travelled (erratic) remnants of ground- and ablation moraine can be observed in a primary position on dark rocks (↘↘). Metre-thick moraine material, rinsed slope-downwards, has been deposited on the already existing moraine at the foot of the slopes. In the fore- and middleground the primary moraine sheet is covered with metre-thick postglacial lake-silts (limnic rythmites) (□). During the Holocene decimetre- to metre deep slope ravines have been cut into the areas of glacial ground scouring (▽). They follow the ac- and bc-clefts of the sedimentary rocks. Their morphodynamics, which - compared with the glacier polishing - is totally different, become obvious by the sharp right-angled working edges on the upper margin of the ravines. (Photo M. Kuhle.)

← *Photo 47*. Twenty-three km W of the settlement of Sang Sang, taken towards the N from 4425 m asl (aneroid measurement) (Figure 2, No. 28; ca. 28°55′ N/86°10′ E): a ca. 150 m high hill from outcropping edges of the stratum of metamorphic sedimentary rocks rises above a ground moraine plain (■). This hill has been polished and abraded by the overlying inland glacier ice (– – = hypothetic minimum height of the ice level). The ground polishing interfered with the outcropping edges of the harder strata (◓ centre) resulting in the characteristic form, shown in the photo. Similar features are left behind by the glacial ground scouring in the Alpes as well as in Scandinavia. A streamlined form of a roche moutonnée is preserved in the background (◓ on the right). The featureless ground- and ablation moraines (■), setting in at the foot of these hills, show no similarity with foot areas built up without an ice cover, which consist of very extended alluvial fans. Here, only the smallest of Holocene alluvial fans have been developed from the moraine, rinsed down-slope (▽). (Photo M. Kuhle.)

← *Photo 49*. Taken at 4490 m asl (aneroid measurement), ca. 33 km W of the caravan settlement Sang Sang, facing N (Figure 2, No. 29; 29°20′ N/86°26′ E). The outcropping edges of the stratum of the sedimentary rocks, dipping steeply to the N (10/50-60), have been polished and abraded by the inland ice (▽ = band polishing of the outcropping edges of the stratum). The hills and mountain ridges also received their round forms (◓) by glacial ground scouring. The prehistoric glacier polishing has been slightly reshaped by the postglacial, Holocene linear erosion through a wide-meshed network of decimetre- to metre-deep ravines. (■) is an up to several metre-thick ground moraine sheet, undercut by the outer bank of the temporary creek in the thalweg (**|**). The ground moraine surface (■), rising as a flat ramp, nearly maintained the shape of its primary deposition. The normal characteristics of a slope with a debris surface, developed subaerially, are absent. This moraine remnant, surrounded by polished rock faces (◓ ▽), has been stripped off from the bottom of the inland ice in the flow shadow of the rock hills, i.e., in a depression opposite of them. (– –) marks the minimum level of the inland ice surface, related to this geomorphology. Almost certainly this relief was covered by a much thicker, namely kilometre-thick, ice body. (Photo M. Kuhle.)

↑ *Photo 50*. 4710 m (aneroid measurement) high transfluence pass at the Transhimalaya caravan route towards the W, E of the nomad locality Chiaote-Lo (Figure 2, No. 29; 29°29′ N/86°24′ 30″ E), about 39 km W of the Sang Sang panorama, taken facing from S to W. The High Glacial (LGM) inland ice has covered the relief to far above the round-polished hill ridges (◓) (– – = pertinent minimum altitude of the ice level), thus polishing and widening the transfluence pass to a flat U-shaped cross profile. Pass and valley bottom are overlain by ground moraine (■). The rather fine-grained ground moraine contains few erratic components up to fist-size, which are rounded, round-edged and facetted (✓✓). It covers metamorphic sedimentary bedrocks. The hardest of these bedrock sedimentary layers develop protruding rock ribs (*I I*). As a result of overgrazing and trampling along the caravan route the grass sods of the meadow vegetation (□) have been torn off and the vegetation-free ground moraine partly has been blown away by the pass wind (foreground). On the valley flanks, subdivided by small side valleys, mountain spurs have been polished back to the form of glacigenically triangular-shaped faces (‘truncated spurs’ = ➘ white). Ground moraine is overlying there, too (■ white). On the right-hand telegraph poles as scale. (Photo M. Kuhle.)

→ *Photo 51*. Fourteen km W of the 4710 m high pass (Photo 50), taken from 4540 m asl (aneroid measurement) (29°28′ N/85°57′ 30″ E; Figure 2, close to No. 29) looking up the Dogxung Zangbo (Tsangbo) to the W. The river and its high water bed with the light-coloured gravel bottom are set into the schist-like, thinly layered sedimentary bedrocks in the shape of a box (☐ black). Probably the valley in its current course has already come into being in the last interglacial (Riß-Würm-interglacial) or before, and developed further by the subglacial meltwater during the last covering with inland ice and the Late Glacial thawing phase. At the same time steep banks ocurred in the bedrock (▼), which point to a hydrostatically confined and therefore very fast meltwater run-off. They cannot sufficiently be explained by the comparatively weak processes of the subaerial lateral erosion observed here at present. This lateral erosion of the river undercuts softly-rounded, glacially-abraded band polishings of the outcropping edges of the strata, which do strongly contrast in the geomorphological sense. They are preserved on the orographically left-hand bedrock schists (◓ right). Ground moraine overlies only in places (■ black). An orographic left-hand Late Glacial (Stadium IV) moraine basement, washed glaciofluvially, is at least 15-20 m thick (▽ IV). The remaining glacigenically rounded (◓ ◓) surface of the Tibetan high plateau, is covered with ground- or ablation moraine up to several metres in thickness (■ white). In the fore- and middleground there are large parts of sandy matrix with ‘swimming’ erratic granite boulders (↙○). They are more than 1 m long and rounded at the edges, i.e., glacially facetted (○). In the foreground on the right, the moraine has been superficially washed by the meltwater and levelled to a terrace (☐ white). On the upper slopes, at places where the alpine meadow has been damaged and torn away by grazing and solifluction, sickle-like forms, which are free of vegetation, have been developed as a result of out-blowing of the sand by the wind (right and left of ↙↙). (– –) is the hypothetical minimum height of the inland ice level, consistent with the relief. Telegraph poles as scale. (Photo M. Kuhle.)



←*Photo 55*. View from the caravan settlement of Raka (ca. 4700–4900 m asl; Figure 2, No. 34; 29°28′ N/85°04′ 30″ E) towards the S across a ground moraine area (■) onto glacigenically polished hills (◓), consisting of metamorphic sedimentary rocks (schist, phyllite). The strata of the bedrock, outcropping diagonally to the run-off (←) of the High Glacial inland ice, which took place from NW to SE, interfered with the ground scouring to the slight lineation (▼) of these ‘glacially streamlined hills’. In sections these hills show classic streamlined profiles (◓ on the left) to the glacigenic development of which no alternative or convergence is known. In its far-travelled pelitic matrix the ground moraine (■) contains portions of local moraine from edged sedimentary rock fragments (○) of the only little resistant schist in the underground. Large boulders are lacking; but there are far-travelled, polymict, mainly edged components the size of pebbles. Neither on the ground moraine plain nor on the hill ridges do pattern grounds exist in the form of periglacial sorting of material to stone rings and fine earth beds. (– –) = geomorphologically necessary minimum altitude of the inland ice cover (LGM-Stadium III). (Photo M. Kuhle.)



↑ *Photo 56.* At 4725 m (aneroid measurement) WNW of Raka, looking over a ground moraine- and gravel floor landscape (■ □) (29°28′ 30″ N/85°01′ E; Figure 2, No. 35) towards the NE. The hills of metamorphic bedrock, round-polished by the glacigenic ground scouring, are covered by a far-travelled ground moraine (■). Up to several metres thick, it contains polymict erratic pebbles and boulders, consisting for instance of granites and other crystalline rocks. Where the current meltwater creek runs down (▽), which drains some small actual glaciers of the 6000 m high mountains of the Gangdise Shan, situated 20–58 km to the NNW (Figure 2 between Nos. 37, 33 and 39; Photo 60), the ground moraine has been washed out, i.e., its clayey matrix has been eliminated. At the same time the gravels have been classified. They cover the wide high water bed (□), which has been flatly deepened by this outwashing. Since the late glacial deglaciation, i.e., during the Holocene and at historical times (Stadia V–XII; Table 1) this glaciofluvial gravel string has been developed in continuation of a valley exit, situated to the NNW. On its outer slope the creek has freshly undercut the ground moraine sheet (▼). (Photo M. Kuhle.)

← *Photo 52.* Looking from 4535 m asl (aneroid measurement) across a source lake of the Dogxung Zangbo (Tsangpo), 37 km W of the nomad locality Chiaotelo (or about 55 km W of Sang Sang) towards the SSW via W up to N (Figure 2, No. 29; 29°29′ 30″ -32″N/86°11′ -16′ 30″ E). This is a Late Glacial tongue basin lake, dammed up by end moraines of Stadium III (■ III). In the fore- and middleground, along the lake edges, there are free-washed, up to several metre-long boulders (● ○), consisting of granite (○), porphyry (● white) and quartzite (● black). Here, in the region of outcropping sedimentary rocks in the underground, they can be addressed as far-travelled erratics from the NW. The boulders are partly edged (● white), rounded at the edges and facetted (● black) and sometimes rounded (○). The insignificant relief energy on the Central Tibetan plateau and the accompanying minimal inclines make an alternative transport of the boulders by down-flowing water or humid mass movements (mudflows) impossible. This is a further evidence of glaciation. As a result of the influx of many meltwater streamlets (e.g. ↗) and the movement of the low water near the shore, which is caused by the wind and whirls-up the moraine clay, the lake remains muddy-milky. At the foot of the S slope of the 5849 m-massif, the main summit of which lies 33 km away, Late Glacial end moraines of Stadium IV (■ IV) and corresponding indicators such as ice marginal ramps (▷) have been deposited. The accompanying glaciers flowed down from cirques (e.g., ▼). The rounded hills on the W shore of the lake (◓) were covered by the inland ice from the High- to the early Late Glacial (Stadium 0 = LGM up to Stadium III); (– –) indicates the minimum altitude of its surface, which could only just make possible the rounding shown (◓) by glacial ground scouring. (Photo M. Kuhle.)

←*Photo 53.* From 4540 m asl (aneroid measurement), 5–6 km SW of the view point of Photo 52, seen over a ground- and ablation moraine area (29°29′ N/86°09′ E; Figure 2, No. 29) in a SW direction. On the concrete-like solidified moraine matrix, rich in pelites (■ white), lies a polymict (quartzite, porphyry, granite, etc.) pebble scatter from at the most fist-sized fractions. These components are edged or rounded at the edges. The moraine cover mantles round-polished rock ridges (roche moutonnée: ■ black). Since deglaciation, which took place at the end of the Late Glacial (after Stadium III; Table 1), i.e., during the Holocene, the down-running rainwater has eroded only few metre-deep rills (microfluviatile rills) (▼) into the glacial loose rock material on flat slopes. From the steeper and more extended slopes and later from the bottoms of the small valleys and valleys of the glacially round-polished Tertiary hill landscape as well (◓), prehistoric moraine material has been fluvially dislocated and heaped-up as alluvial fans (◁) on the margins of the ground moraine plain (■ white). (– –) marks the minimum altitude of the surface of the prehistoric inland ice sheet, derived from the above-mentioned geomorphological characteristics of this section of Central Tibet. (←) is the main direction of the ice run-off from ca. NNW to SSE, deduced from the large-scale incline of the high plateau and the glacial formings of ground scouring. (Photo M. Kuhle.)

← *Photo 54.* Ground moraine area with roches moutonnées and streamlined hills (◓) in thinly stratified bedrock schists in Central Tibet (Figure 2, No. 33–36; 29°25′ N/85°16′ E, 4675–4700 m asl: aneroid measurement), taken 5–6 km E of the nomad caravan-settlement Raka, facing NW. There is no granite bedrock in the underground. Thus, the granite boulders (○) which 'swim' in the ground moraine (■) must be far-travelled erratics. Inclusive of the several hundred metre-high mountain ridges, the relief was covered by the High Glacial (LGM = Stadium 0) up to Late Glacial (up to and including Stadium III, see Table 1) Tibetan inland ice. ( – –) marks the minimum altitude of the prehistoric ice level needed to form this landscape, which with regard to its exact height remains hypothetically. (Photo M. Kuhle.)

← *Photo 59.* At 4880 m asl (aneroid measurement) (Figure 2, No. 38; 29°37′ N/84°58′ E) facing E across a roches moutonnées landscape polished by the inland ice (◓ middle ground), which is covered by ground moraine (■). It contains metre-long erratic granite boulders (✓), 'swimming' in isolation from each other in the fine material matrix, the transportation of which took place over a distance of at least 10 km from the N. There are the nearest bedrock granites (on the left-hand outside the photo; Figure 2, Nos. 38–39). From the left margin right into the photo there stretches a fjell-like mountain landscape in the background, which also consists of granite and which has been overflowed by the High Glacial inland ice (– – minimum ice level of the LGM). The valleys of this mountain landscape, set upon the Tibetan plateau, show typically glacigenic trough- and U-shaped forms (▽ black). In the course of the Late Glacial deglaciation, interrupted by less and less Late Glacial glacier advances, the valley bottoms (△ white) ending on the Tibetan high plateau, which is the immediate foreland of those mountains, have been more and more covered and filled with ground- and end moraine. In the fore- and middleground are post-volcanic springs (○ ○), coming out of the sedimentary rocks of the underground. They cover this region of ground polishing and ground moraines with a large-scale limestone sinter overlay (□). (Photo M. Kuhle.)

↑ *Photo 57.* 4800 m asl (aneroid measurement; according to ONC map 100-200 m higher), ca. 10 km NNW of the locality in Photo 56, i.e. about 18 km from Raka (29°29′ 30″ N/84°58′ E) towards the ENE, looking over ground moraines (■) and polished and abraded rock ridges (◓). The large area of excavation lying in between is a local meltwater run-off (□), by which (at first subglacially) gravel floor strings of displaced and thereby outwashed moraine have been – and still are – sedimentated during the late Late Glacial (Stadia III–IV) and then from the Holocene up to these days (Stadia V–XII; Table 1). The ground- and ablation moraine on this side of the flat valley (■), which is not outwashed, contains erratic granite boulders (○), superficially grubbed-up and stamped out of the original moraine formation by grazing yaks. These boulders have been transported over distances of at least decakilometres from the N, i.e., from the mountain system, the eastern foothills of which are visible in the background (Figure 2, between Nos. 38 and 39). (– –) indicates the Ice Age (LGM) level of the inland ice. (Photo M. Kuhle.)

↑ *Photo 58.* The profile of the Photos 56 and 57 continued rectilinearly 2–3 km towards the NNW (Figure 2 Nos. 36,37, 4820 m asl aneroid measurement), looking to the NNE across a valley landscape, covered by ground moraine. Due to the subglacial meltwater run-off during the Early- and Late Glacial, the valley has been embedded box-like into the tilted, more or less metamorphic sedimentary bedrocks (△). It has a bottom of outwashed ground moraine material (□). A primarily deposited (non-outwashed) ground moraine sheet, which contains far-travelled metre-long erratic granite boulders (← →), overlies the glacigenically abraded and polished edges of the strata of the bedrock (△) in metre-thickness. The postglacial to present-day lateral erosion of the concentrated meltwater has undercut the ground moraine cover (← →) as well as the bedrock (△). (Photo M. Kuhle.)



→ *Photo 61.* At 4945 m asl (aneroid measurement or 5150 m according to ONC), ca. 3 km N and 100 m below the pass (viewpoint of Photo 60), taken from the southern end of the lake facing E via S to NW across the valley with the tongue basin lake (□) (Figure 2, between Nos. 39 and 40). Hanging glaciers (○) are visible in the background (cf. Photo 60); the 5250 m high transfluence pass situated below, is covered with ground moraine (■ background). Mountain ridges E of the transfluence pass have been rounded by the inland ice (LGM) (◓ ◓). (– –) marks the minimum height of the High Glacial level of the inland ice, which has completely covered the relief. The ice run-off took place from N to S, i.e., from the right to the left side. During the Late Glacial (probably Stadia III to IV; Table 1) the valley was still filled with glacier ice, which at that time already flowed down to the N. The result was the present-day lake basin, developed from a tongue basin, which was fringed by moraines. The ground moraine cover (■ foreground) visible near the shore line and the subrecent shore platform of the lake has been washed out surficially by the surf and – owing to the deposition of moisture – has undergone an increased frost weathering. In consequence the coarse loose material on the surface has sharp edges and has been weathered into shard-like forms (●). (▽ ▽) are subrecent shore ridges; (▼ ▼) mark cliff forms of higher lake level positions. Due to the erosive lowering of the spill-over into the damming moraine (❙), the lake level has dropped in several steps. (Photo M. Kuhle.)

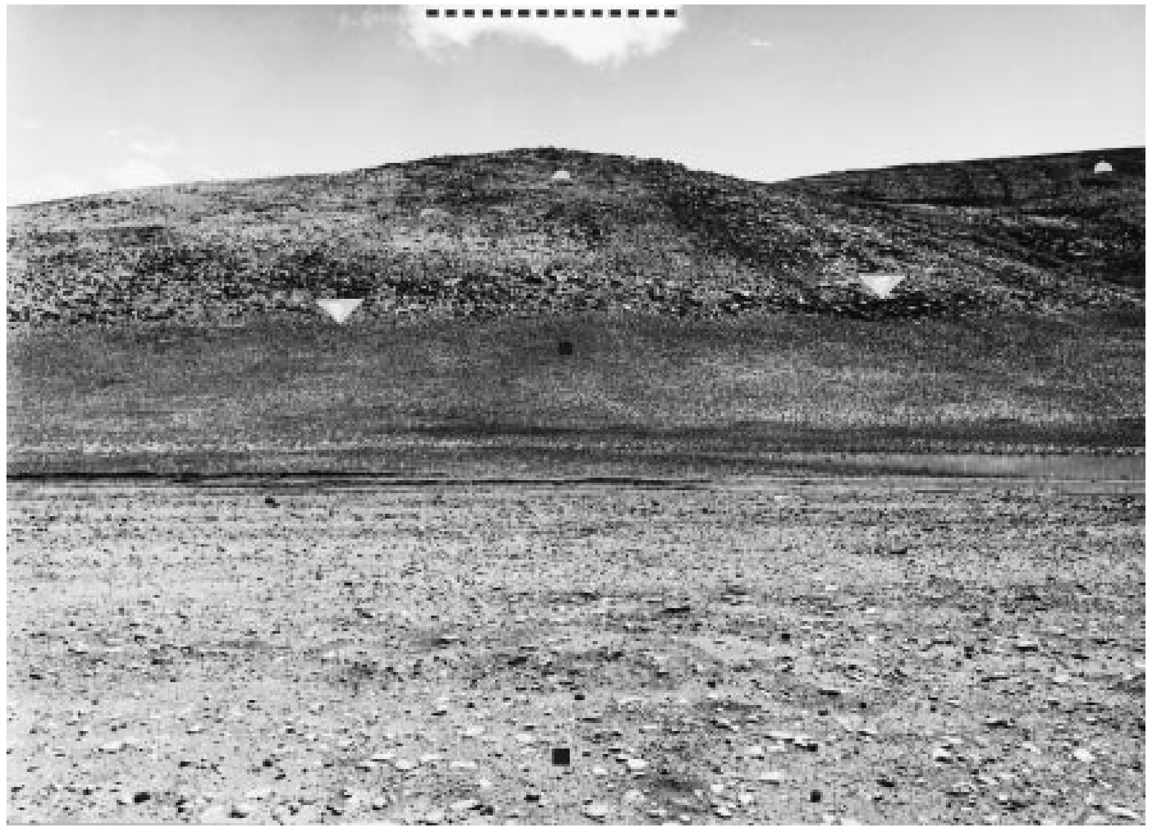
← *Photo 60*. About 17 km N of the locality of the thermal springs (Photo 59) there is a transfluence pass (5045 m asl aneroid measurement, 5250 m asl according to ONC map 1:1 000 000; Figure 2 between Nos. 39/33 and 38/40) from which this photo was taken, ranging from WSW (left margin) to N. The summits in the W reach an altitude of more than 6000 m, showing hanging- and cirque glaciers as well as short valley glaciers (○). (◓) mark glacial flank polishings on back-polished mountain spurs, developed between the short cross valleys of this mountain ranges. During the LGM (Last High Glacial) these mountains were completely covered by the inland ice; (– –) indicates the corresponding ice level. Ground moraine surfaces and -ridges are stretching in the fore- and middleground (■). This moraine cover shows lineaments, pressed in by the overflowing ground ice during the Late Glacial (△). The large boulders contained are up to several metres long (✓). The late Late Glacial tongue basin lake is somewhat more than 20 km long (N–S extent). Today its level lies 120 m below the pass (cf. Photo 61). Probably the overdeepening of the lake basin goes back to the embedment of a dead ice complex during the late- to postglacial decay of the inland ice. During the High Glacial the depression of the lake basin possibly was sealed by ‘cold based ice’, frozen to the ground. The inland ice run-off from approx. N to S might have taken place nearer to the surface and as a result of its shearing from the ice that was frozen to the ground. (Photo M. Kuhle.)

→ *Photo 62*. At 4955 m asl (aneroid measurement), E of the ca. 20 km long lake (cf. Photo 60; Figure 2 between Nos. 32 and 39) near its northern end (break-through of the moraine: ↓), facing N. Ground moraine (■) spreads from the foreground up to the lake bottom (middle ground). On its surface it is covered by an overlay of fine sands, a few centimetres in thickness, which has been washed out of the ground moraine by the lake water. The washing-out took place continuously during the successive lowering of the lake level (cf. Photo 61). This lowering was connected with the break-through of the over-spill which cut into the moraine, damming up the lake (↓). Glacially round-polished hills and mountain slopes (◓ ◓) rise on both sides of the lake (▲). (– –) is the minimum height of the prehistoric glacier level. (Photo M. Kuhle.)

↑ *Photo 63.* At 4780 m asl (aneroid measurement), N of the 5600-m main pass, 300°-panorama across the E Gangdise Shan (Figure 2, No. 40; Transhimalaya); locality: Figure 2, between Nos. 41 and 42 (29°59′ N/84°26′ E). The photo ranges from NW (left margin), looking into orographic left-hand side valleys, via N down the main valley, via E (middle of the panorama) into the right main valley flank, via S (left of the camp) up the main valley, up to SW (right margin) into the left-hand main valley flank with joining side valleys. A ground moraine plain stretches from the fore- to the background (■ foreground). As far as the larger components are concerned, it consists of polymict material, up to the size of blocks, rounded at the edges. Figures 17 and 5 (diagram 29.08./1) show the glacigenic nature of the matrix. Parts of these ground moraine surfaces have been reshaped by meltwater, i.e., washed. On the sides of the actual riverbeds and historic to present gravel floor plains (□) Stadium – 2 to – 8 cf. Table 1), Late Glacial to neoglacial glacier mouth gravel floors (sanders) (Stadia IV to VI; cf. Table 1) break away in the form of 2–3 m high terraces (▼ ▼). (– –) marks the High Glacial (LGM) minimum ice level of the inland ice, completely covering the area. This makes understandable the fact that the mountain ridges are round-polished up to their culminations (◓ ◓). On the hills and mountains, reaching more than 5100 m, fresh snow can be observed, which fell during the night (in August). In reaction to the ground scouring of the inland ice masses, the layers of the sedimentary bedrocks developed typical features of band polishings of outcropping edges of the strata (◓ white). The substantial roughness on the surfaces of some other hill- and mountain slopes (❙ ❙) derives from the outcrops of more resistant layers, i.e., protruding edges of the strata. Here and there ground moraine lies on the slopes (■ background on the right). In many places this moraine cover has been eroded, i.e., transferred to the slope foot and laid down there as small flat fans (▽ ▽). (Photo M. Kuhle.)

↙ *Photo 65.* At 4837 m asl (aneroid measurement; more likely 5000 m; Figure 2, No. 43) on the caravan route, ca. 4 km WSW from the locality of Photo 64, facing S (left margin of the panorama) via W (centre) to N (right margin), looking across a basin. Such intramontane basins are typical of the whole of Central- and W-Tibet. The bottom of this basin is covered by thick glaciofluvially washed ground moraine (■ ■). The meltwaters of the Late Glacial to postglacial deglaciation (Stadia IV to XII, i.e., up today; cf. Table 1), i.e., the back-melting of the prehistoric ice margin up to the high regions of the Gangdise Shan which are still glaciated, and also the seasonal snow meltwaters have cut and dissected this ground moraine plain (■ ■) by flatly inset drainage channels with gravel floors (below ▼). Thus, there have been developed terrace steps, a few metres in height (▼ ▼). In some places the bottom of valleys, joining the basin, have already been cut by the subglacial meltwater as far as to the bedrock (↓), so that the valley flanks, smoothed by the ground scouring of the ice (second ◓ from the left), have been undercut by a lower slope, steepened by lateral erosion (↑ ↑). Geomorphological evidence of this provides the sharp working edge from below set against the flat polished rock slope from above (↑ ↑). In comparison with the High Glacial the coming up of subglacial meltwater was connected to a markedly higher snow line, i.e. it was coupled with the Late Glacial (probably Stadia I–III; Table 1). During the High Glacial (probably LGM = Stadium 0) the snow line ran below the basin, i.e., lower than the entire valley- and basin-bottom. Owing to a probably more than 1000-m thick inland ice cover, frozen to the ground by cold-based ice, there could not have been any more subglacial meltwater. The polymict ground moraine (■ ■) contains local material of bedrock phyllites (sedimentary rocks) from the underground and the environs. The mountains, covered by fresh snow (though it is summer), are glacially polished and well to perfectly rounded (◓). (– –) marks the minimum surface level of the prehistoric inland ice sheet, the geomorphological proof of which is given by this rounding. (Photo M. Kuhle.)

→ *Photo 64.* View from 4885 m asl (aneroid measurement; Figure 2 between Nos. 41 and 42) on the flat saddle of a pass WNW of the main-Transhimalaya 5600-m pass (cf. Figure 2, No. 40, Gangdise Shan) towards Central Tibet. The 'chorten' marks the culmination of the pass. It is situated 6 km NW from the locality of Photo 63 at 30°01′ N/84°33′ E. The picture was taken towards the W. Typical monsoon weather situation with snowfall during the night at the end of August. The saddle, overflowed by the inland ice (LGM) and now showing a decimetre-thick ground- and ablation moraine sheet (■) (as for the substrate, cf. Figures 17 and 5, diagram 29.8./1), is representative of the complete glacigenic formation of numerous transfluence passes in the nearer and farther environment. Saddle and valley have trough cross-profiles. The slopes, i.e., mountain ridges, consist of sedimentary bedrocks and have been glacially rounded (◓). Here too, the cover of loose material is only a few centimetres- or decimetres-thick and down the slope has been reshaped by solifluction and the trampling of cattle. A truck serves to compare the size. The cross valley of the next-higher order (I) is already adjusted to one of the lowest older surface levels of Central Tibet and thus only falls away flatly (to the *N* = to the right). Its gravel floor of some hundred metres in width (I) has been accumulated by the Holocene to historic meltwater ('braided river'). Such valleys can also be found in the Arctic (e.g., Spitzbergen and Greenland). They are characteristic of the areas of sedimentary bedrocks. (Photo M. Kuhle.)



↑ *Photo 67.* View from 4610 m asl (aneroid measurement), 23 km N of the 4885-m pass (Photo 64), looking towards the E. The plain is made up by ground moraine (■), which contains substantial portions of local moraine material. Accordingly, it is free of large boulders (Figure 2, No. 42), because there is sedimentary bedrock in the surrounding area (but no massif-crystalline rock) (cf. in contrast Photo 68). The largest rock fragments contained are fist-sized (i.e., relatively small) with edges and broken into shards, i.e., not far-travelled. The snow, fallen during the night, has melted away over large parts (12.40 at noon, middle of August); under the decimetre-thick summer thawing layer ('active layer') the meltwater (foreground) stagnates on the ground moraine, which is rich in pelites, as well as on the permafrost table. The mountain ridges, reaching up to 5400 m, have been polished by the inland ice (◓). (– –) marks the minimum level of the ice. (Photo M. Kuhle.)

↑ *Photo 68.* At 4580 m asl (aneroid measurement), 11 km further down-valley from the locality of Photo 67 to the N, granite bedrock (◓) can be observed on the orographic right-hand side. Accordingly, the local ground moraine (■ foreground) is rich in coarse boulders (Figure 2, No. 43). The local granite boulders are mixed with far-travelled, for the most part detrital moraine material from fragments of the up-valley sediment rock (Photo 67). The ground moraine material (▼), presently solifluidally transported down from the steeper upper slopes, is set off with a clear margin and change of material against the ground moraine on the lower slopes (■ background) and on the valley bottom, because it has been moved further down and is therefore polymict and has undergone a heavier detrition. (– –) = LGM to Late Glacial minimum level of the ice. (Photo M. Kuhle.)

← *Photo 66.* At 4635 m asl (aneroid measurement; probably ca. 4800 m), 10 km N of the locality of Photo 65, facing SW (left margin) via WNW (centre) up to N (right margin) (30°06′ 30″ N/84°34′ E; Figure 2, No. 42). The bottom of the high basin is covered by ground moraine, which has surficially been washed by the meltwater (■ white). The boulders, up to the size of a fist, 'swim' in the relatively large portion of fine material matrix; coarse pebbles with an extension of up to 2 cm in length are dominant. Most of these pebbles are rounded at the edges, with only a few edged. More or less metamorphic sedimentary bedrocks (phyllites) occur in the underground. The surrounding high ridges with a temporary summer, i.e., monsoonal snow-cover and the classically formed roche moutonnée in the middle ground also consist of it (◓ white; Figure 2, No. 42). This glacigenic keyform shows a scour side, which to the S, i.e., up-valley, inclines more flatly (△). This proves a direction of ice run-off from S to N (from left to right), i.e., down-valley during the Late Glacial. It developed, when the inland ice had already melted and fallen apart into several complexes, orientated by mountain groups. Now, too, separate valley glacier streams flowed down to the N from these ice complexes, following the small-scale relief and valley incline. This happened during Stadia II-III, when the ELA-depression still was 800–1000 m compared with the current course of the snow line, and the equilibrium line (ELA) ran at 4900–5100 m asl (cf. Table 1). In the High Glacial (LGM = Stadium 0), however, the upland and the mountain ranges, visible here, were totally covered by the inland ice (0– – = minimum altitude of the inland ice surface). According to the large-scale incline of the high plateau, the ice run-off took place from N to S, i.e., from right to left. During the High Glacial the valley area of excavation many kilometres to decakilometres in width, which surrounds this roche moutonnée (◓ white), was probably filled with ground ice, frozen to the rocky underground. The actual ice run-off might have taken place in much higher ice layers close to the inland ice level (0– –) across the hill- and mountain thresholds (◓ black). (■ black) marks a polish threshold, covered by ground moraine. Narrow rills, a few decimetres- to metre deep (–), are set into the ground moraine, in parts reaching as far as the bedrock. (Photo M. Kuhle.)

→ *Photo 69.* 4560 m asl (aneroid measurement), 6 km N of the locality of Photo 68, looking across a surficially washed and glaciofluvially reshaped ground moraine sheet (■ foreground). This reshaping is the result of the meltwater of the thawing ice during the late Late Glacial (ca. Stadium IV; Table 1). The loose rocks on the valley floor are polymict and built up from components of granite- (the light boulders) as well as sedimentary- and metamorphic rocks. The great portion of pelitic matrix between the edged, rounded at the edges and facetted boulders has preserved its morainic character and is rich in clay. Down from the culminations of the mountain ridges the valley slopes are covered with moraine in increasing thickness (■ background). Biconvex accumulations of loose material in the form of debris cones or -fans on the foot of the slope are kame terraces and remnants of lateral moraines, slightly reshaped after deglaciation (▽). They have been left behind by a valley glacier in the late Late Glacial. (– –) is the prehistoric inland ice level, necessary to understand the geomorphological indicators. (Photo M. Kuhle.)

↑ *Photo 70.* The same valley as in Photo 69, again 6 km further to the N and 30 m lower (4530 m asl; aneroid measurement) (Figure 2 Nos. 43/44; 30°47′ N/84°32′ E), taken towards the NW. The ground moraine in the foreground (■) has been blown out on its surface. As a result it is covered with a deflation paving of quite large stones and pebbles, which have not been taken away by the wind. The light fine material on the slope, glimmering through the overlying larger components (▼ ▼), is erratic ground moraine matrix. The sedimentary bedrock in the underlying bed of the ground moraine mantle is dark. Debris which weathered *in situ*, is totally lacking on the slopes of this 'glacially streamlined hill' (◓). (Photo M. Kuhle.)



*Photo 71.* Taken at 4520 m asl (aneroid measurement; Figure 2, Nos. 45/46), 23 km N of the locality of Photo 70, facing W. In the fore- and middle-ground stretches a polymict ground moraine plain, surficially washed by the meltwater (■ black, foreground). The components contained consist of granite as well as of sedimentary rocks. Granite bedrock (◓) is already found on the orographic left valley flank; it has been smoothed by flank polishing (◓ left) and – in continuation of a small intermediate valley ridge – has been formed into a 'whale back'-roche moutonnée (◓ centre). The granite bedrock has been roughened by Holocene (postglacial) erosion and turned into a boulder scatter (↙). (■ white) marks a ground moraine ledge, preserved on the orographic left (western) valley flank - perhaps also remnants of a lateral moraine formation. It belongs to a very low ice level shortly before the complete melting, i.e. the Late Glacial. (◓ on the very right) points to a mountain spur, polished back by the glacier ice. (– –) is the minimum altitude of the High Glacial inland ice level, necessary to understand the relief forms. (Photo M. Kuhle.)

↑ *Photo 73.* 4590 m asl (aneroid measurement; actually 150 m higher: 4740 m), ca. 5 km NW from the locality of Photo 72. 360°-Panorama (Figure 2, left of No. 49): the left and right margins are approx. facing N, the centre is in the S (locality of Photo 72); somewhat left of it the Zhari Nanico (lake, Figure 2, No. 47) is situated in the background (not clearly visible in the photo). Half-left in the panorama is E, half-right is W. Ground moraine plains stretch from the fore- to background (■ ■). The composition of this ground moraine, very rich in fine material, is recognizable by the pelitic condition of the surface of the jeep track, from which the periglacial pebble cover, increasing by deflation, has been removed. The puddles visible there provide evidence of the characteristic swelling capacity and accordingly water-retaining qualities of this fine material matrix. Its high portion of clay in consequence of the glacial trituration points to an important glacial (at last LGM = Stadium 0; Table 1) thickness of the inland ice. Some of the surrounding hills and mountain ridges present a strikingly good glacial rounding (◓). Only in places, where the sedimentary bedrocks show substantial small-scale differences in resistance and the layers are upturned steeply, do the mountain ridges have some ribs, small crests and peaks (↑), i.e. there are no forms which are evidence of glacial ground scouring. But even here the slopes are covered with ground moraine (■). (– –) marks the altitude of the minimum ice level during the LGM. Besides the deflation pavement on the ground moraine above-mentioned (■), an overlay of wind-blown sand can be observed on the rounded hills (○). (Photo M. Kuhle.)

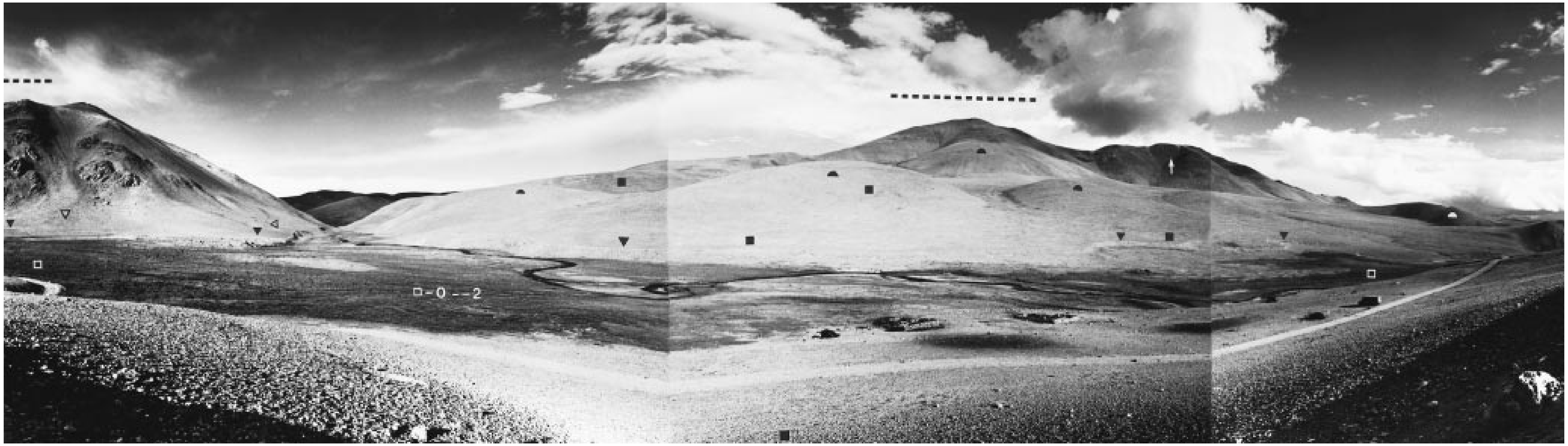
← *Photo 72.* 4485 m asl (aneroid measurement), ca. 5 km W of the military station Coqen (also Tsochin or Maindong) (Figure 2, No. 49; 31°01′ N/85°07′ 30″ E). Picture taken from the bottom of the intramontane basin in which the extended Zhari Nanico or Taje Tso (a 50 km long and 20 km wide lake, Figure 2, No. 47) is situated. Here, the valley with the geomorphological profile shown in Photos 64–71 comes to an end (**I**). The panorama ranges from N (left margin) via E (centre) to S (right margin). Glaciolimnic and glaciofluvial remnants of terraces (▼) occur below the view point as well as on other bank sections on both sides of the river and its kilometre-wide gravel floor ((□) = Nos. –6 to –8 according to Table 1). They show at least five levels (three main levels), situated ca. 5, 8, 21, 30 and 40 m above the river level (▼ ▼) (= Nos. 4, 3, 2 according to Table1; Figure 2, Nos. 46, 47). The point of view is on the third level from below, 21 m above the river. The terraces can be classified as belonging to the Late Glacial deglaciation from the High Glacial (LGM) inland ice up to the Holocene to modern condition of the interglacial. (△) indicates cross- and deltaic layers in the limnic sands. The corresponding Late Glacial lakes have been dammed-up by the most important valley glaciers, which in the Late Glacial (Stadium I to III; Table 1) still filled the main valley net of this mountain group, set upon the Tibetan plateau. In the joining side valleys (↓) as well as in the basin of Coqen (fore- and middle-ground and towards the left margin of the panorama) there existed such lakes, more or less communicating with each other. They have been dammed-up by separate rather large ice lobes, flowing down from the mountain massifs and entering the basin. Part of these sands, which are preserved in terraces, were again overthrust by the meanwhile advanced glacier ice: as a result, these sands are covered by a decimetres-thick ground moraine sheet (foreground) (■). (◓ ◓) mark keyforms of High Glacial (LGM) glacier erosion; (– –) is the minimum height of the accompanying ice sheet. (Photo M. Kuhle.)

↑ *Photo 74.* View from the 5050 m pass (Figure 2 between Nos. 52 and 49; 4885 m aneroid measurement), looking from S via E up to N (from left to right) (31°05′ N/84°52′ 30″ E). This saddle, which has been polished by the inland ice (LGM) from right (N) to left (S), is built up in reddish-brown sandstone bedrock. The few decimetre- to centimetre thick ground moraine (■) lying on this sandstone, contains green porphyry erratics. The ridges reaching up to 5300 m, are also covered by thin ground moraine containing much local moraine material, which has been broken out of the underground (sandstone components). The rounded hills show streamlined contours (◓) with leeward steepenings immediately below the culmination, characteristic of glacier ground scouring (↓). Further keyforms are the exaration rills (△) by which the out-carving and out-polishing ice has cleared out the outcropping edges of the sandstone strata (glacial band polishing of outcropping edges of the stratum). (– –) = minimum altitude of the inland ice level. (Photo M. Kuhle.)

↑ *Photo 75.* At 4490 m asl (aneroid measurement; probably 4650 m asl) on the caravan route, 89 km N from the view point of Photo 70, looking from SW (left) to N across a limnically reshaped ground moraine (■) (Figure 2 right of No. 53). The lake expanses of this late-Late Glacial tongue basin (ca. Stadia III or IV; Table 1), remaining up to the present time, stretch in the middle ground (□) and background. The surface of the High Glacial inland ice (LGM, Würm, Weichsel, Wisconsin, Waldai) towered above the surrounding hill- and mountain chains (background). (– –) indicates the minimum height of the Tibetan inland ice, being 1000 m thick here. Besides sharp-edged to round-edged large boulders of the sedimentary bedrock in the underground and nearer environs (○ white = local moraine), the ground moraine (foreground) also contains far-travelled erratic granite boulders (○ black). At the time when the shore line was running in this area (foreground), the lake water has surficially washed the ground moraine, so that a coarser matrix developed. (Photo M. Kuhle.)

↓ *Photo 76.* At 4560 m asl (aneroid measurement; according to ONC map 1:1 000 000 = ca. 4700 m asl), in the same lake basin shown in Photo 75 but 16 km towards the NE (Figure 2 between No. 53 and 51; 31°21′ N/85°05′ E), looking from S via W to NE across the residual lake (○) and the bordering mountain groups and hill systems as far as a distance of decakilometres. They rise to a height of at the maximum 5900 m. The former lake bottom, extending up the slopes and hills of the mountains, has covered High- to Late Glacial ground moraine. As a result of the late Late Glacial step-by-step reduction of the lake surface and the connected lowering of the lake level as far as to its Holocene and recent extensions, i.e., level positions, the ground moraine covers (■ ■) have undergone a temporary surficial redeposition and washing-out by the surf near the shore line, which slowly worked itself across here. The inflow and outflow of this lake into, i.e., out of neighbouring valleys and basins – according to the communication of the pertinent water positions – has created flat gravel bodies with small-scale steps, made up from gravel terraces a few metres in height (▼ ▼). Late Glacial moraine- and kame terraces (□) extending decametres up the hill- and mountain flanks in the form of steps, show undercuttings (➞) by those highest late Late Glacial (cf. Stadium IV; Table 1) lake level positions. Hitherto the former (Late Glacial) local hydrology and limnology respectively, and their chronology are rather unknown in detail. It is certain that the early lake periods belong to the phase of the Late Glacial ice decay, and the lake has come into being between the dead ice complexes of the thawing-off area. At that time not only the present-day basin- and mountain-relief dictated the damming-up of the lake, but the dimensions and heights of the dead ice barriers first determined the dimensions and depth of a multitude of rather small lakes and afterwards of an extended lake. (▽) marks a prehistoric (probably late-Late Glacial, see above and Photo 75) lake spillway, which led as a narrow V-shaped gorge into a neighbouring valley and has been deepened by backward erosion. At the same time it had already begun to erode the level of the basin bottom (▲ black) deepening it in linear form. Accordingly, it belongs to a later period, the lake level of which has already been lowered by drainage. The ice which has taken part in the prehistoric damming-up of the lake can indirectly be diagnosed by the construction of such new spillways, set off against the older slopes through sharp working edges (e.g., ◇). These spillways can be recognized as being young, because lakes which are solely subordinated to the relief only drain through very old and therefore broad basin outlets. They do not develop such 'spillways'. (◓) marks glacially rounded hill- and mountain ridges. (– –) is the minimum height of the High Glacial (LGM) inland ice surface. (Photo M. Kuhle.)

↑ *Photo 77.* View from 4655 m asl (aneroid measurement; ONC-map 1:1 000 000 = 4800 m asl) on the caravan route, but 21 km more N than the locality of Photo 75. Panorama facing N (left) via NE up to E (Figure 2, No. 51). A slightly undulating ground moraine area (■) stretches up the slopes of the hills (background). Its material consists of polymict drift of porphyry and other volcanic rocks as rhyolite and quartzite, silt and sandstone. As a result of the Holocene to modern backward erosion, the light ground moraine matrix has partly been exposed on slope steepenings as well as on spring depressions (▽). Here, the covering character of the ground moraine and its thickness of up to few metres can clearly be diagnosed. On the upper slopes of the higher mountain ridges consisting of red sedimentary rocks, the residual detritus developed *in situ* is dovetailed with the ground moraine, i.e., covers it over large parts (**I**). The High- (Stadium 0 = LGM) to early Late Glacial inland ice (Stadia I–II; Table 1) has rounded the upland relief by glacial erosion (◓). (– –) marks the verifiable Ice Age glacier level. During the late-Late Glacial (Stadium IV) hanging- and cirque glaciers on the higher mountains (○) have been developed. (Photo M. Kuhle.)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← *Photo 78.* At 4785 m asl (aneroid measurement), 5–6 km up-valley from the locality of Photo 77 (Figure 2, No. 51; 31°28′ N/85°12′ 30″ E) across a typically Central-Tibetan glacial landscape, facing ENE via S to WSW. The Tibetan tents and rectangular cattle kraals in the foreground are a scale for the proportions. Round-polished and abraded by the inland ice (◓), this landscape is made up of more or less metamorphic stratified rocks, outcropping as edges of the strata at the valley head (left margin). Only there do slope forms influenced by the rock structure occur, and ground moraine has been transported as debris up to the slope foot, forming cones and fans (▽). The rest of the hills and slopes is covered by ground moraine with a yellowish fine material matrix (■). Merely the highest, still soft-shaped hills from reddish sandstones show no ground moraine and have a mere decimetres-thick debris cover weathered *in situ* (↑). The valley bottom consists of ground moraine with a thin glaciofluvial gravel sheet (□ –0 to –2). It has been accumulated by the meltwaters of small glaciers and rather large firn shields – situated on the mountains connected to this valley by the slope –, which still existed in the Neoglacial (ca. Stadia V to 'VII; see Table 1). At the same time the older ground moraine has also been rinsed and out-washed in many places. The water-retaining clayey-silty ground moraine matrix leads to the impounding of wetness. Thus alpine meadow vegetation on the valley bottom is possible, even under semiarid climate conditions. The valley floor, still in the process of being transformed by the small meandering river, has undercut the base of the slopes (▼ ▼), so that the yellowish High (LGM)- to Late Glacial ground moraine is exposed along the actual working edges. The character of this landform reminds of the most arid region (250 mm/yr) of Spitzbergen (Dicksonland at 78° N at 200–400 m asl; cf. Kuhle, 1983a), where a ca. 1000–1500 m thick glacier ice cover occurred in the High Glacial. (– –) indicates the minimum level of the inland ice sheet. (Photo M. Kuhle.)

→ *Photo 79.* At 4825 m asl (aneroid measurement) about 10 km N from the locality of Photo 77 (Figure 2, No. 51), looking towards the SE. The higher mountain ridges of this glacial landform, polished and abraded by the inland ice, have preserved the slightly edged contours of outcropping edges of the stratum (**I**). Sedimentary bedrocks occur here. Ground moraine extends in the foreground (■) and also covers the rather steep slopes in the background. It can be recognized by the light matrix (↑). Merely on steep slopes it is mantled by debris weathered *in situ.* Only in places are the rounded surfaces, predominant by far (◓), interrupted by few metres-deep run-off rills and small valleys (▽), incised by the meltwater since the late- to postglacial deglaciation. (– –) marks the minimum prehistoric height of the ice sheet, necessary to understand this geomorphology. (Photo M. Kuhle.)



← *Photo 81.* At 4855 m asl (aneroid measurement at high-pressure), i.e., at ca. 5100 m asl (31°40′ 30″ N/85°07′ E; Figure 2, No. 57) looking to the ENE slope of the 6815 m-massif (1). Panorama ranging from SSW (left margin) via W (centre) to NW (right margin). At this exposition the modern glacier tongue flows down the lowest (▽), ending at ca. 5350 m asl. At a medium height of the catchment area at 6200 m asl, the orographic ELA comes to ca. 5800 m asl (6200-5350=425+5350=5775). The front of the glacier tongue (▽) is relatively steep and heavily fractured, ie., resolved in marginal crevasses. From this a present (1996) advance of the glacier end can be inferred. In the forefield of the glacier tongue are up to 80 m high end moraine ramps of the historical Stadium X (younger Dhaulagiri Stadium X; Table 1), which have been pushed together, i.e., built up during the last 180 years (■ X). In a comparable parallel-arranged tongue basin (partly hidden by the perspective), the orographic left-hand lateral- and ground moraine slopes can be traced back from this historical Stadium X up to the Nauri Stadium V, i.e., to the older Neo-Glacial (■ V-X) 5500 years ago (cf. Table 1). On the mountain ridges polished round during the High Glacial (LGM = Stadium 0) (◓ ◓) and on the cross-valley intermediate valley ridges on the periphery of the mountain group, late-Late Glacial ground moraines of Stadia III and IV are preserved in the form of a boulder scatter with matrix (■ III and ■ IV right) and as lateral moraines of Stadium IV as ramp-forms of a coarser composition, containing more boulders (■ IV left to centre). In the foreground a fan form stretches into the mountain foreland, i.e., on the Tibetan high plateau, attaining about 5000 m. It is made up by washed glacial ground moraine (■ ■ 0). The ground moraine fan is interrupted by the historic to actual gravel bed of the meltwater stream of the recent glacier (□ –6 to –8; see Table 1). Due to the night-frost nearly no water flowed at the time when the photo was taken, i.e., at 8.30 in the morning, even in summer (30 August 1996). The snow of the precipitation from the days before still lies on the mountain slopes. (– – 0 – –) marks the minimum height of the glacial inland ice at ca. 6000 m, reconstructed according to the upper polish line. The summits rising ca. 800 m higher (1) have been glacially sharpened as nunatakr by the flank polishing and its lateral erosion (cf. Photos 80, 83 – –). This mountain massif is built up by metamorphites (phyllites) and sedimentary rocks, especially limestones. (Photo M. Kuhle.)

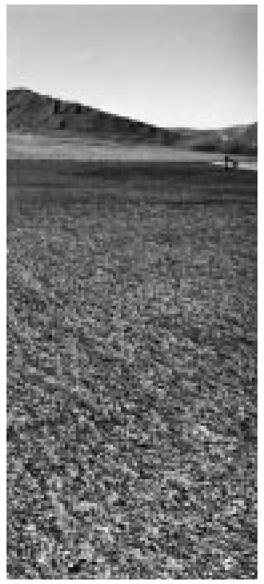

↓*Photo 82.* At 4755 m asl (aneroid measurement), actually ca. 4950 m, 10 km N from the locality of Photo 81, looking from the Central Tibetan plateau facing S (left margin) via W (centre of the panorama) up to N (right margin). (■) marks the Ice Age ground moraine cover, containing no coarse boulders here (Figure 2, No. 58). The reason for the lack of large components is the occurrence of sedimentary bedrocks as far as the further environs. Owing to its minor hardness their detritus has been ground to a finer fraction. The ground moraine covers the plateau area and some hills and mountain ridges. Since deglaciation the ground moraine – orientated according to ravines, i.e., steep little valleys (▼) – has been transported down the higher northern spurs of the 6815 m-massif (1 and 2) and removed to the mountain foot. This happened from the late-Late Glacial until recently. The dislocated moraine material has been accumulated in the form of mudflow fans (▽). Such mudflow fans are situated at places where the mountains are high enough to develop a small self-glaciation in the form of hanging- and cirque glaciers or just firn shields during the late-Late Glacial (Stadium IV), i.e., after deglaciation of the inland ice. (○) marks the localities of the self-glaciation in this interim period. (– – white and black) indicate the glaciogeomorphologically extracted minimum level of the inland ice (Stadium 0 = LGM) about 6000 m asl. (It seems as if the height between – – white and – – black differs, but this is caused by the perspective. They correspondingly mark the 6000 m-level). (1) is the 6815 m-summit, (2) the 6138 m-summit lying more to the S. (◓) are glacially rounded features. (Photo M. Kuhle.)

← *Photo 80.* At 5015 m asl (aneroid measurement), actually at ca. 5200 m, from a pass of the nomad- and caravan route (Figure 2, No. 55) 13 km N from the locality of Photo 79 (31°33′ N/85°12′ 30″ E) looking to the N: facing NW (left margin) via NE (centre of the panorama) to SE (right margin). In the NW the 6815 m-peak (1) of the N Gangdise Shan is situated (cf. Photo 81; Figure 2, No. 57); right of it, at the level of a ca. 6000 m high satellite peak (3), the reconstructed minimum height (– – 0 – –) of the inland ice (LGM). Apart from the high summits, the relief was totally covered with ice. Evidence of this provide the roundings of rock thresholds and hills (◓ ◓). There are sedimentary bedrocks, among them bedded to stratified limestones. As in all inland ice regions the latter develop somewhat more precipitous features (△). The rock thresholds are mantled with decimetre-thick ground moraine (■). (■ on the very right) shows a 45 cm-deep excavation through this ground moraine down to the bedrock. At an altitude of over 5400 m asl covers of fresh summer-snow can be observed. (Photo M. Kuhle.)



↓ *Photo 83.* View from 4660 m asl (aneroid measurement; probably 4700–4800 m), 33 km N of the 6815 m peak (1). The panorama is ranging from E (left) to S (right, 1). The ca. 400–500 m high mountain (left) consists of limestone and has been polished and abraded by the inland ice up to its culmination (– – minimum altitude of the LGM ice surface) (Figure 2, No. 59). The round forms, created by the glacier polishing, are preserved much better on the lower slopes of the limestone mountain than on its upper slopes (◓ left). It might seem that this mountain as a whole is a rather inadequate glacial indicator because its rounding is not very conspicuous. But exactly the opposite is true: it shows the unmistakably characteristic feature of subglacially shaped limestone mountains, the rock structure of which – also subglacially – partly remains. An example of the same form is the 588 m high Oeksberget in N Norway, 35 km NE of Alta at 70°N/23°30′ E. This, too, is a limestone mountain polished by the inland ice. Of course the low hills, which are situated more to the S (◓ in the left and right middle of the picture) and consist of basement sediment rocks, have also been smoothed. Above ca. 6000 m the 6815 m-peak (1) has been glacially sharpened (cf. Photos 81 and 82 above – –), i.e., has towered ca. 800 m above the inland ice surface (– –) as a nunatakr. The rock floor of the high plateau is covered by ground moraine from the fore- to background (■). It is made up by polymict pebbles of up to 5 cm in length in a pelitic matrix rich in clay. The pebbles are not classified, but – isolated from each other – are incorporated into the pelitic ground mass. On the foot of the glacial mountain ridges and hills the ground moraine clings to the rocks as attached ramps of loose material forming ramp-slopes (■ black). Since deglaciation and still under the currently semi-arid climate conditions, the ground moraine ramps have been dissected by the meltwater, running down from the rocks (the precipitation is solely snow here), thus forming ravines and rills (▽). (Photo M. Kuhle.)

→*Photo 85.* At 4275 m asl (aneroid measurement), actually ca. 4450 m asl, 14 km NNW from the locality of Photo 84 (Figure 2, No. 60; 31°56′ N/84°58′ E), looking across the large excavation area running in Central Tibet to the WE, in which the ancient caravan route of Lumaringbu (Figure 2, No. 65) or Gertse (Kaitse) in the W led to Pubu (Figure 2, right margin) and Amdo in the E (N of Nam Co, cf. Kuhle (1991d), Figure 43, Nos. 6–9, settlements of Pagnag and Nagqu). Panorama ranging from NW (left margin) via N (centre) up to NE (right margin), looking to the mountain chain stretching NE, i.e., beyond the excavation area. It consists of metamorphic sedimentary rocks. Especially on its lower slopes it has been roughened and fissured by the structure of the stratified rock (↓). The upper slopes show a glacial rounding of the mountain ridges and -cupolas (◓ ◓). Owing to the mountain heights reaching 5000–5300 m asl, small late-Late Glacial hanging glaciers (Stadium IV, see Table 1) existed after the melting of the inland ice at the heads of the high valleys and high basins (○ ○). They belonged to the cirque glacier type. The linear meltwater discharge of these glaciers has modified the relief, which the inland ice had formed more softly, by V-shaped valley profiles, sharpened towards the valley exits (cf. Photo 85a). The bottom of the excavation area stretches as ground moraine plain (■) in the form of a mountain foreland across the middle- to foreground of the photo. The nature of the ground moraine material can be taken from Figures 21 and 5, diagram 30.8./1. During the monsoon the sealing of the pore volumina by the clay portions of the ground moraine leads to large flat lake- and water areas without an outlet (□), which are markedly reduced by evaporation in the autumn. On the edges of the shore ascending salt- and limestone solutions have been crystallized-out to form white crusts by capillary influence (▼). The ground moraine surface has been slightly washed and rinsed by the temporary water faces (■); (cf. Figure 5 diagram 30.08./1). (– –) marks the minimum height of the High Glacial inland ice surface. (Photo M. Kuhle.)

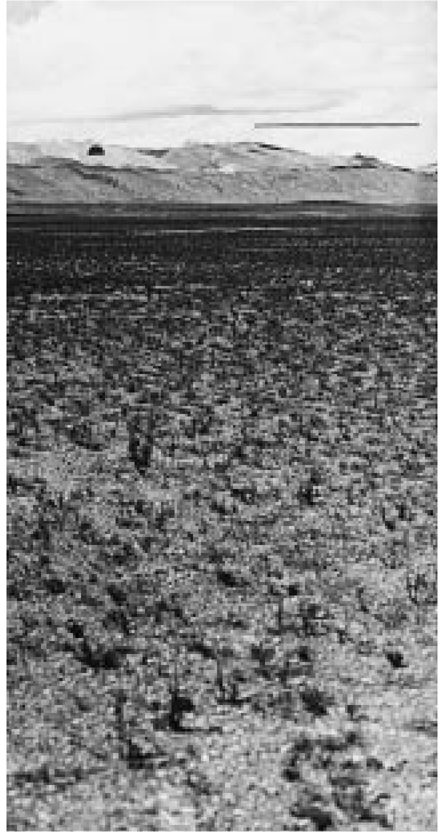


← *Photo 84.* At 4400 m asl (aneroid measurement during a high-pressure situation), probably 4550 m, about 24 km N from the locality of Photo 83. The panorama ranges ca. from the locality Figure 2, No. 59 (31°48′ N/85°08′ 30″ E) facing N (left margin) via E (centre) up to S (right margin) looking across a ground moraine plain (■ ■). On the very left, as well as on the very right, the light trail of the caravan route is visible (◁ ▷). In the right half of the panorama are ridges, more or less round-polished by the inland ice, which can only partly be referred to as 'glacially streamlined hills' They have been developed in sandstone bedrock. The well-rounded hills still show a lighter ground moraine sheet (▲ ▲), whilst at the places where the hills rise higher it has already been washed down and removed to the slope foot. On these hills the bedrock structure outcrops in the form of edges of the stratum. At a distance of 20 to 25 km towards the N to NNE the mountain ridges have also been completely overflowed by the inland ice in the High Glacial. According to their rough structure, which corresponds to the sedimentary bedrock, they show only few glacial roundings (◓ left) (cf. Photos 85, 85a). (– –) indicates the minimum surface height of the High Glacial inland ice sheet (LGM) drawn from the relief forms. (Photo M. Kuhle.)

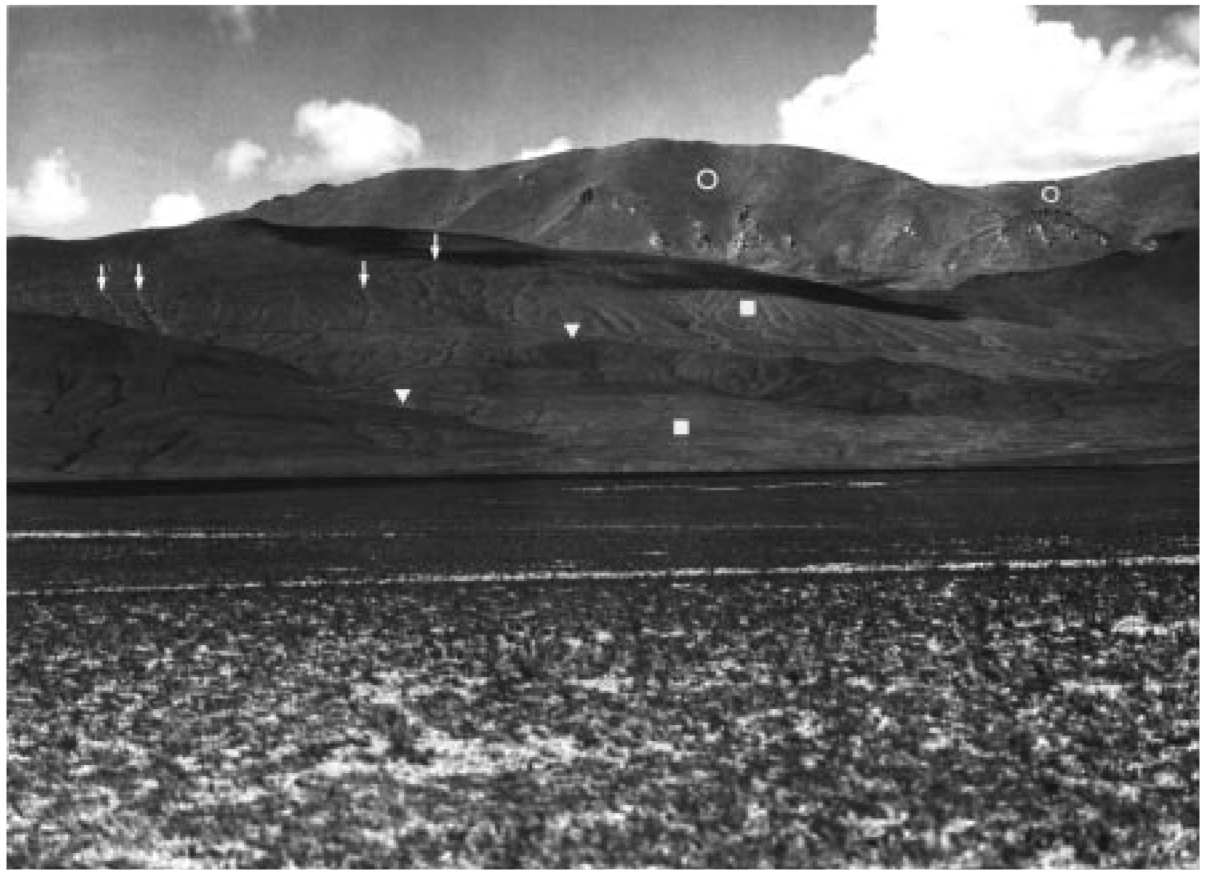


↑ *Photo 85a.* Mountain section of the same slope as shown in Photo 85 but at a smaller distance. Here, one can recognize much clearer that the high valleys and its heads have been polished, rounded and glacigenically smoothed (○) – which is typical of cirque- and short-valley glaciers. Down-valley, the V-shaped valley cross profiles and ravines of the glacier meltwater (↓) flowing down in the late Late Glacial, continue. From the valley exit as far down as into the foreland, flat alluvial- and mudflow fans (▼) have been heaped up, being part of this Late Glacial glaciofluvial denudation- and removal process. They consist mainly of displaced moraine material. The sharpening of the relief which took place after deglaciation of the inland ice, has been favoured by the narrow-fissured structure of the sedimentary bedrocks, broken through by light pegmatitic veins (▽). (Photo M. Kuhle.)

← *Photo 86a.* Section of the mountain chain shown in Photo 86 in a more extensive perspective, now seen in detail towards the SSE. The edges of the strata, i.e., banking structure have been glacially rounded (◓). Since deglaciation at all places where the easily eroding ground moraine is situated, slope ravines (↓ ↓) have been cut into it. Owing to having initially settled into this loose rock, rich in fine material, the thalweg was able at some places to cut into it as far as the underlying bedrock (↓). (■) marks a several metres-thick ground moraine cover. (○ ○) are N-exposed late Late Glacial nivation niches (Stadium IV, Table 1). They could develop after the melting of the inland ice at an ELA about 5100 m asl (orogr. snow line at 4900 m). Due to the meltwater discharge of their snow- and firn deposits, the V-shaped profiles (▽), which in the preceding interglacial period had also been formed fluvially or nival-fluvially and eroded flatly into the slopes of the 'glacially streamlined hills', became intensified. (Photo M. Kuhle.)



← *Photo 86.* Taken from the same locality as Photo 85, facing SE via S to SW to the mountain ridges and hills bordering this Central Tibetan excavation area in the S. The ridges are made up of sedimentary rocks (partly from reddish sandstones = seemingly dark rocks) and have been abraded and round-polished by the ground scouring of the inland ice (LGM) (◓ ◓). Polished edges of the stratum outcrop on several slopes (↓ ↓); at other places they are covered by light-looking ground moraine (■ black). The band polishing of the outcropping edges of the strata (↓ ↓), in many places shining through the ground moraine or thin cover of residual detritus developed *in situ*, is a glacigenic key form in the sedimentary rock as interference of forming process and rock structure (cf. v. Klebelsberg, 1948, Vol. 1). (– –) marks the minimum height of the inland ice surface, which must be derived geomorphologically from the relief characteristics. (■ white) is the ground moraine surface (Figure 2, No.60) with a deflation pavement of pebble-sized components (cf. Figure 5, diagram 30.08./1). See Photos 86a and 86b. (Photo M. Kuhle.)






↑ *Photo 87.* In comparison with Photo 85 this view point has been shifted 250 m to the W (4450 m asl; Figure 2, No. 60). Looking towards the W across the ground moraine plain (■) of the extended high plateau area, i.e., the flatly inset excavation area between the W/E-trending parallel mountain- and hill chains (Photos 85, 86), where the ancient caravan route to Lumaringbo (= Gertse or Kaitse) ran. The rock pavement of the ground moraine surface (■) created by deflation consists of pebble components free of fine moraine matrix. It shows that the moraine contains no large boulders in this region. The round-polished mountains in the background (◓) mainly consist of sedimentary rocks which provide the pebble fraction in this moraine (local moraine). The lower slopes of those mountains show coverings of ground moraine (see Photo 87a ■ background). (– –) marks the minimum height of the ice surface of the High Glacial (LGM) inland ice necessary for the explanation of the analysed geomorphology. See Photo 87a for geomorphological details of the 5720 m-massif in the background (2). (Photo M. Kuhle.)

← *Photo 86b.* A further section of the landscape visible in Photo 86. The N-exposed slopes of the mountain chain seen at a smaller distance towards the S. The lower slopes are covered with ground moraine up to several metres in thickness (■). The somewhat lighter material (this is mainly the colour of the yellow moraine matrix) contrasts with the series of underlying sandstone bedrock. Thus, the margin of the somewhat thicker moraine cover (▼ ▼) is clearly recognizable there. These thicker ground moraine overlays have been cut deeply and in particular markedly (i.e., sharply) by postglacial ravines and flushing rills clearly visible here (↓) (see text of Photo 86a). Despite the fact that the relief has completely been overflowed by the inland ice during the LGM (Photo 86 – –), the ground moraine cover is missing on the upper slopes. The reason for this is (as it can also be observed on the Scandinavian fjells in Sweden, Norway and Finland) the increasingly glacial erosion by ground scouring towards the exposed convex mountain ridges and the increase of accumulation towards the concave hollow forms situated lower by the stripping of subglacial moraine (= moraine which has been taken up by the ice and clings to the bottom of the glacier). Because of this the ground moraine is thickest in the depressions (■). In addition the denudation by late-Late Glacial firn shields and snow patches (○ nivation depressions) in the region of the former ELA which are dependent on the upper slopes must be taken in consideration (see text of Photo 86a). (Photo M. Kuhle.)





← *Photo 87a.* This mountain is also visible in Photo 87 (Figure 2, Nos. 61–63). It reaches ca. 5700–5800 m (5720 m according to ONC map 1:1 000 000) and presents the geomorphological characteristics of mountains in the Scandinavian fjells N of the polar circle (e.g., in the Kebnekaise- and Sarek massifs, 67–68° N/17–18° E, in the N European inland ice area of the LGM; the mountain Aka is similar). The peak shown here has also been overflowed by the inland ice. (**– –**) marks the minimum height of the LGM inland ice level. This summit superstructure shows rounded ridges and edges in the bedrock up to the summit (◓), whilst an only decimetre-thick debris cover of Holocene to sub-Recent origin lies on the slopes. During the later-Late Glacial (Stadium IV) the steep source- and valley depressions (○) set into the summit, contained few kilometre-long hanging- and valley glaciers. As is shown in Table 1, the snow line (ELA) had dropped about 700 m at that time, so that the summit towered ca. 400–500 m above it. The High- to Late Glacial ground moraine cover stretches in the foreground and mantles the round-polished threshold in the middle ground (■) (cf. Photo 87; 2). Rain- and meltwater, running down the slopes since deglaciation, has cut small decimetres- to a few metres-deep ravines into the ground moraine (▽). Here, a cover of residual detritus, developed *in situ*, is completely lacking. (Photo M. Kuhle.)

← *Photo 88.* At ca. 4450 m asl (aneroid measurement: 4300 m), 30 km NW of the viewpoint of Photo 85 facing NNE. Locality: Figure 2, No. 61; 32°10′ N/84°40′ E, W of the Tung Hu (lake). Looking across the ground moraine plains (■) S of the thalweg of the extended excavation area and to the currently non-glaciated mountain ridges, which rise up to a height of 5790 m and are situated to the N. (3) marks the highest peak visible, on which several perennial snow patches can be observed till summer. Flat flushing rills have cut and dissected (**I**) the ground moraine plain by backward erosion from the thalweg of the main valley (of the large excavation area). Essential and characteristic of the upland landscape is the lack of fluvial terraces in the area of the excavation bottom. Only large-scale alluvial fans (▽) have been undercut by the main valley bottom in the area of the thalweg. They have built up 1 to 3 m-high steep steps (▼). These alluvial fans (▽) are so-called cone sander, i.e., glaciofluvial gravel floor fans, accumulated in the Late Glacial (ca. Stadia III to IV, cf. Table 1). Accordingly, they only come from rather large valleys. (**– –**) is the minimum height of the Ice Age inland ice surface. (Photo. M.Kuhle.)

← *Photo 89.* At ca. 4500 m asl (aneroid measurement: 4355 m asl) facing W, looking up the bed of a blind creek (□). Locality: Figure 2, No. 62; 32°13′ N/84°28′ E; 10 km WNW from the viewpoint of Photo 88. The temporary creek (flowing down periodically during the monsoon or just episodically) has undercut and exposed the basal ground moraine on this outer slope (■ white). The continuation of the corresponding ground moraine deposit can be observed in the background (■ black). Whilst the material on the base of the exposure is completely mixed (■ white), it shows an increasingly perfect stratification towards the upper edge of the exposure (↓). This is accompanied by a slight sorting of the grain sizes. The reason for this is a glacio-fluvial outwash after deglaciation. (Corresponding surficial outwashes of ground moraine were observed in NE Tibet E of Chaling Hu (lake) along the caravan route between Mado and Hishikai about 4200 m asl.) The reddish colour of the ground moraine provides evidence of a largish portion of local moraine originating from a region to the S, where reddish sandstone bedrock occurs. (▽) is a late-Late Glacial (Stadium IV) cone sander accumulation, deposited on the High- to Late Glacial (Stadium 0 = LGM to Stadium III; Table 1) ground moraine by the glacier meltwater stream of the mountain group adjoining to the S. (◓) are mountain ridges rounded by the inland ice. (– –) indicates the minimum surface height of the inland ice estabished geomorphologically. (Photo M. Kuhle.)

↓ *Photo 90.* Panorama taken at ca. 4550 m asl (aneroid measurement 4390 m asl) ranging from W (left margin) via N up to NNE (right margin) looking over the Central Tibetan upland with its slightly undulating ground moraine surface (■ ■). Locality: Figure 2 between Nos. 61 and 64; 32°13′ N/84°28′ E; ca. 14 km W from the viewpoint of Photo 89, at the place where one of the 'chorten' is situated not often found in this region. Several of the partly rounded mountains (◓), which border the over 30 km-broad W/E trending excavation area in the N, are completely covered with ground moraine. The higher ones show ground moraine sheets only on their lower slopes. (– –) marks the minimum level of the glacial inland ice shield which can be evidenced geomorphologically. (Photo M. Kuhle.)



←*Photo 91.* At 4450 m asl (aneroid measurement 4290 m asl) looking over the large W/E trending excavation area facing NNE. Locality: Figure 2 at No. 64; 32°16′ 50″ N/84°04′ 30″ E; 2 km E of the settlement of Lumaringbo (Gertse, Kaitse). The few metres-thick surface of the limnic sediments (☐) is blown away from the main valley-(excavation-) bottom by wind gusts of a monsoonal thunderhead. As late-Late Glacial to historical and recent lake deposits the limnites have been sedimentated over the High- to Late Glacial (Stadia 0 to III; Table 1) ground moraine cover in the underlying bed. Today the seasonal and episodic flat lakes mentioned still lead to the transport and deposit of pelites of washed ground moraine, as is shown in the foreground (■). The rounded hill- and mountain ridges (◓) partly covered with ground moraine, point to the minimum level indicated of the Ice Age (LGM) inland ice cover (– –). (Photo M. Kuhle.)

← *Photo 92.* At an altitude of ca. 4400 m (aneroid measurement 4265 m asl), 19 km W of Lumaringbo, looking N over a ground moraine landscape without large boulders (■) (Figure 2, No. 65). Locality: 32°16′ N/83°54′ E. The 'chorten' on the ground moraine ridge (above ■ on the right) was built up at the centuries-old caravan route from Lumaringbo (Kaitse) to Shiquanha (or Ali) in W Central Tibet. (☐) shows the floor of a small valley, flatly embedded into the ground moraine which, as a result of the temporary water run-off after heavy rainfalls or at the time of the snow melting, has been washed. Typical of the relatively great resistance of the moraine – as loose rock material – to such washings are the clay layers, which are first compacted by the process of removal and then indurated by desiccation (☐). The further course of the small valley can be followed by the rather dense dwarf scrub vegetation in the direction of the main valley thalweg. Set into an older topography of different development, the small valley provides a further geomorphological indication of the totally different, i.e., accumulative landscape genesis in prehistoric times in which flowing water did not participate. (◓) marks the hills rounded by the inland ice beyond the W/E-trending main valley at a distance of 20 km. (– –) is the verifiable minimum height of the High Glacial (LGM) inland ice surface. (Photo M. Kuhle.)


← *Photo 93*. Viewpoint ca. 7 km W from the locality of Photo 92, also at 4400 m asl (aneroid measurement 4265 m) looking SSE to mountain ridges of limestone bedrock. Locality: Figure 2, No. 66; 32°16′ N/83°49′ E. A ground moraine sheet (■ black) stretches as far as the mountain slopes. Since deglaciation it has been cut by ravines and rills only 1–2 m deep (▽). Linear mudflows emerged from such ravines. Escalating to the form of tongues up to lobes, they have been deposited as accumulations of dislocated moraine material (foreground □ □). Here, the now increased components of the ground moraine are visible (□ white), showing a size up to that of blocks. Due to its large portion of water-retaining and swellable clay, ground moraine is especially susceptible to the development of mudflows. Thus, on the softly inclined (1–4°) slopes of these limestone mountains (background) with only a small, 150–300 m-high catchment area and under the semi-arid climate conditions in addition, the humid mass movements could only develop in this area of an extended ground moraine occurrence. The mudflow accumulations were deposited on the still undisturbed ground moraine in the foreground (lower margin of the photo). On the slopes Late Glacial front- and lateral moraines have been left behind (■ I-II = Stadium I-II, cf. Table 1). Remnants of ramparts can be observed with 80–120 m-high frontal slopes. As a result of solifluction their lower slopes flowed down on the ground moraine cover after deglaciation (below ■ I–II). During the High Glacial (LGM = Stadium 0) the relief was completely covered by the inland ice (‒ ‒0 = minimum surface height of the ice). (Photo M. Kuhle.)

→ *Photo 94*. At 4450 m asl (aneroid measurement 4300 m), along the caravan route but 20 km more to the W than in Photo 93, looking WNW (left margin) via N to E (right margin) across ground moraine expanses (■) (Figure 2, No. 67). A 3–12 m-high ground moraine ridge (■ ■ middleground) is set on this flattest area, running down from W to E (from left to right). The longitudinal axis of its streamlined body contours (Figure 2, No. 67) indicates the direction of the High Glacial inland ice run-off, following the large-scale incline of this part of Central Tibet to the W. As a result of the updoming of its relief and the loose material of which it has been built up, the ridge has regressively been cut by transverse, metre-deep ravines (▷ ◁). These microfluvial rills come from correspondingly small spring niches. (▲ ▲) marks a kilometre-long wall of glacial drift the size of boulders, which has been piled up by yak nomads as the border of the communal property and pasture. (‒ ‒) indicates the minimum height of the High Glacial (LGM = Stadium 0) inland ice level. It has been deduced from the large-scale deposits of ground moraine and the glacially rounded hill- and mountain ridges. (↓ ↓) mark the foot bend of the mountain slopes towards the ground moraine plains (cf. Figure 23). (Photo M. Kuhle.)

→ *Photo 95.* The same hill chain visible in Photo 94 on the left, now taken from the opposite (NW) side. The viewpoint (Figure 2, No. 68; 32°24′ N/83°20′ 30″ E) at ca. 4530 m asl (aneroid measurement 4380 m) is situated ca. 10 km W (over these hills) of the viewpoint of Photo 94. Looking from E (left margin) via S (centre) to W (right margin) across an accumulation plain consisting of ground moraine (■). A Holocene to present stream bed is inset there, which is only flowed through temporarily (□). Small streamlets are adjusted to this main thalweg (▽), regressively cutting into the ground moraine cover. The hill- and mountain ridges consist of sedimentary rocks. They have been abraded and round-polished by the inland ice (◓), the minimum surface height of which (– –) was lying several hundred metres above the relief. In the places where the prehistoric glacier ground scouring interferes in an acute angle with the outcropping edges of the stratum of the sedimentary bedrock, the typical lineation of the so-called glacial band polishing of the outcropping edges of the stratum occurs (v. Klebelsberg, 1948, Vol. 1) (◓ white, right half of the section). After deglaciation the down-flowing rain- and meltwater has cut ravines into the ground moraine cover – which on the steeper slopes was rather thin (i.e., several decimetres- to few metres-thick) – as far as to the bedrock in the underlying bed (↘). (↓ ↓) mark the narrow-concave transitional arc – which at a distance seems to be a foot bend – of the ground moraine overlay on the lower slope into that one on the base formed like an alluvial fan (cf. Figure 23). (Photo M.Kuhle.)

↓ *Photo 97.* At ca. 4575 m asl (aneroid measurement 4
of the valley, the thalweg (□) of which dips to the left
on the left margin of the photo is free of the normal pe
flat alluvial fans (▽) have been accumulated through t
slope ravines, show a much smaller outline. They are
moraine on the slopes of the mountain ridges (■ back
i.e., remarkably unambigous (between the two ◓). Her
outcropping edges of the sedimentary rock (↙). Situat
crests. This different shape of the mountains observed
behind and thus cannot give definite information on
mountain forms overflowed by the inland ice, have b
one and the same minimum surface level; however, be

← *Photo 96.* At ca. 4550 m (aneroid measurement 4400 m), 4 km E of the pasture settlement of Yueko (Figure 2, No. 69; 32°24′ 30″ N/ 83°15′ 30″ E) facing ENE looking at a roche moutonnée (◓ centre) surrounded by a ground moraine plain (■). As a result of weathering and exaration- and detraction processes a small-scale dissection and roughening has taken place on its surface. The steep layers of the sedimentary rocks (55° dip to the N (5–7°)) and the small-scale petrographic rock change recognizable by the differing colours, favour these processes. The ice has overflowed the roche moutonnée from left to right, i.e., from W to E, which can be deduced from the flat luff-side (left of ◓ in the centre) and the steeper leeward side (right of ◓ in the centre). At the same time the structural surfaces, breaking away at an angle at the outcropping edges of the strata, have been levered upward from a great depth and tilted out of their bonded strata. Later rounding of the hogbacks (▽) carved out in this way indicates that this in fact has taken place subglacially. A moraine train in the flow shadow of this roche moutonnée forms the link to the nearest bedrock head. Behind this, a morainic leeward accumulation adjoins and then once again a roche moutonnée (/ right). (◓ left) is a well-preserved glacial polish surface. (– –) marks the minimum surface height of the glacial inland ice, evidenced according to the features of the landscape. (Photo M. Kuhle.)

rement 4425 m), 2–3 km W of the pasture settlement of Yueko, looking from S (left) to W (right) across the orographic right-hand flank the left (to Yueko) (Figure 2, No. 70). A ground moraine area (■) stretches from the fore- to middleground. The trail (used by the cattle) ormal pebble overlay with deflation pavement. There, the clay-bearing pelite matrix of the ground moraine is visible. Since deglaciation hrough the comparatively small side valleys on the ground moraine bottom of the valley from the S. The debris cones (▲) emerging from hey are largely built up of dislocated ground moraine. The alluvial fans (▽) also contain shifted moraine material. There is still ground (■ background). The glacier polishings have been developed differently, i.e., their state of preservation varies. Partly they are perfect ◓). Here, the accompanying forms of exaration rills, indicating the band polishing of the outcropping edges of the stratum, occur in the ). Situated behind them, the mountains with similar altitudes which were also covered by the inland ice, show comparatively very sharp observed in many places, can only be explained by the differing bedrocks. The author has not visited the mountain chain lying further tion on the bedrocks there. It is limestone, which tends to a form of that sort, even under the influence of an inland ice cover. Such , have been evidenced in NE Tibet (Kuhle 1997b, p. 249, Photo 147). The three High Glacial (LGM) inland ice levels (– –) belong to vever, because of perspective reasons they have been marked in the form of steps from left to right upwards. (Photo M. Kuhle.)



↑ *Photo 98.* At ca. 4500 m asl (aneroid measurement 4350 m), 4 km E of the uninhabited, i.e., temporary, yak nomad- and caravan settlement of Alt Oma, looking at glaciofluvial gravels to the NE (☐); (locality: Figure 2 between Nos. 72 and 73). They contain large portions of gravels (light components up to the size of a fist) transported here from the limestone mountains towering at a distance of 7–13 km to the S (partly visible in Photo 99 on the left margin in the background). The approximately horizontal position of the gravel layers is slightly altered (irregularly tilted, i.e., it shows flexures or undulations). The surface is overlain by 1–3 decimetres-thick ground moraine (■), containing portions of limestone gravels of the subjacent gravel layer. These are Late Glacial gravels of a local glaciation, which have then been compressed and polished by the ice advance (⇓). The glacially rounded hills visible in the background (◓) prove a High Glacial (LGM) inland ice cover, the minimum surface height of which is marked by (– –). As far as there exists no contradictory absolute dating with respect to the development and following overthrusting of the gravel layers (for the dating of which we also have to wait methodically, because up to now we have no substrate that can be dated), we have to assume Stadium IV (see Table 1). After the retreat of the ice at the end of Stadium III, a repeated late Late Glacial advance of Stadium IV took place. (Photo M. Kuhle.)

↓ *Photo 100.* At an altitude of ca. 4700 m (aneroid measurement at high pressure 4525 m asl) in the area of the transfluence pass visible in Photo 99 (◡ right), the culmination of which can be recognized on the right margin of this section (◡) (Figure 2, No. 74; 32°24′ N/82°48′ E). The viewpoint is 14 km W from that of Photo 99. The picture is taken facing S (left margin) to NW (right margin). A continuous ground moraine cover stretches from the foreground as far as the hill slopes and in parts somewhat up these slopes (■ ▪). Their surface is covered by a pavement developed by the periglacial freezing on to them of rocks and the process of deflation. The dark-coloured hills consist of metamorphic bedrocks and have been polished by the inland ice (◓ white). However, because of the structure of their strata they have not really been rounded. In the places where light granite bedrock occurs, intruded into these sedimentary rocks, the hills are comparatively perfectly rounded (◓ black). (▽) are exaration rills scored into the foot slope of this hill by the ice overflowing from right to left. They present glacial erosion forms typical of restricted glacier flow cross profiles. (◡ ◡) indicates saddles rounded by the overflowing inland ice. (– –) is the height of the minimum inland ice level: the relief of hills and mountains was totally covered. (Photo M. Kuhle.)

←*Photo 99.* Looking from ca. 4500 m asl (aneroid measurement at high pressure at 6°° in the morning: 4290 m asl) from the western periphery of the temporary yak nomad-settlement of Alt Oma on the S edge of Ningchu Tso (lake), 7 km W of the viewpoint of Photo 98 (Figure 2, No.73; 32°24′ N/82°57′ E), looking SSE (left margin) via W (centre) up to NNW (right margin). (⇧) are walls built up from coarse boulders of the ground moraine area (■), which border the pastures and the caravan route. (6) is a summit reaching roughly 5800 m asl with a glaciation visible at its N-exposition. Besides short hanging glaciers, several firn shields can be observed along the crests. (◓) marks hills and mountain ridges rounded by the inland ice, partly showing roche moutonnée form (cf. second ◓ from the left). Owing to the sequence of bedding of the sedimentary rocks, dipping to the N, this roche moutonnée presents a flatter slope facing right and a steeper one facing left. Some of these hills (◓ black and ◓ white on the very right) are covered by a thin ground moraine overlay. Since deglaciation erosional ravines up to 4 m deep have been cut into the slopes mantled with ground moraine (△) by the precipitation water. However, mostly they are not nearly as deep. Their cutting depth is limited by the surface of the bedrock beneath the ground moraine, which is much more resistant. Thus, it depends on the thickness of the moraine, such that the development of ravines always takes place only in the soft ground moraine overlay, i.e., is spatially connected to it. The steep slopes dissected by deep flank cuts (on the left above the tent, background) are characteristic of slopes of the edges of the strata in an arctic permafrost climate in the prehistoric inland ice areas, as for instance W-Spitzbergen. (◡) marks transfluence passes which, by the inland ice overflowing these local water divides, have been polished and abraded broadly in the cross profile and in the longitudinal profile to a flat threshold. Here, too, are ground moraine sheets (■ background on the left). (– –) is the indication of the inland ice level which with regard to the actual height is hypothetical. However, the relief was covered with a continuous ice surface. (Photo M. Kuhle.)

↓*Photo 101.* At a height of ca. 4690 m (aneroid measurement at high pressure 4490 m asl) 8 km WNW of the locality in Photo 100, beyond (NW) the culmination of the transfluence pass visible on the left margin (◡) (Figure 2, No. 74). The picture was taken facing S (left margin) via WSW up to NW (right margin). The ground moraine surface (■) is covered by a stone pavement of quite coarse components. The coarse components of the ground moraine consist of fractions the size of pebbles up to fists. There are no large boulders (see legend Figure 2, No. 74). The hills up to 400 m high, are situated in the contact area of dark sedimentary rock and light granite. Only in parts have they been rounded classically-glacigenically (◓). Other parts show the angular forms dictated by the structure of the sedimentary rock strata. Accordingly it can be assumed that the High Glacial inland ice sheet with its ground ice was frozen to the roughenings of this small-scale hill relief. (– –) marks the minimum level of the inland ice. The actual thickness of the ice might have been much more important. However, because of methodogical reasons this remains hypothetical. (Photo M. Kuhle.)

←*Photo 102.* At ca. 4500 m asl (aneroid measurement at high pressure 4325 m), 9 km W from the viewpoint of Photo 101 (locality: 32°31′ N/82°31′ E). The picture was taken from NNW up to E. The relatively homogeneous ground moraine, showing coarse components at a maximum the size of pebbles or fists (Figure 2, No. 74) (■ ▪) stretches as far as the glacially-rounded hills in the background (◓) and mantles them (■ in the background). As a result of the soft (slightly-resistant) ground moraine cover compared with the bedrock in the underground, the precipitation water running down their slopes was capable of cutting narrow, sharp-edged rills up to a metre-thickness in the course of the ca. 12 000 years since deglaciation (△). Owing to the ice transfluence the geomorphological saddles connecting the hills have been formed into rounded rock thresholds (◡). In parts the characteristic fine lineation of exaration rills can be observed (right of ■ small and black in the background). (– –) indicates the minimum level of the prehistoric inland ice, deduced from the rounded relief covered by ground moraine. (Photo M. Kuhle.)


↙*Photo 103.* At about 4450 m asl (aneroid measurement 4270 m at high pressure) 14 km W from the locality of Photo 102 looking SW (left margin) via NW up to N (right margin) (Figure 2, No. 75). Ground moraine stretches from the fore- to middleground (■ large ; as to the composition of this ground moraine sheet, see Figure 24 and Figure 5 diagram 31.08./1) which has been reshaped – and is still being so – by two processes since deglaciation. (1) deflation, as a result of which the pelitic matrix of the ground moraine is blown off, so that a pebbly deflation pavement develops, and (2) seasonally monsoonal precipitation followed by the accumulation of pelitic moraine matrix towards the flat bowl-like depressions in the ground moraine plains (■ black). Under repeated limnic deposition (caused by stagnant water) this fine material, washed out of the ground moraine (■ white), also covers the rocks of the deflation pavement (■ black). Because of this change of deflation and limnic accumulation the obviously very short geomorphological period becomes recognizable as being just seasonal. The depression, temporarily covered by a flat (1–5 m deep) water body, is fringed by ground moraine ridges (■ small). With its longitudinal axes they follow the run-off of the latest covering ice overlay taking place here in an EW direction (Late Glacial, ca. Stadium II-III; see Table 1). (◓) marks hills round-polished by the High Glacial (LGM) inland ice. (◡) is a transfluence step, round-polished by the ice, leading to an adjacent bowl-like depression. The massif in the background (4) reaches a height of somewhat over 6000 m and is still glaciated. The mountain ridges in the middleground as well as the massif (4) sharpened postglacially by its short hanging glaciers, were totally covered by the inland ice (– –). (Photo M. Kuhle.)

↑*Photo 104.* At a height of ca. 4420 m (aneroid measurement 4245 m asl at high pressure) (32°35′ N/82°10′ E) taken 21 km W of the locality of Photo 103. Directions: facing NW (left margin) via N (centre) up to ENE (right margin), looking over a Late Glacial lake basin, in the middle of which occurs a salt-bearing residual lake (□) of the W/E arrangement of the Tuerhko Hu lake chain. The Late Glacial lake had been developed on the water-retaining High Glacial (LGM) ground moraine plain (■ ■). With the help of cliffs its lake level positions are confirmed on at least four levels (↑ ↑) (Figure 2, Nos. 76–78). These shore lines, along which the ground moraine has been limnically washed, have undercut the sedimentary bedrocks of High Glacial roches moutonnées (◓) with its cliff forms so concisely that there are even preserved wave-cut notches (↑ ↑) (cf. Photo 105). The highest lake level (↑ right) was situated about 60 m above the basin bottom, so that a corresponding, i.e., due to later uplift of the lake bottom, somewhat greater depth of the lake must be assumed. Such an important local impounding of a lake requires the damming influence of Late Glacial glacier tongues, reaching the bottom of this WNW/ESE-trending Tuerhko depression of over 35 km in length. Due to the increase of the snow line by already 400–600 m against the LGM, Stadia III–IV (Table 1) are the probable stadia of these high positions of the lake level (ca. 14 250–13 000 Ka). (– –) is the minimum height of the High Glacial inland ice level. (Photo M. Kuhle.)

→ *Photo 105.* At ca. 4400 m (aneroid measurement 4235 m asl; Figure 2, Nos. 76–78) taken from a locality W of the viewpoint of Photo 104 in the area of the same Late Glacial lake basin (32°37′ 20″ N/82°N). Panorama ranging from NW (left margin) via N up to E (right margin). (□) indicates the light limnic lake sediments of Tsa Tso (lake), which is one of the residual lakes in the region of the W/E stretching lake depression of Tuerhko Hu. The lake sediments visible there as a light stripe lie on Ice Age ground moraine, which can also be observed in the foreground (■). The lake clays contain recrystallized calcium monocarbonate (CaCo3) and sodium chloride (NaCl). Thus, they can be addressed as terrestrial evaporites. The evaporation sediments are characteristic of lakes without run-off in which an increasing preconcentration of limestone, gypsum and salt could take place by evaporation during the Holocene (postglacially). By means of cliffs with wave-cut notches and -platforms (↑ ↑), three Late Glacial lake level positions can be recognized which have washed ground moraine. (◓) are mountain ridges and hills covered by the High Glacial (LGM) inland ice. In the places where sedimentary bedrocks prejudge a small-scale dissected relief, covers of wind-blown sand have been deposited up to several metres in thickness (△). (– – 0) is the minimum surface height of the relief-covering prehistoric ice sheet. (Photo M. Kuhle.)

← *Photo 106*. At ca. 4400 m asl (aneroid measurement 4220 m at high pressure), 7 km W of the locality in Photo 105, looking from WNW via N up to NE (right margin) (32°39′ N/81°57′ 40″ E). On the edge of the Tsa Tso (lake) basin (□) with its evaporites, the settlement of Yan Hu (△) is situated, lying in the western part of the Late Glacial Tuerhko Hu lake basin. Here, the limnic salt deposits which crystallized-out, are actually exploited. (■) are the High Glacial ground moraines (Figure 2 between Nos. 75 and 78) reached by the Late Glacial lake level (cf. Photos 104 and 105) and surficially washed. Their coarse components range in size from fists to heads; large boulders are absent. The petrographic composition of this ground moraine is polymict (portions of sedimentary rock and granite are mixed). (◓) are mountain ridges and hills more or less rounded by the inland ice; some of the flatter hills show forms of roches moutonnées (◓ left). The mountain ridges of dark sedimentary rock are preserved less well-rounded. (0 – –) is the minimum surface height of the inland ice. (Photo M. Kuhle.)

← *Photo 107*. At an altitude of ca. 4450 m (aneroid measurement 4260 m asl at high pressure), 4 km S of the salt-opencast settlement of Yan Hu (32°39′ 40″ N/81°55′ E). The locality is situated SW of the roche moutonnée in Photo 106 (◓ on the very left); the picture was taken facing N. In the foreground, the caravan route of the yak-nomads crosses from N to S breaking-up the otherwise solidified ground moraine surface (■ black) with its sparse grass vegetation. Here, as throughout the area, the ground moraine is rich in pelites. Besides phyllite boulders the size of fists, it contains up to 1.7 m-long erratic granite boulders (▽) (Figure 2, No. 77). They indicate a portion of local moraine admixed from the S. The nearest occurrences of granite bedrocks are at a distance of maximally 7 km. The ground moraine plain, patterned by moraine bulges of a lighter appearance (between ■ white), mantles High Glacial roches moutonnées (◓) (Figure 2, No. 78) weathered and simultaneously roughened since deglaciation. Rock boulders have been freshly weathered out of the glacigenic roundings of the sedimentary bedrocks (\). The syngenetic development of roches moutonnées (◓) by the ground scouring of the inland ice at elevated points in the field and of the ground moraine cover (■) in the depressions and flat areas lying in between, can be recognized by the ground moraine surface (■ white) which extends to the roches moutonnées and clings to its base. To this also belong ground moraine overthrustings developed on the luff-side and the development of leeward trains behind the roches moutonnées. The reason for the lateral attachment of ground moraine in the form of flat ramp slopes (■ white) is that the roches moutonnées reduce the ice pressure in their immediate surroundings. (0 – –) marks the minimum height of the High Glacial (LGM) inland ice surface, situated above the highest elevations of the relief in this region. (Photo M. Kuhle.)

↑ *Photo 108.* At about 4640 m (aneroid measurement 4460 m asl at high pressure), 7 km S of the viewpoint of Photo 107, taken from the bottom of a high valley leading to a 4900 m-high pass (Figure 2, No. 80) looking down to the NNE (32°39′ 30″ N/81°54′ 30″ E). The trough- i.e., U-shaped cross profile of the valley confirms its genesis by glacial erosion (Figure 2, No. 79). The valley flanks have been rounded by the glacial polishing up to their culminations, i.e., up to the highest regions of the intermediate valley ridges (◥ ◓ ◤). (– – 0 – –) marks the the minimum height of the High Glacial (LGM) inland ice surface, which can be deduced from this prehistoric shaping. The wide valley bottom is covered by ground moraine (■). It contains substantial portions (15–20 volume %) of large, i.e., over 1 m-long boulders (○ black). These are granite boulders evidenced as local ground moraine boulders because the same petrographic-mineral mica granite bedrock occurs on both the valley flanks (◥ ◤). The bedrock granite weathers into the form of coarse boulders, which are already rounded at the edges at the time of their weathering (*/*). Thus, these rounded edges (○ black) are no indication of far-travelled granite boulders. Besides the granite portions, fragments of sedimentary bedrock transported here by the down-flowing glacier ice from areas further up-valley (cf. Photo 110) are part of the coarse material of this ground moraine cover (○ white). Naturally, the ground moraine has been slightly reshaped fluvially near the thalweg and by several small mudflows during the Holocene, so that some of the moraine boulders have been removed from the original bond. They now lie in some places on the ground moraine sheet (□). The ground moraine cover (■) belongs to the late Late Glacial (Stadium IV, cf. Table 1) when a local ice cap covered the mountains of Gangdise Shan (Transhimalaya) and its outlet glacier tongues reached the area of No. 77 (Figure 2) (cf. Photo 107 ■ ▽). (Photo M. Kuhle.)



↑ *Photo 109.* At ca. 4780 m asl (aneroid measurement 4600 m at high pressure), 4 km up-valley from the locality in Photo 108, looking towards the SE (Figure 2 in the trough valley between Nos. 78 and 79). Over large parts the flat and wide trough valley bottom is covered with ground moraine rich in pelites (■). Besides sharply-edged local boulders of sedimentary rock fragments it contains erratic granite boulders (↓). Sedimentary bedrocks occur in the underground and on the valley flanks. In some places flatly-polished roches moutonnées, showing a classic 'whale-back'-profile, pierce the ground moraine cover (◓). The one visible here, presents a flatter scour-side exposed up-valley (on the right) and a steeper lee-side facing down-valley (on the left). This corresponds to the prehistoric direction of the ice flow on the valley bottom from right to left (←). On its lower slopes, the valley flanks and mountain ridges extensively rounded by the inland ice (◥ ◤), show a ground moraine sheet recognizable by its lighter colour. It stretches upwards (■ white), in the form of inclining ramp- slopes pushing against the steeper upper slopes as a concave foot bend (▽) (cf. Figures 22, 23). In the lowest area of the valley bottom, along both sides of the narrow stream bed, a small gravel floor has been washed out of the ground moraine and at the same time deepened into it (□). In this mountain group, presently free of glaciers, this took place during the Late Glacial deglaciation. The yaks of nomads can be noted whose tents are erected on both sides of the roche moutonnée. (– –) marks the minimum height of the surface of the glacial inland ice cover. (Photo M. Kuhle.)

← *Photo 110*. At ca. 4850 m (aneroid measurement at high pressure 4675 m asl), 2 km N of the 4900 m-pass (Figure 2, No. 79) facing NE (left margin) via E up to S (right margin) (32°38′ 20″ N/ 81°54′ E). The dimensions of the landscape can be estimated by the two tents of yak nomads 3.2 m in height at a distance of somewhat over 1 km (middleground). Two further temporary pasture settlements (two separate tents) are in the background on the right. Over large parts the area is covered by ground moraine (■). The rough-edged debris on its surface is an indication of local moraine, because it consists of sedimentary bedrocks of the mountain slopes in the background (☗ white), which weather into shards. Secondarily, i.e., after deglaciation, the development of periglacial rock pavement and deflation (deflation pavement) accumulated coarse material on the moraine surface (■ white). The important portion of pelitic ground mass, characteristic of subglacial trituration, is recognizable by its light colour on small steep steps in the moraine cover, polished into the ground moraine by exaration (⇩). Owing to present-day washing processes it comes to the surface at this place as well as further to the right (■ black). The coarser debris portions of the ground moraine cover on the slopes have been reshaped by rhombic cattle steps (at ☗ white). At some places, the ground moraine cover passes over from the valley bottom to the mountain slopes as a soft transition arc (↙). Below small valleys and thalwegs small cones of dislocated ground moraine have been deposited (▽). (☗) are mountain ridges, round-polished by the High Glacial inland ice; by means of their height the minimum altitude of the ice surface forming them can be deduced (– –). (Photo M. Kuhle.)



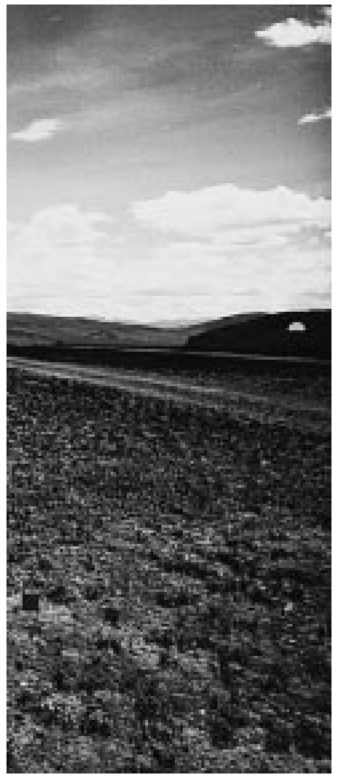
← *Photo 111*. At ca. 4480 m (aneroid measurement 4295 m asl at high pressure) from a high plateau area situated 20 km SSW of the 4900 m-pass (cf. Photo 110) (32°36′ N/81°53′ E). Direction: facing WSW (left margin) via W up to N (right margin). The ground moraine sheet covering this high plateau section (■ foreground) is divided into several flat bowl-like depressions (glacigenic overdeepenings of ground scouring) in which were located late- Late Glacial and Holocene to recent lakes as well as smaller water surfaces. They still exist episodically or periodically. (□ black) shows an alluvial floor of pelites, washed out of the ground moraine; (□ white) marks a larger lake bottom with xenomorphic meso-halophytic scrub- and dwarf scrub vegetation (Tamarisks, Myricaria, etc.) along its shore, settling thin veils of wind-blown sand in this depression. The corresponding late- Late Glacial (Stadium IV; see Table 1) lake level positions are preserved as four clear shorelines (▽) (Figure 2, No. 81) on a ca. 15 m high ground moraine ridge (■ white in the middleground). The mountain ridges reaching 5000 m are made up of more or less metamorphic sedimentary rocks and have been rounded by the inland ice up to their culminations (☗). This suggests a High Glacial (LGM = Stadium 0) minimum surface height of the ice level at (– – 0 – –). Ground moraine (■ black) is also found on the mountain slopes. A Holocene gullying, typical of slopes in sedimentary rocks, has roughened the glacial smoothings in some parts. Additionally, the High Glacial mountain features have been reshaped by large Late Glacial nivation niches and small cirques (○) in the E-exposition visible here. (Photo M. Kuhle.)

↑ *Photo 112.* At ca. 4460 m (aneroid measurement 4280 m at high pressure), taken 14 km SSW from the viewpoint of Photo 111 (32°34′ 10″ N/81°52′ E). Direction: facing SE (left margin) via S up to SW (right margin). (– –) marks the minimum height of the High Glacial inland ice surface and thus the minimum thickness of the ice above the mountain ridges necessary to round these mountains by ground polishing (◓). For this to happen the ice must have been at least 300–400 thick. From the late-Late Glacial (Stadium IV, Table 1) up to now, part of the ground moraine cover of these mountain slopes (■ white in the background) has been washed and removed along a thalweg down to the highland plaine (△). The material has been re-sedimentated at the mountain foot as cone sanders (alluvial fans accumulated by meltwater △) by the meltwater of flat ice caps and hanging glacier tongues still remaining on the mountain tops (◓). These fans (△) are younger than the Late Glacial end- and lateral moraine ledge, which has been pushed like a frontal moraine 120–180 m up the mountain slopes by the inland ice that had already melted far down (↓ ↓ ↓) (cf. Photo 93). Without absolute age datings (which with present working techniques are anyway impossible) as to their origin, only the Late Glacial Stadia I to II can be taken in consideration. Such an overthrusting of an end moraine requires a relatively long (several 100 to 1000 years) positive mass balance of a Late Glacial ice mass – again built up after the decay of the connected inland ice sheet of Tibet – leading to the renewed advance of such an isolated ice complex, i.e., to the development of an important local ice cap. (■ black) indicates a 2–6 m-high ground moraine ridge which, during the High (LGM) Glacial and probably still during the early Late Glacial (Stadium I), has been forced upwards by the bottom of the inland ice over a distance of ca. 5.5 km. It stretches towards the E and indicates a local direction of the ice run-off. Owing to its small-scale steepness its surface has been rinsed postglacially. (▲) are fluvial run-off rills which – following the local surface incline down the mountain ridges (◓) – cut this ridge transversally as far down as to the lower ground moraine layers. They are adjusted to the large-scale ground moraine plain (■ foreground; Figure 2, No. 80). This consists of surficially washed material with polymict rock components. (Photo M. Kuhle.)

↓ *Photo 113.* At an altitude of ca. 4600 m (aneroid measurement 4430 m asl at high pressure), from a locality situated at the caravan route 7 km away from the locality in Photo 112, looking WNW (32°32′ 50″ N/81°51′ 50″ E). The rock pavement of the ground moraine surface (■ foreground) has been reshaped artificially and to a great extent destroyed by the caravan route. Beyond the route thrown up by traces of yaks and goats there are roches moutonnées in metamorphic sedimentary rocks (◓). In part they are covered and masked by ground moraine (■ ■ background). The ground moraine consists of polymict components at the most the size of fists or heads, which are smooth-edged to rounded at the edges. At the place where the roches moutonnées break away in a 4–10 m-high step (the two ◓ on the left) subglacial meltwater erosion (↓) took place during the down-melting of the inland ice in the Late Glacial (Stadia I–II, see Table 1). It cut and halved the complete roche moutonnée forms (◓), which had developed under cold-based ice during the High Glacial (LGM = Stadium 0). The subglacial meltwater run-off took place from the left (a 4850 m-pass, Figure 2, No. 83) to the right, without there being a present-day thalweg. Accordingly, it has largely been canalized by an ice tunnel in the immediate neighbourhood of the roche moutonnée (↓). (Photo M. Kuhle.)

↑ *Photo 114.* At an altitude of ca. 4850 m (aneroid measurement 4675 m asl) from a flat pass-saddle (Figure 2, No. 83; 32°30′ 30″ N/ 81°50′ 30″ E) facing N (left margin) via E (centre) up to S (right margin), looking from the N slope of the pass across the pass depression to the S slope of the pass. The round-polished mountain ridges (◓) consist of limestone series (◓ black), limestone marls and other sedimentary rocks (clay-, silt- and sandstones). In the W-exposition visible, nivation niches or small cirques (○) have been carved into their High Glacial rounding. Probably they were already laid out before the LGM, but have experienced their last deepening in the Late Glacial, after the inland ice had melted and when only small hanging glaciers (Stadium IV) existed there. Their post-High Glacial shaping is proved by the erosion of the working edge from below (↖) against the High Glacial rounding (◓ white on the left). (△) shows the accompanying alluvial fans, i.e., cone sanders accumulated by the meltwater of the small névé- and ice depositions in which removed ground moraine material from the High Glacial has been re-sedimentated. On adjacent slope sections the older (LGM) ground moraine is preserved (■ white, back-ground). (■ black, background) indicates horizontally-striped ground moraine on an underlay of limestone bedrock. Downslope the stripes have somewhat been reshaped by washing and solifluction. However, it can be traced back to a lineation by exaration rills left behind by the ground scouring of the inland ice and it continues up to the left margin of the panorama. The matrix of the ground moraine overlay stretching in the foreground (■) is analysed by Figures 26 and 5, diagram 31.08.96/2. The coarse components consist of limestone- and sedimentary rock pebbles and -stones which are smooth-edged or rounded. In parts the limestone components are slightly corroded. (– –) is the minimum surface height of the High Glacial inland ice. (Photo M. Kuhle.)

← *Photo 115.* Roche moutonnée forms in limestone bedrock on the W-side of the depression of the 4850 m-pass (Photo 114) taken facing SW. (■ black) is the ground moraine catena the matrix of which is determined more exactly by Figures 26 and 5, diagram 31.08./2. (■ white on the left) is a ground moraine covering of the roche moutonnée slope and (■ white on the right) is a ground moraine train in continuation of the leeward roche moutonnée spur. Accordingly, the local direction of the ice run-off was from S to N (left to right). (■ white on the left) is a residual remnant of the ground moraine cover, immediately recognizable by its secondary fringes of washing on both sides (↖). (◓) indicates rock roundings roughened postglacially by subaerial corrosion as a result of the ground scouring of the inland ice. The conspicuous irregularity of the roche moutonnée as a whole is typical of such glacial forms in limestone bedrock. Exaration- and detraction processes in the course of which large rock cubatures were broken out of the bedrock and – because they were frozen to the inland ice bottom according to the phenomenon of regelation – drawn out of their bonding, led to the fragmentation of this perfectly streamlined form. (– –) marks the minimum surface height of the glacial inland ice. (Photo M. Kuhle.)



↑ *Photo 116.* About 4800 m (aneroid measurement 4625 m at high pressure), 3 km S of the 4850 m-pass, looking from W (left) to N (right) on round-polished limestone ridges (◓ ◓) (Figure 2, No. 83). Partly these are classic streamlined bodies which can be addressed as roches moutonnées (◓ large), partly differently modified hill forms of ground polishing (◓ small), caused by their geological structure (i.e., by the vertical a/c and b/c jointing). By means of freshly crumbling niches in the previously round-polished rock (▽) and freshly weathered edgy rock pieces, stones and boulders lying below, the reshaping of the glacially eroded forms can be evidenced as being insignificant only since their deglaciation. A thin ground moraine veil, in many places not even covering the limestone rock, lies on the ground-scouring faces (◓). On the lower slopes of the roches moutonnées and hills, in depressions, hollows and valleys between these rock ridges, ground moraine (■) has been deposited by the inland ice. The condition of its matrix is analysed in Figures 26 and 5, diagram 31.08./2. A path (with game and/or cattle tracks) runs between the two (■) in the left half of the panorama. (– –) marks the minimum height of the Ice Age inland ice surface derived from the field investigations in this place. (Photo M. Kuhle.)

← *Photo 117.* At ca. 4700 m (aneroid measurement 4530 m asl, high pressure), 6 km SW from the locality of Photo 116, facing NW (32°30′ N/81°48′ E). We look at a glacial ground moraine landscape (■) with a ground moraine plain (■ foreground) and a 10–14 m high ground moraine ridge, showing a drumlin (whaleback) character, which is set upon this plain (■ background) (Figure 2, No. 84). Wherever the postglacial precipitation water – in consequence of the dip of slope – runs down with a little more energy, and is thus more erosion-effective, the ground moraine material and its matrix is exposed by the development of fresh microfluvial rills (▽). (↑ ↑) indicate horizontally-arranged exaration rills. These lineaments have been carved into the ground moraine by the scouring of the inland ice and the impregnation of its ice bottom by submoraine (moraine attached from below). The direction of the ice flow (←) can be deduced with the help of the flat scour sides and the steeper lee sides of the round-polished mountain ridges of sedimentary bedrock in the background (◓). The arrow points from NE to SW. (– –) is the minimum surface height of the High Glacial (LGM) inland ice, necessary to create these features. (Photo M. Kuhle.)

➞ *Photo 118.* About 4620 m (aneroid measurement 4440 m asl at high pressure), 13 km W of the locality of Photo 117 (Figure 2 between Nos. 84/85) facing N (left margin) via E (centre) up to S (right margin), looking across a glacigenic roche moutonnée area (◓) and a lake district developed after the Late Glacial deglaciation, situated in between (☐). Its origin is based on a slight glacigenic overdeepening by the ground scouring of the inland ice as well as on a later overdeepening by Late Glacial glacier tongue ends. Varying somewhat in accordance with their extent, the shallow lakes (☐) reach a depth of a few metres. They have been developed on the underlay of ground moraine cover impervious to water. It stretches up to the foreground (■) overgrown with dwarf scrub vegetation. Along the edges of the lakes, which are flooded seasonally or at least episodically, a dense alpine meadow vegetation with periglacial earth hummock bottoms occurs. There are tents of nomads and a domesticated yak herd (△). The ground moraine not only covers the polish depressions between the roches moutonnées (■), but also mantles polish thresholds and clings to the lower slopes of the roches moutonnées (■ small, background on the left). However, in places this might be end moraine of the Late Glacial which has been overthrust by a repeated advance of a local ice complex of minor thickness, the front of which had run against that hill (▲). There are also flat, drumlin-like ground moraine ridges (■ small, background on the right) set upon the ground moraine plain (■ white). They reach more than 10 m. The glacially-rounded mountains and ridges (◓) present a characteristic fjell-landscape set upon the Tibetan plateau as is typical of Scandinavian mountains. Flattened summits and ridges (◓ black) rise up to one or several levels of older plains. They have been rounded by an inland ice. (– – 0 – –) is the minimum height of the High Glacial (LGM = Stadium 0) inland ice surface which completely towered above the relief of the Tibetan plateau section visible here. (Photo M. Kuhle.)

← *Photo 119.* About 4630 m (aneroid measurement 4450 m asl at high pressure situation) on the W margin of the lake district shown in Photo 118 (2 km W from the locality in Photo 118; 32°30′ 20″ N/ 81°46′ E), facing N. Ground moraine remoulded by the shore platform of the lake is in the foreground (■). It has been smoothed to a perfect plain by the limnic surf dynamics, levelling the unevenness of the primary ground moraine surface by the fine ground moraine matrix, which the lake water had surficially washed-out. The subrecent lake, still reaching the lake edge (visible in the foreground ○ ■) with its episodically higher level positions, has undercut the ground moraine tiltings on the lower slopes of the hills (■ background). This led to the exposure of the ground moraine (■ background on the right). Horst grass on the lake bottom forms earth hummocks (○). The mountain ridges (◓) round-polished by the inland ice (LGM as far as the Late Glacial Stadium I, cf. Table 1) are made up of metamorphic sedimentary rocks. (←) indicates the main direction of the ice flow which caused the flatter luff-, i.e., steeper leeward slopes of these 'glacially streamlined hills'. (– –) is the minimum height of the inland ice surface necessary to form this glacigenic landscape. (Photo M. Kuhle.)

➞ *Photo 120.* About 4620 m (aneroid measurement 4455 m asl at high pressure situation) taken towards the E across an area indicating the ground-scouring of the inland ice by rounded cupolas (◓) and depressions lying in between, which are covered by ground moraine (■) (Figure 2, No. 86; 32°30′ 20″ N/81°44′ 30″ E; 5 km W from the locality in Photo 119). Two people to compare the dimensions (△). Here, near a temporary pasture settlement, the ground moraine cover (■) has surficially been loosened over large parts by cattle tracks (yaks and goats) for centuries. As a result, the coarse components forming a rock pavement by periglacial freezing processes and deflation during the Post Glacial, have been displaced from their primary positions on the surface of the matrix bonding by the hoofs and are now laid down loosely on the ground moraine (foreground). These coarse components the size of a fist are polymict and consist of differently coloured sand-, silt- and clay stones and of limestone. With the exception of limestone, such sedimentary bedrocks are in the underground. At this locality it becomes particularly clear how the ground moraine cover – reaching its most important thickness of several metres in the depressions and hollows (■) – clings to the round-polished rock cupolas (◓) in the upward direction (■ background), thinning away on its upper slopes, so that the culminations (◓) are nearly free of ground moraine. This provides evidence of the immediately adjacent syngenetic interplay of ground-scouring and glacial erosion on the cupolas and the accumulation of ground moraine in the depressions, situated in between, by the largely overflowing inland ice. (– –) is the hypothetical minimum surface height of the relief-covering High Glacial (LGM) inland ice. (Photo M. Kuhle.)



↑ *Photo 121*. Taken from a viewpoint 8 km W away from that of Photo 120 at about 4650 m (aneroid measurement 4475 m asl at high pressure) facing NE (Figure 2 between Nos. 85/86; 32°32′ 20″ N/ 81°43′ 15″ E). Beyond the ground moraine face lying in the shadow (■ white) a hilly area continues, polished by the inland ice (◓). Due to the sedimentary bedrocks it is dark-coloured - as far as it is free of ground moraine. The light faces are ground moraine (■ black) consisting of a different erratic material which, accordingly, is also differently coloured. Apart from rather minor washing processes since deglaciation, only those faces are free of ground moraine, from which the meltwater of the Late Glacial (Stadium III–IV, Table 1) local plateau ice cap has washed away the High Glacial ground moraine attached to the slopes below (cf. Photos 123–125). (△) indicates washed ground moraine material which has been re-sedimentated in the form of an alluvial fan. (0 – –) is the inevitably hypothetical surface height of the relief-covering glacial (LGM) inland ice. (Photo M. Kuhle.)



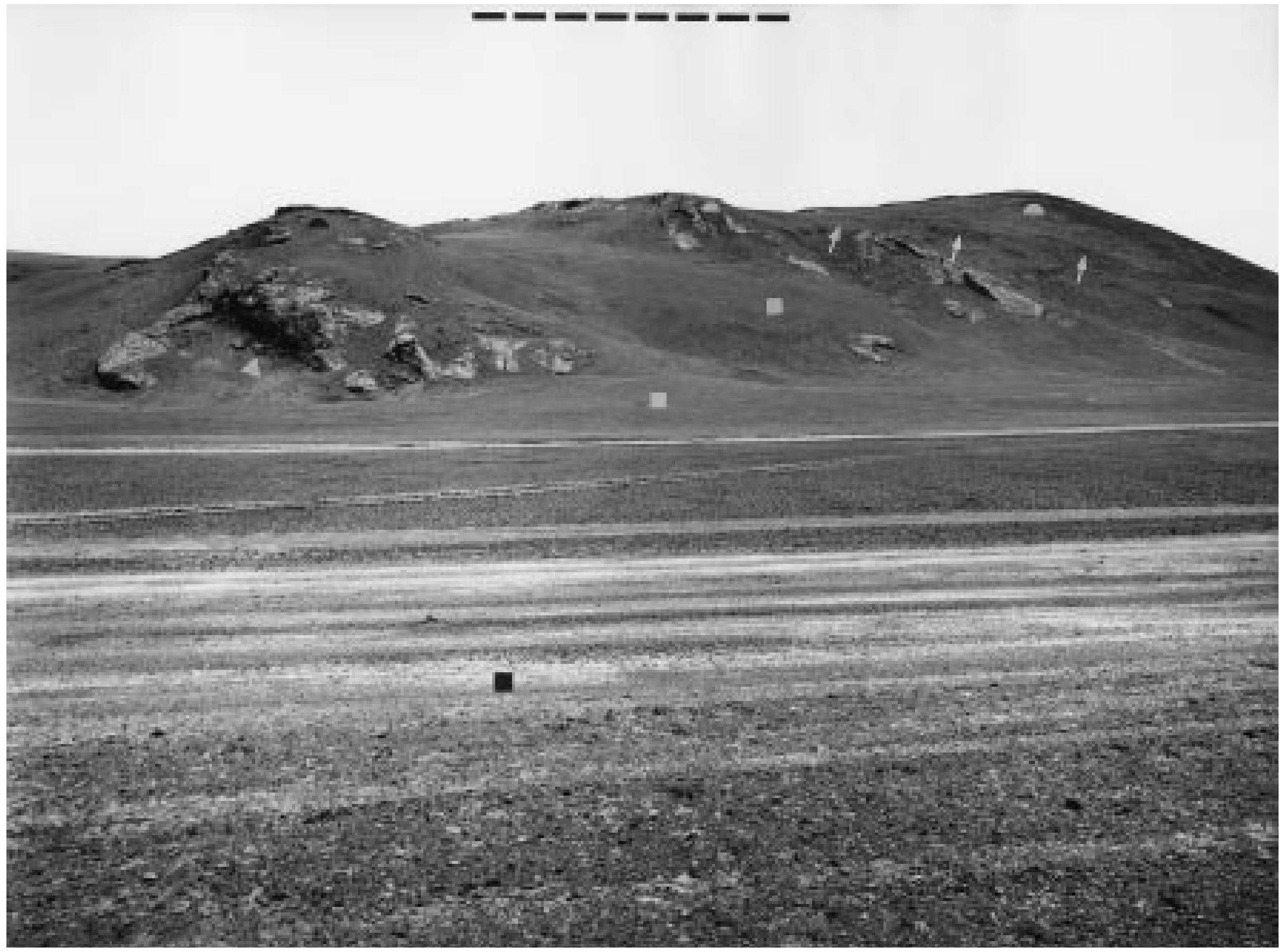
← *Photo 122.* At about 4650 m (aneroid measurement 4475 m asl at high pressure situation), 1 km W from the viewpoint of Photo 121, taken facing W (Figure 2 between Nos. 85/86). (◓) are roches moutonnées in metamorphic sedimentary rock. In the background on the right (left of the right ◓) the winding caravan paths of the seasonal nomad route to the W can be noticed. Ground moraine stretches from the foreground (■) upwards as far as half of the roche moutonnée slope (■). The surficially cohesive rock pavement (developed polygenetically as deflation pavement and periglacial pavement bottom) on the approximately even ground moraine sheet in the foreground consists of polymict pebbles which are edged or rounded at the edges. On the lower slope the surficial rock pavement is thinner, so that the lighter pelitic ground moraine matrix shines through in some places (■ background). Solifluction terraces (loop-bottom) occur on the upper slope (△). The clearness of their structure is due to the weathering of the large boulders of sedimentary bedrock on the roche moutonnée, forming these loops. (– –) indicates the minimum surface height of the Ice Age inland ice cover. (Photo M. Kuhle.)

→ *Photo 124.* At ca. 4800 m (aneroid measurement 4610 m asl at high pressure), 6 km WNW from the locality in Photo 123 facing SSW (Figure 2 between Nos. 85–87; 32°37′ N/81°34′ 30″ E). The polymict ground moraine (■) stretches evenly (foreground) and also up the slopes (middleground). (▼) indicates the actual working edge of the ground moraine sheet, undercut by lateral erosion on the outer slope of a temporary meltwater stream in the thalweg. The mountain ridges have been glacially rounded (◓) and show rock polishings and -abrasions by the ground scouring of the inland ice. As a result of subaerial weathering, active from deglaciation until now, the smoothed rock face on the mountain ridge breaks away on its margins (△), thus vanishing at present, i.e., interglacially. This provides evidence of the fact, that the visible forms are of prehistoric origin and have not been developed subaerially. At the same time it is an indirect indication that these rock roundings and -smoothings are subglacial form elements. A direct indication is that such edges and margins of the fracture (△) would have been rounded and levelled subaerially, i.e., the smoothed faces had not developed but would have been torn out by the attacking ground ice, hooking onto these sharp edges, and modified to roughnesses of the surface. (– –) is the hypothetical minimum surface height of the inland ice, overflowing this landscape. (Photo M. Kuhle.)

↑ *Photo 123.* From ca. 4725 m (aneroid measurement 4545 m asl at high pressure), 10 km W from the viewpoint of Photo 122, looking over an area of ground moraine (■ ▽), roches moutonnées (◓) and 'glacially streamlined hills' (◓) as well as a glacial 'fjell-landscape' (▼) (Figure 2, Nos. 85/86; 32°35′ N/ 81°38′ E). Direction: facing E (left margin) via S, SW (centre) and W up to NE (right margin). The ground moraine in the foreground (■) shows polymict boulders up to the size of a head (l=35 cm), consisting of basalt, porphyry, quartzite and metamorphic schist (phyllite). They 'swim' in a pelitic fine material matrix. (▽) marks a light ground moraine sheet, lying on a small high plateau, which rises ca. 200–350 m above the general level of the Tibetan plateau base at this place (recognizable by a ground moraine overlay in the fore- and middleground). The marginally darker hills and rock ridges have been rounded by the glacial ground polishing without having a ground moraine cover. This has been washed away by the meltwater during the Late Glacial (Stadia III–IV, Table 1) (cf. Photo 125). (◓ white centre) marks round-polished mountains and ridges integrated into a high plateau landform (▼) with rounded edges reminding of Scandinavian fjells. (■ small, background in the centre) is a drumlin-like ground moraine ridge. (■ small, background on the right) shows the ground moraine – forced by the overflowing inland ice to the windward side of a roche moutonnée (◓ large) – with its transition arc from the basal ground moraine plain (■ large) to the lower slope of the roche moutonnée. (←) was the local direction of the inland ice run-off from NNE to SSW, as a result of which the roche moutonnée (◓ large) formed of phyllite has been created. At the same time the flat scour slope and the steep leeward slope (←) have been formed. Processes, such as the regelation and detraction of rock fragments by the reduction of the ice load have taken part in its development. The rock fragments were frozen to the ice bottom by the refreezing of the waterfilm and have been torn out of the bedrock bonding by the ice movement. This caused the steepness and the roughness of this slope (←). (– –) is the minimum surface height of the inland ice (LGM), necessary to bring about the rounding and forming of this section of the Tibetan landscape. For perspective reasons it looks as if it were staggered, but actually it is only one level. (Photo M. Kuhle.)



↑ *Photo 125.* Long distance exposure from the same locality as Photo 124, facing SE towards the area a section of which is shown in Photo 123 (▽) (Figure 2, No. 85). Deposited at High Glacial times, the ground moraine cover (■ white) on what is here the lowest Tibetan upland area stretches up to a 200–350 m-higher old plateau surface, covered by a lighter Late Glacial ground moraine (■ black). It originates from a time, when the snow line had increased to such an extent, that the lower plain (■ white) has no longer been covered by a local plateau ice complex, whilst this plateau still was so. This happened during the Late Glacial or late Late Glacial Stadia III or IV (see Table 1). At this time part of the older Late Glacial to High Glacial (Stadium 0) ground moraine has been washed away from the lower slopes by the meltwater of the local plateau ice, which accordingly now are much darker (left and below ■ black) (cf., Photos 121, 123). (◁) are the traces of the caravan route patterning the oldest ground moraine surfaces. The mountains still glaciated today in their summit-level (background), reach a height of ca. 5600 to 5900 m at maximum and are proof of a recent W-exposed local snow line about 5750 m asl. In the early Late Glacial (Stadium I) these summits have pierced the inland ice surface and at the same time have been sharpened by the lateral erosion of the ice like Norwegian tinders, Greenland nunataks or alpine glacial horns. Some of the summits have preserved the glacial rounding up to their culminations (◓ centre) thus confirming an inland glaciation covering the entire mountain relief during the High Glacial (LGM=0). (– –) is its hypothetical minimum surface height about 6000 m asl. From these observations a minimum ice thickness about 1200-1400 m can be derived for this section of Tibet. (○) are cirques and short troughs still glaciated in the late Late Glacial (Stadium IV, Table 1). (Photo M. Kuhle.)



← *Photo 127.* At ca. 4900 m (aneroid measurement 4730 m at high pressure), ca. 4 km W from the locality in Photo 126, facing SW to an orographic right valley flank. The very wide, flatly inset high valley leads westwards to the 5000 m-pass (Figure 2, No. 87; Photo 129). (◓) marks glacigenically round-polished limestone rocks. This mountain ridge, polished by the prehistoric ice shows an undulating profile line with three rounded culminations (◓). A rock-specific similarity with the mountain ridge in Photo 115 is obvious. Here, too, the ground abrasion of the inland ice has selectively removed big rock segments from the ridge – either as separate pieces or in a detraction process by which a connected segment was torn out of the banking structure – so that a really smoothed hill surface could not develop. (◀) marks a rock niche, also created by detraction, from which the ice has removed a large rock boulder according to the banking structure. The smaller boulders are postglacial crumblings since deglaciation. Ground moraine accumulations (■ white) are preserved at the slope foot and also partly on the slopes. On the upper slope exaration rills or -furrows (↑) have remained, indicating a local ice flow direction from ENE to SSW (from diagonally left to diagonally right). The mere forms and positions of the ground moraine remnants (■ white) - apart from the fact that they doubtless consist of ground moraine material (cf. Photo 128) – concede no other than a glacigenic deposition mechanism: (a) the small hill form situated at the slope foot (■ white below) does not emerge from a bottom contour line on the slope, so that a remnant of an alluvial debris fan ought to be suggested as an alternative; (b) the bulbous accumulation on the slope itself (■ white on top) received its form secondarily, i.e., by marginal down-washing and linear erosion on both sides. Consequently, the bulge developed residually and has not been deposited primarily from a bottom contour line lying above. (■ black) is the ground moraine matrix rich in pelites, exposed by truck-traces. (– –) is the minimum height of the High Glacial (LGM=Stadium 0; see Table 1) inland ice surface necessary to develop this relief section. The actual thickness of the inland ice was much more important. (Photo M. Kuhle.)



← *Photo 126.* At ca. 4860 m (aneroid measurement 4680 m asl at high pressure) from the route to Napug across the 5000 m-pass (Figure 2, No. 87), looking SW (left margin) via W up to N (right margin) over round-polished limestone mountains and -hills (◓). Lorry tracks have removed the rock pavement of the glaciofluvially washed ground moraine surface. Thus, the fluvially redeposited matrix, which can nevertheless still be diagnosed as moraine matrix (■ black) by its high pelite portion, has been exposed. Separate coarse components of a polymict composition 'swim' in it. Apart from insignificant processes of slope flushing, the lower hill slopes and the rock thresholds lying in between are covered with primarily preserved ground moraine (■ white). (▼) marks the two steps of a glaciofluvial terrace. The lower one amounts to ca. 3 m and the higher one to 3.5 m. This concerns Late Glacial (Stadia III–IV; Table 1) gravel floor fans (cone sanders) accumulated by meltwater through a glacier outlet situated up-valley to the SW (valley incision in the background on the left). They have remoulded the ground moraine plane in the foreground (■ black). The main attention should be focussed here on the glacigenic hill form, typical of limestone bedrocks (◓) (cf. Photo 83). Despite the rounding effect of the ground-scouring of an inland ice, the rock structure of layered or stratified limestones still remains subglacially in the form of a strikingly edged roughening (⇧). (△) is an alluvial- and mudflow fan, built up by the dislocation of ground moraine from the upper slope since deglaciation (in the Holocene). (– –) is the hypothetical minimum surface height of the High Glacial (LGM) inland ice. (Photo M. Kuhle.)



← *Photo 128.* From nearly the same locality as Photo 127 facing NNE (centre), looking into the orographic left flank of the same valley. In the foreground on the left the postglacial bottom contour line is visible. It has been developed since deglaciation and cut into the ground moraine up to a depth of 0.6 m (■ black). The ground moraine consists of a light pelitic matrix with unsorted polymict boulders 'swimming' in it (○). They are partly rounded (○ left) and rounded at the edges, then showing polishing facets (○ right). Left of (■ black) the 16x10 cm case of a tape-recorder to compare the size. 5 km wide, the slightly undulating surface of the ground moraine forms the bottom of this valley (■ white). (▽) marks a further merely decimetres- to a few metres-deep cut into the ground moraine, developed by the linear erosion of the down-flowing water since deglaciation. (■ black in the background) are ground moraine remnants on the lower slopes of the orographic left valley flank. Several of the mountain ridges have been rounded by the inland ice (◓), whilst others – despite the ground-scouring of the ice – remained steep because of their sedimentary rock structure and its characteristic ac- and bc-jointing by cleft-controlled backward erosion of the slope (below – –). (– –) is the minimum surface height of the Ice Age inland ice, necessary for this local formation. (Photo M. Kuhle.)

↓ *Photo 129.* From the culmination of the 5000 m-pass (Figure 2, No. 87; 32°42′ N/81°27′ 20″ E), looking towards the NW (left margin) via N (half left) and E (half right) up to SE (right margin) across this Ice Age (from LGM, i.e., Stadium 0 to Stadia I or II; Table 1) transfluence pass and the fringing hills. The soft rounding of the pass (third ◓ from the right) wears all the geomorphological characteristics having been formed by an inland ice cover. The pass is overlain by a merely 2 to 1.5 decimetres-thick ground moraine sheet (■ fore- and background). The bedrock in the underground consists of limestone and reddish sandstone. The same applies to the mountain ridge in the background (◓; the two ◓ on the right consist of limestone). (▽) indicates the steep sandstone mountain ridge in Photo 128 (background below – –). The mountain ridges preserve the ground-scouring of the inland ice differently, i.e., according to their rock and its bedding: at places at which the edges of the strata of the sandstone form the slope, the (ac- and bc-) joints arranged vertically to the bedding dip, cause precipitously steep slopes (▼). There, the prehistoric subglacial abrasion and detraction as well as the crumblings induced by weathering since deglaciation, took place by the control of the clefts. This means, that on these slopes the rectilinear joint planes and -edges remain form-determining and cannot be reshaped to a round form by the diagonal polishing planes. At other places rounded mountains have been left behind over large parts (◓). (– –) marks the minimum surface height and thus the thickness of the High Glacial inland ice cover, necessary for the obviously glacial rounding of the entire relief. (Photo M. Kuhle.)

← *Photo 130.* From a viewpoint a little beyond the 5000 m-pass (Figure 2, No. 87), i.e., W of its culmination and the viewpoint of Photo 129, again at an altitude at nearly 5000 m, looking SSE over a slightly-sloping ramp formed of ground moraine without any large boulders (■ black and white on the right in the background). A perfect trough valley is visible in the background on the left (■ black). It has been worked into the rounded mountain ridge landscape (◓) and ascends with its ground moraine-covered bottom (■ black at the back on the left) from a height of 5200 up to 5600 m. Local roughnesses occur on the outcrops of more resistant sedimentary rock layers (◓ black). (▽) marks lineaments of exaration rills crossing the mountain ridge. They are evidence of the direction of the down-flowing ice from NNE to SSW (from diagonally left to diagonally right) (cf. Photo 127 ↑ ↑). (– –) indicates the minimum surface height of the High Glacial (LGM) inland ice which was the cause of these relief characteristics. (Photo M. Kuhle.)

← *Photo 131.* At ca. 4700 m (aneroid measurement 4560 asl m at high pressure weather situation), 25 km SW of the 5000 m-pass (Photo 129; Figure 2, No. 87) (32°36′ N/81°19′ E), in a kilometre-wide high valley leading down to the source branch of the Indus, looking E into the orographic left valley flank. (■ in the foreground) is a gradually-sloping ramp of ground moraine (cf. Figure 20), patterned by two lorry tracks. (■ middle- and background) are ground moraine plains, extending from the valley bottom up to the steeper slopes of the mountain range. (■ between ↑ and ☐) are drumlin-like ground moraine hills, the accumulative streamlined forms of which document an ice flow direction from left to right (approx. from NNE to SSW). (↑) is a scatter of metre-long moraine boulders, which lie together with an only decimetre-thick ground moraine cover on the bedrock rounded to a roche moutonnée (◓ left). At (☐) the ground moraine sheet has been surficially washed by the down-flowing meltwater and dissected by meltwater gullies. The meltwater flowed off the short troughs and cirque-like source depressions of side valleys (○) in which small glaciers were situated in the late Late Glacial (Stadium IV, Table 1) when the inland ice had already melted down and the main valley was free of ice. Owing to the sedimentary bedrocks, which are very coarsely structured by layering and jointing and thus predetermine an extreme roughness, glacial roundings are largely absent, i.e., are merely preserved as some hill cupolas (◓) (cf. in contrast Photo 132). (– – 0 – –) marks the minimum surface height of the inland ice sheet (0=LGM). (Photo M. Kuhle.)

← *Photo 132*. From approx. the same locality as in Photo 131, looking W into the orographic right flank of this flat valley with a trough-shaped cross profile. (■ fore- to middleground) is ground moraine with polymict boulders up to the size of a head, which are rounded to rounded at the edges, and for the greater part originate from the glacial erosion in the nearer environs (local moraine portions). As on the opposite valley side (Photo 131), the ramp-like flat slope on the valley bottom (■ foreground) (cf. Figure 20) is continued by steeper slopes covered with ground moraine (■ background). On this valley side, too, traces of glaciofluvial reshaping occur in the form of local cone sanders (□), deposited through small hanging valleys which in the late Late Glacial (Stadium IV) still had glacier fillings (○). Today – if at all – their further forming occurs at the time of the snow melt. Then they become dissected by fresh microfluvial rills, i.e., covered by an actual pattern of lines. (◓) are the ridges of sedimentary bedrock (sand- and siltstone) rounded by the High Glacial (LGM) ground-scouring of the inland ice. (△) mark the more or less horizontal band polishings of the outcropping edges of the strata or/and exaration rills which the ice has gouged into the underground. Their down-valley direction from right to left testifies to the local flow direction of the inland ice diagnosed on the left-hand valley side (Photo 131) from NNE to SSW down to the upper Indus valley (Figure 2, between Nos. 87, 88). (↗) indicates the remoulding of these exaration lineaments arranged transversely to the slope incline. As it is characteristic of actual fluvial morphodynamics this takes place by slope ravines running at right angles to it, which immediately follow the slope gradient. (– –) is the estimated minimum surface height of the High Glacial (LGM) inland ice according to the local covering with ground moraine (■) and the glacial rounding of the relief reaching even several hundred metres higher (◓). (Photo M. Kuhle.)

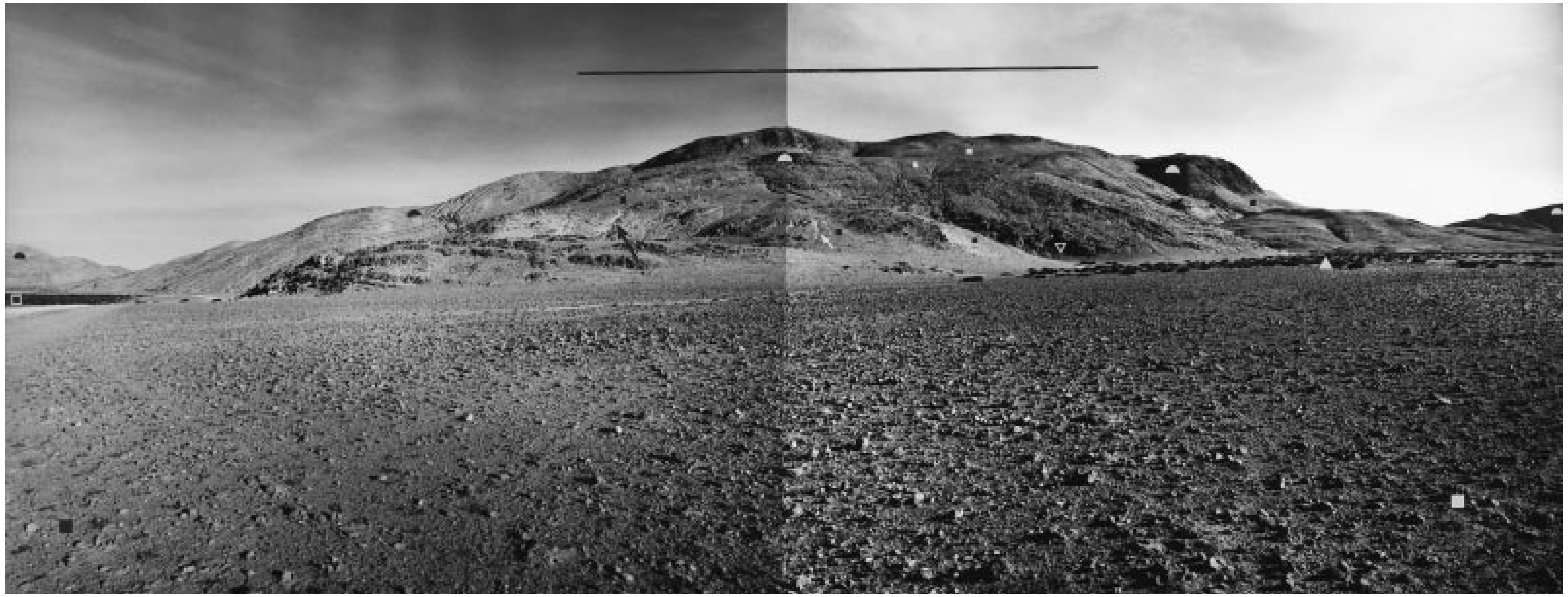
↙ *Photo 133*. At ca. 4600 m (aneroid measurement 4460 m asl at high pressure weather situation in the evening) 9 km S of the locality shown in Photo 132, taken from SE (left margin) via S up to W (right margin) looking across the N source branch of the Indus (↓ ↓) the local name of which is Senko Tsangpu (according to ONC 1:1 000 000 G-7) (Figure 2, Nos. 89–90; 32°22′ 30″ N/81°10′ 30″ E). In the centre of the photo a permanent settlement (left of the left ↓) of semi-nomads (yak- and sheep-nomads) can be observed. The basis for their living is staggered grazing. The settlement consists of loam-houses with flat roofs. It is mainly inhabited during the winter. (■) is the hilly surface of polymict moraine material including over 1 m-long granite boulders (a boulder of this type lies 10 m away from the viewpoint outside this photo). Granite bedrock on the valley flanks occurs in the near vicinity (at a distance of 300 m from the boulder). (□) are glaciofluvially reshaped ground moraine planes 1–2 m above the receiving stream of the Indus river. The valley cross-profiles show box-shaped trough forms (Figure 2, No. 89) (cf. Photo 134). Flank abrasion on the orographic left valley side (◓ black) has caused a truncated spur. (◓ white) are round-polished hills and mountain ridges formed of perpendicular standing (dip angle 75° to the E (95°)) massive rock layers. This is, in the geomorphological sense, a very simply-formed landscape. Since deglaciation their glacigenic abrasion- (◓) and accumulation elements (■ □) have been partly reshaped by moraine material, resedimentated in the form of cones and fans by crumblings (▼) and solifluction as well as mudflows down the slopes. (– –) is the minimum surface height of the inland ice which has covered this clean-looking mountain landscape. (Photo M.Kuhle.)

→ *Photo 134*. At ca. 4600 m (aneroid measurement 4445 m asl), 6 km down the Senko Tsangpu valley (N source branch of the Indus) from the viewpoint of Photo 133, looking from the orographic right valley flank towards the SW (left margin) via W (centre) up to NW (right margin) (32°24′ N/81°05′ 40″ E). The box-shaped trough profile is formed by glacigenic flank polishings (◥ ◤ white) with ground moraine overlays (■) and a valley bottom of glaciofluvially reshaped, i.e., surficially washed ground moraine partly covered with flatly-inset gravels (□). The water-retaining ground moraine portion of the valley bottom makes alpine meadow vegetation and grazing possible (□ left). (↑) indicates the meandering main river on the valley bottom. (▽) are slope- and fan forms consisting in the core of primary ground moraine and on the surface of ground moraine, which has been displaced down-slope. This down-slope shifting of moraine material immediately after the Late Glacial deglaciation was brought about by the meltwater of glacier remnants persisting on the mountain ridges until the late-Late Glacial (Stadia III and IV; Table 1). (□ large) is local moraine, bearing over metre-long granite boulders; (■ small) is far-travelled moraine with large portions of fine erratic material matrix. (▼) are fresh rock crumblings at the valley flank steepened by the glacigenic polishing. (◓) indicate mountain ridges rounded by the relief-over-riding inland glaciation. They are the geomorphological basis for a provisional estimation of the minimum surface height of the ice (– –). For (◓ black), cf. Photo 135. (Photo M. Kuhle.)

← *Photo 135.* At ca. 4540 m (aneroid measurement 4380 m asl at high pressure) from a viewpoint ca. 25 km down-valley from that of Photo 134, at the settlement of Napug (Figure 2, between Nos. 91 and 93) or Kochi (ONC G-7 1:1 000 000; also named 'Geggi' what means 'happy' or 'gay'), looking towards the NW (centre of the photo) at the orographic right valley flank of this source branch of the Indus valley (Senko Tsangpu) (32°28′ 30″ N/80°52′ 40″ E). It consists of glacigenically polished limestone bedrock (◓) partly showing ground moraine overlays (■) (Figure 2, No. 94). At some places the ground moraine has got a decimetre- to metre-deep pattern of fresh slope rills (↖). Since deglaciation through to the present time they have been incised by precipitation water. In the Late Glacial (ca. Stadia II–III; see Table 1) glacier tongues flowing down from this local high plateau (fjell) (□) set upon the Tibetan basal level, have transported the moraine material which had been deposited during the High Glacial (LGM) down from elevated positions (■ white). At the same time the material removed has been newly accumulated into the form of ramps (■ black). (□ white on the right) is a fan form of High- to early-Late Glacial (Stadium I) ground moraine and younger end moraine from the high valley above (▼), displaced glaciofluvially down the slope and resedimentated by the Late Glacial glacier meltwater. The root of the fan (△) starts at the exit of a gorge-like meltwater scoring incised as far down as the bedrock, set into the bottom of this trough-like hanging valley. (□ black and white on the left) present glaciofluvially washed ground moraine (Figure 2, No. 95) containing over 1 m-long boulders. (– –) is the minimum surface height of the Ice Age inland ice cover. (Photo M. Kuhle.)

← *Photo 137.* At 4440 m (aneroid measurement 4275 m asl under high pressure weather conditions), 14 km downwards from the view point of Photo 136, looking down the Senko Tsangpu from the orographic right valley side (Figure 2, No. 98). The picture was taken facing S (left margin) via W (left of the centre) and N up to NE (right margin). Over large parts the valley bottom is built up from a late Late Glacial (Stadium IV; Table 1) to neoglacial (Stadia V to 'VII) glaciofluvial gravel field (□ on the left) into which the river (▼ white) has cut up to a depth of 1.5 to 2 m, thus creating a lower terrace (□ on the left) where horses are grazing (for size-comparison). (□ on the left) also marks a stagnant water branch with a denser grass vegetation, slightly inset into the terrace surface. (◓) are mountain ridges rounded by the ground scouring of the inland ice. They consist of sedimentary rock, the layers of which dip to the N at an angle of 25–27°. Afterwards, i.e., since deglaciation, the foot slopes of one of the rounded ridges have been undercut by the Senko Tsangpu river along an outer slope (⇗). (■) indicate the light High- to early Late Glacial ground moraine covers on top of the subjacent darker layers of sedimentary bedrock, which can clearly be diagnosed in many places (↑ large). (↗ small) shows a fresh crumbling on the edge of this moraine cover, caused by a slope rill, which has been deepened postglacially by down-flowing water. (/) mark three exemplary postglacial flushing rills in the moraine material on the orographic left valley flank. They are a function of the relatively soft surface of this fine-grained loose material. Since the Late Glacial, i.e., accompanying the down-thawing of the post High Glacial valley glacier in the Senko Tsangpu, the moraine material has been transported solifluidally and in particular fluvially down the valley flanks – which were now free of ice – and also from the steep side valleys as far as the main valley bottom and deposited in the form of fans (△). The older of these fans, still heaped up against the edge of the valley glacier, remained as remnants of classically developed kame terraces (▲ black). The lower, younger of the moraine-containing fans, which after the complete melting of the valley glaciers were able to be accumulated further into the main valley, have been undercut distally by the Senko Tsangpu river (□ black and □ white on the right). Due to the Late Glacial (Stadia III-IV) cover of local hanging glaciers and their meltwater run-off, the mountain cupolas and upper slopes (◓) have largely been relieved of their High Glacial (LGM) ground moraine sheets. (– – 0 – –) is the minimum surface height of the relief-covering inland ice, the ground scouring of which caused the rounding of the mountain ridges (◓). (Photo M. Kuhle.)

→ *Photo 136.* At ca. 4550 m (aneroid measurement 4380 m asl at high pressure), 23 km down-valley from the locality depicted in Photo 135 (i.e., 9 km from the sampling location of Figure 27), looking into the right flank of the Senko Tsangpu valley towards the ENE and onto a roche moutonnée, i.e., a mountain ridge round-polished by the ice (◓ ◓) (Figure 2, No. 97; 32°32′ 20″ N/80°36′ 20″ E). (□) is the bottom of the main valley (Senko Tsangpu) consisting of gravels of the Late Glacial. The gravel floor forms a ca. 1.5–2 m-high terrace (cf. Photo 137) overgrown with dwarf scrub. (■ foreground) shows a ground moraine plain, the surface of which has been washed glaciofluvially and by postglacial flushing through precipitation water. It has also been reshaped by deflation (cf. Figure 27: sample of ground moraine matrix in the vicinity). (◓) are glacigenically round-polished layers of limestone and lime marl. The polished rock faces cut diagonally across the outcropping edges of the strata (second ◓ from the left), so that – seen as a whole – a streamline-like macroform, rounded on all sides, has been developed (◓ black and white). However, small-scaled ledges, depressions and steps, i.e., breaks in the profile line on the surface of this streamlined form (e.g., above the left white and below the middle ◓ white) are predetermined by the layer- and cleft structure of the rock. (▽) is an example of correspondingly structure-dependent crumblings, which have taken place since deglaciation. The partly preserved ground moraine cover has a tendency to smooth and level the streamlined body, so that a rather perfect form has been developed (■ small in the background). During deglaciation at many places 1–3.5 m-broad and 0.5–2 m-deep microfluvial rills have been eroded into the ground moraine on the slopes (↖). (△) is a special alluvial fan consisting of postglacially removed ground moraine material that emerged from the structure-dependent, small V-shaped valley system (on the left above ▲). (– –) is the minimum surface level of the inland ice, leading to the abrasion of the relief (◓). (Photo M. Kuhle.)

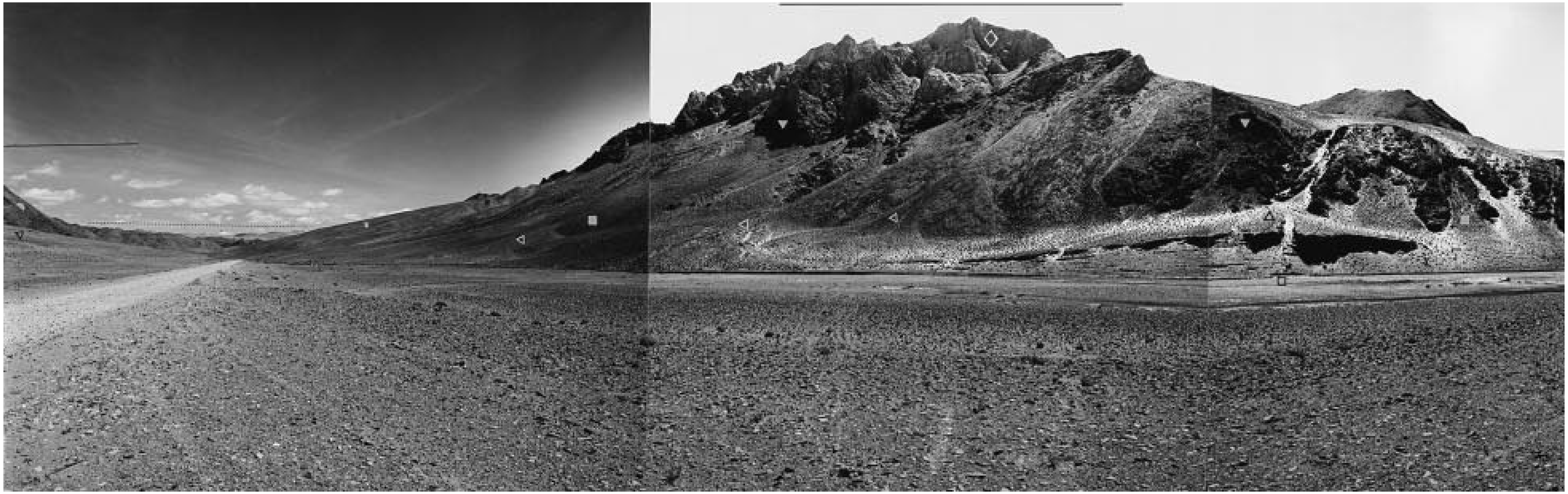


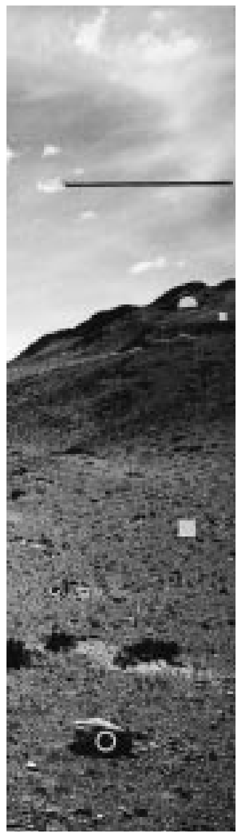
← *Photo 138.* Senko Tsangpu, at a height of ca. 4400 m (aneroid measurement 4220 m asl at high pressure). The viewpoint is situated down-valley from the locality shown in Photo 137, looking into the orographic left valley flank (Figure 2 between Nos. 98 and 99; 32°30′ 30″ N/80°27′ E). Direction: facing SE (left margin) via SW up to W (right margin). (■ large) is ground moraine with the usual ablation moraine cover, melted out from the inland ice layers near to the ground under the influence of the meltwater during the phase of down-thawing. Thus, compared with the subjacent pure ground moraine, its matrix is somewhat coarser with a stone paving that has been frost-heaved (periglacially) and slightly blown out by deflation. Separate polymict boulders of sedimentary rock (○ black) as well as granite and rhyolite (○ white) up to the size of a metre lie on the surface of the moraine cover. (◁) indicates fresh fan forms on the opposite valley side, developed by mud flows. (⇧) is the actual thalweg which is flowed through periodically or episodically. It is flatly inset into the main fan. The fans are built up from flushed ground moraine, the remnants of which cling to the slopes up to high positions (■ small). (↗↖) are rills which have been set postglacially into the ground moraine. (◓) marks mountains rounded by the inland ice (– – = minimum surface height) rising up to 5100 m. (●) describes the back-slopes of cirque- and short valleys. In the late Late Glacial (Stadium IV, Table 1) separate glaciers still existed in this N exposition. Probably the damming-up by the right glacier (lying in the form ● on the right) has led to the development of a small temporary ice-dammed lake in the middle valley (● centre). Its sudden outbreaks, typical of glacier-dammed lakes, might have led to the build-up of those large mudflow fans (△). In any case, their existence suggests the late Late Glacial damming-up of ice-dammed lakes in this appropriate topography. (Photo M. Kuhle.)

➞ *Photo 140.* From a height of ca. 4370 m (aneroid measurement 4190 m asl at high pressure), 5.5 km more to the W than the viewpoint of Photo 139, looking down the Senko Tsangpu into a further orographic right side valley (Figure 2, No. 100). The photo was taken towards the NNE. (☐) is a ground moraine pedestal with a terrace (Figure 2, No. 100: pedestal moraine). Rock ridges (roches moutonnées) rounded by the glacier ground scouring are integrated into this ground moraine, which contains large, i.e., over one metre-long boulders; some other neighbouring roches moutonnées (second ◓ from the right), which – in this case – are situated nearer to the thalweg of the side valley, have probably already been exposed subglacially by the meltwater, i.e., relieved from their moraine mantle during the Late Glacial. The ground moraine pedestal (☐) with its 11 to 13 m-high terrace, which coincides exactly with the exit of the side valley, i.e., stretches along the right flank line of the main valley, falls away to the ground moraine cover of the main valley (■ large, in the foreground). This indicates the marginal juxtaposition of the Late Glacial tributary glacier stream to the main glacier, which had a greater depth. Thus, this ground moraine pedestal of the side glacier at the same time is a subglacial orographical right bank formation of the main glacier. The roche moutonnée (second ◓ from the right) is a rounded bar-mountain, pre-glacially (i.e., pre-Quaternary = Tertiary) cut out from an initial junction threshold of the side- and the main valley. The higher level of the side valley bottom, situated upwards of this junction-threshold, has led to the build-up of the ground moraine pedestal due to the fact that the side glacier – in order to maintain its bottom level – has compensated for the decline of the valley bottom with an underlay of ground moraine in the area of that prehistoric junction-threshold. (◓) are glacially rounded sedimentary rock slopes, mountain ridges and rock thresholds, partly covered with ground moraine (■ small, background). (– –) is the minimum surface height of the High Glacial (LGM) inland ice which must have caused the glacigenic forming of the landscape diagnosed here. (Photo M.Kuhle.)



⟵ *Photo 139.* At a height of ca. 4390 m (aneroid measurement 4210 m asl), about 4 km westwards from the spot where Photo 138 was taken, facing NNE, looking up-valley into an orographic right side valley of the Senko Tsangpu (Figure 2, No. 99; 32°33′ 30″ N/ 80°28′ E). The High- to Late Glacial (LGM = Stadia 0-II) ice influx which took place along this side valley towards the northern source branch of the Indus (Senko Tsangpu) is documented by round-polished (◓ white) and back-polished (◓ black) mountain spurs. They consist of thinly-layered sedimentary rock; consequently they have not been able to preserve the roundings of the prehistoric glacier polishing for a longer time. This is a sure indication for the fact that these traces of ground- and flank polishing are no pre-Last Glacial forms (Riß = Stadium -I; pre-Last High Glacial; cf. Table 1). (■) are preserved ground moraine remnants. (▼) marks the level of an alluvial fan terrace preserved on both sides and undercut by the river bed. The alluvial- and mudflow fans consist of moraine substrate from the slopes which has been flushed and resedimentated. (△) shows a 9 m high remnant of a gravel floor terrace at the approximately same relative altitude level as the alluvial fan terrace. The gravel floor terrace is a late Late Glacial (Stadium IV) sander remmant (glacier mouth gravel floor). High- to Late Glacial- and glaciofluvial sediments have been reworked and displaced in the modern valley bottom and the gravel floor of the actual river (☐). (– –) is the minimum surface height of the High Glacial inland ice cover extracted from the relief forms. (Photo M. Kuhle.)





← *Photo 142.* Taken from ca. 4650 m (aneroid-measurement at high pressure: 4530 m asl), 22 km W of the settlement of Shiquanha (or 'Ali') across a pass (on the left a mani-wall with prayer flags and ghost traps) which leads from the basin of Shiquanha into the Gar Zangbo, the southern source branch of the Indus valley (32°24′ 30″ N/79°55′ E; Figure 2, No. 105). Direction: from E (on the very left) via SSE (centre) up to W (right margin). The pass is situated in an area of sedimentary rock and consists of interbedded limestones, lime marls and thinly-layered silt stones. The hills, towering up to 5000 m, have been polished extensively (◓). They provide evidence of the ground scouring by the down-flowing glacier ice. In many places a thin ablation- and ground moraine sheet covers the rounded rock ridges (■). It contains 0.7 m long boulders broken out locally, i.e., little transported, as well as boulders which are rounded at the edges and facetted, i.e., transported over a distance of at least one kilometre (○). They also consist of silt rock and limestone (○). Despite its petrographic variety this hill-, i.e., ground scouring landscape appears rather uniformly smoothed. This can be explained by a thickness of the overflowing ice of at least 200–300 m. (– – bold) is the LGM minimum surface height of the ice above the transfluence pass. (↓) shows a striking incision into the flatly layered limestone or lime marl of the hills forming the culmination of the rock threshold. This small valley has no catchment area capable of providing down-flowing water for its erosion. This applies all the more as the climate is semi-arid. Only subglacial meltwater brings about such an incision. Due to its channelizing by ice tunnels and its hydrostatic pressure, it is able to flow along or diagonally to such mountain- and intermediate valley ridges and in addition has even the capacity to erode. Immediately left of (↓) a syngenetic rock smoothing – on top convex and below concave – can be observed as a brightly shining rock face. It has been created by the hanging glacier scouring into this meltwater rill. (□) marks the valley bottom of the box-shaped trough of Gar Zangbo (Figure 2, No. 131; Photos 143, 144), built-up of ground moraine and gravel floors. The orographic left valley flank (◓ black on the right) situated above the gravel floor, has been polished by the Ice Age main glacier which flowed down from there to the right. (– – fine) indicates a very clearly preserved upper polish line below the summit-pyramids, along which the flank polishing diminishes at about 5700 m in an upward direction or perhaps even completely breaks off. Thus, the Ice Age minimum surface height of the ice stream can be recognized. (Photo M. Kuhle.)

↑ *Photo 141.* Taken at a height of ca. 4300 m (aneroid measurement 4130 m at high pressure), 30 km W from the viewpoint of Photo 140, 8 km E of the settlement of Shiquanha (also Ali or according to ONC G-7 Nikoli) (Figure 2, No. 103). Direction: looking up the Tsenko Tsangpu, i.e., the Indus towards the E (left margin) via S and W down the Indus (Tsenko Tsangpo, from here also Gar Zangbo, cf. Figure 2) and into the basin of Shiquanhua (half-right in the background) up to the N (right margin). On the horizon in the W, the easternmost foothills of the Zaskar mountains (Figure 2, W of No. 107) are visible, being there up to 6500 m high. (◓ ◓) mark a rock ridge abraded by the glacier ground scouring which consists of metamorphic sedimentary rock (phyllite). Its flat areas are covered by a ca. 1–8 m thick ground moraine (■ black, immediately left of ◓ and ■ white, directly above ◓ on the left). (△) shows moraine material which since deglaciation has been removed down-slope by flushing and newly deposited in the form of cones and fans. (▼) are more or less fresh crumblings. Since the Late Glacial they partly took place (second ▼ from the right) on the steep outer rock-slope which has already been developed subglacially. The meltwater tunnel ran approximately along the present-day thalweg (□) beneath the Late Glacial (ca. Stadia II–III; cf. Table 1) glacier. Its confined water, flowing down under hydrostatic pressure, has steepened the rock slope by lateral erosion. An ice cover existing even later is documented by the ground moraine inclines, left behind on the foot of the outer slope (■ white, background below of ◓), because they have been deposited directly by the ice after the undercutting through the subglacial meltwater. (■ white and black in the middle of the foreground and in the background on the left and right) show further ground moraine occurrences. Along the slopes they are partly buried by the postglacial cones and fans (△) above-mentioned (first to third from the left, white, and first △ from the right, black). At (■ in the foreground) the polymict composition of the ground moraine becomes obvious. (◥ ◤) are locally preserved glacier flank polishings. (– – 0 – –) indicates the minimum surface height of the High Glacial (LGM) inland ice sheet. The summits have been sharpened (◇) during the Late Glacial after they had already pierced the inland ice surface. They then took on the form of a glacial horn by the glacial lateral erosion of the ice, attacking from several sides. (Photo M. Kuhle.)


→ *Photo 144.* Taken at ca. 4300 m (aneroid measurement at high pressure: 4115 m asl) from the valley bottom of the Gar Zangbo, the southern source branch of the Indus, on the orographic right side of the thalweg. The overgrown gravel floor (□), which has been accumulated at historical times, is now used as grazing land by the settlement (middleground). Location: about 15 km to the SE, up-valley from the viewpoint of Photo 143 (32°18′ 30″ N/79°57′ E). Direction: facing SSE (left margin) via W (centre) up to N (right margin). Ground-, i.e., ablation moraine (■ large) which has been rinsed and blown out, extends in the foreground and contains large granite boulders (○). The 'chorten', showing a prayer flag, is covered with skulls and horns of goats and ibexes. As a signpost for the caravan route it is built up from several decimetres-long granite boulders of the moraine, which are rounded at the edges or facetted (○ left). The loose moraine material at the viewpoint contains local moraine. Granite bedrock can be observed on the orographic right valley flank (◓ white on the very right). Ground moraine ramps are preserved on the slope foot (■ small, background on the very right). Since the deglaciation during the Late Glacial (Stadia III–IV; Table 1) they have been transported down-slope by fluvial processes and again deposited in the form of alluvial fans (◁ black). These ground moraine ramps (■ small, background on the very right) cannot be mistaken for debris cones because they do not emerge from small valleys but are connected to rock ribs, i.e., their dissection and removal takes place in the continuation of the thalweg (▼). (2) and (3) are 6739 m and 6836 m-high massifs of the eastern prolongation of the Zaskar mountains. (**I**) marks the most extended present hanging valley glaciation in the NE exposition visible here. The corresponding orographical snow line runs at about 5600 m (cf. Kuhle, 1982, pp. 166–170; 1988, pp. 468–470). (●) is an exemplarily flat, trough-shaped hanging valley bottom (Figure 2, No. 106/107) of the highest old plateau level (about 5000 m asl), upon which neoglacial moraine and glaciofluvial gravel have been deposited (Stadia V–'VII and –0 to –3; Table 1). (↓) show V-shaped valleys through which steep side valley glaciers flowed even during the late-Late Glacial (Stadium IV), i.e., at an ELA depression of 700 m (as far down as ca. 4900 m asl). These glacial side valleys interrupt the High Glacial (LGM) flank polishing which at other places is united (the three ◓ on the left). The small four (■) on the left, background, mark flat ground moraine ramps on the lower slope of this main valley flank. The second and the fourth ramp (■) from the left consist of Late Glacial piedmont moraine which, emerging from the two connected side valleys, has been thrust over the older ground moraine of the main glacier after its deglaciation. (◁ white) are Holocene (neoglacial to historical) alluvial fans, i.e., genetically speaking: these are cone sanders or glacier mouth gravel floors accumulated by the down-melting of the side valley glacier mouths. Because the gravel floors have been canalized and transported through the V-shaped valleys situated in between (above ◁), they have no longer a connection to the glacier and can be determined as so-called 'indirect gravel floors' (Kuhle, 1982). (0 – –) is the High Glacial (LGM) minimum surface level of the over 10 km-broad upper Indus parent glacier, derived from the highest unambiguous polish line. This glacier has drained the entire ice stream network of its tributary glaciers to the WNW. (Photo M. Kuhle.)


← *Photo 143.* Taken from ca. 4600 m (aneroid measurement at high pressure: 4410 m asl), ca. 3 km W of the 4650 m-pass (Photo 142; Figure 2, No. 105) towards the SSE (left margin) via WSW (centre; Figure 2, No. 131) up to N (right margin) across the southern source branch of the Indus valley (Gar Zangbo). Round-polished rock ridges and hills are visible on both margins of the photo. They belong to the orographic right main valley flank of the Gar Zangbo and consist of sedimentary rocks (◓ on the very left and three ◓ on the very right). They have been developed by prehistoric glacier polishing. This becomes clear not only by the roundings itself, but also by the bend-less 'cross-cutting of the structures' of these regularly rounded faces (the three ◓ on the right). Denudative or erosive slope flushing, by contrast, would have preserved the outcropping edges of the strata and bedding planes with their petrographically-dependent differences in resistance as edged form elements, but not in the levelled form of these roundings. At the places on the lower slopes of the hills where sharp steep crumblings occur, confined subglacial meltwater has later undercut the rounding developed by the glacier polishing (▼). (■ white) marks the ablation- and ground moraine overlays. In some places they can already be recognized at a distance by their pattern caused by a special decimetre- to 2 m-deep type of flushing rills (✓). (□ black) are glaciofluvially remoulded ablation- and ground moraine inclines, several metre- to decametre in thickness, with glacial drift cover sand ('Geschiebedecksand') which in the depressions is overlain by veils of flying sand hold back by dwarf scrubs. Decimetre- to somewhat over 1 m long boulders (○) are contained, rounded at the edges and facetted. (□ white) is the bottom of the box-shaped main valley trough, built up from moraine- and gravel floor material. Postglacial (Holocene) alluvial debris fans (△) extending over kilometres are adjusted to this valley bottom. They have been accumulated as glaciofluvial gravel floors (cone sander) by the meltwater of the Holocene (Neoglacial Stadia V–'VII; Table 1) and historical glaciers (Stadia VII–XI) (sander –0 to –8 according to Table 1) and spread fan-like from the side valley exit into the main valley. (**I**) shows the positions of the larger modern valley- and hanging glaciers on the NE-exposed slope of this mountain crest which elongates the Zaskar mountains to the SE (Figure 2, No. 107; Figure 12 between Nun Kun and Kamet). Peak (2) reaches a height of 6739 m and peak (3) 6836 m (according to ONC 1:1 000 000 G-7). (■ black) are exemplary localities with orographical left ground moraine inclines left behind by the parent glacier filling up the main valley from the High Glacial (LGM = Stadium 0) up to the Late Glacial (Stadia I – ca. III; see Table 1). (■ black on the left) is mantled with end moraine of a side valley glacier of Stadium IV (cf. Photo 145 ■ on the left). (◓ second and third from the left) are 'truncated spurs' polished back by the glacigenic flank abrasion. (– – 0 – – fine) indicates the minimum surface height of the Ice Age (LGM) inland ice, i.e., ice stream network, derived from the highest, very clear polish line about 5700 m asl. From here the highest peaks (2 and 3) rose to a height about 1000 m. (– – -I-0 – – bold) is the hypothetical minimum surface height of the ice of the penultimate (Riß = Stadium -I) and the last Ice Age (Würm = LGM = Stadium 0), which can be deduced from the polyglacial relief forms. (Photo M. Kuhle.)



←*Photo 145.* At ca. 4300 m (aneroid measurement at high pressure: 4115 m asl), a perspective 5 km up-valley from that of Photo 144, looking into the orographic left-hand flank (Figure 2, No. 106) of the Gar Zangbo, being here over 10 km-broad. Direction: SW. (**I**) marks NE-exposed modern glaciers; their tongue ends reach as far down as ca. 5000–5400 m. (▼) are glacigenic side valleys, the concavely polished cross-profiles of which are V-shaped or at most slightly trough-shaped. The main valley- or parent glacier filled the Gar Zangbo up to the polish line at 5700 m asl (**– –**). Only after its thawing did the side valleys receive their present-day steep flanks by the scouring of the tributary glaciers. Before that, their drainage was restricted by the very slow main glacier which they joined. At an ELA depression of 700 m these glaciers still reached as far as the proximity of the valley exits (Stadium IV; Table 1). During Stadium III (ELA depression 800–900 m) they flowed down to the bottom of the main valley – now free of ice – , where they left behind piedmont ground moraines (■). At the same time gravel floor fans have been accumulated from the lower catchment areas (△). (↗) is the incision of the glacier stream into the piedmont moraine covers, linked with the retreat of the tributary glaciers. (□) show glaciofluvial gravel sheets covering High Glacial ground moraine on the valley bottom. (Photo M. Kuhle.)

↓*Photo 148.* At ca. 4630 m (aneroid measurement at high pressure: 4470 m asl) from the highest orographic left lateral moraine terrace (□ on the left and ■ on the right, foreground) in the Gar Zangbo (Figure 2, Nos. 109/110; 31°56′ 30″ N/80°09′ E, in the valley chamber of the settlement Gar), 7–8 km up-valley from the viewpoint of Photo 146. Direction: facing W (left margin) via ENE (centre) up to S (right margin). (▼) is the locality of the moraine exposure shown in Photo 147. The lateral moraine terrace from which the photo has been taken (□ left and ■ right, foreground) lies ca. 230 m above the ground moraine valley bottom (below of □ black); it can be classified as belonging to the oldest Late Glacial Stadium I (■ black, on the very right; I). Its down-valley continuation comprises the terrace levels (I and 4) in Photo 146. (**– –** 0 **– –**) marks the minimum surface height of the High Glacial (Stadium 0; cf. Table 1) inland ice. This is suggested by the rounded mountain forms (◓ black, on the very left; the two white ◓ on the very right) as well as by the glacigenic triangular-shaped slopes, i.e., back-polished mountain spurs ('truncated spurs') along the orographic left main valley flank (◥ ◤) and the ground moraine sheets, attaining heights of over 400 m above the lateral moraine level I (left white ■ in the background; the four ■ in the background on the right). (**– –** fine) half-right up-valley and (**– –** fine) on the opposite, i.e., NE (orographic right) valley side, is the corresponding LGM minimum surface level of the inland ice. Evidence of this is provided by ground scouring faces (the three black ◓ in the centre) with a ground moraine cover (■ black centre, at the very back). (**I**) are glaciated and firn-covered massifs the summits of which tower above 5800 m asl, thus documenting modern climatic snow line altitudes between 5800 and 6000 m asl. The Late Glacial lateral- and end moraines of this valley chamber of Gar contain erratic granite boulders (Figure 2, No. 110; Photo 147↗). On the surface of the lateral moraine Stadium I (□ left and ■ right in the foreground; Figure 2, No. 109) postglacial (Holocene) flushing processes took place (cf. Photo 147 □) as well as the weathering of rather large morainic boulders of sedimentary rock – lying on the surface – into sharp-edged (shard-like) fragments. (■

white, II) is the next lower, and thus younger, Late Glacial lateral moraine terrace which belongs to a thinner and narrower Gar Zangbo glacier of Stadium II (Figure 2, No. 109). Here, the postglacial linear erosion which occurred according to the water run-off from the lateral mould along the outside of the lateral moraine (⇓), has exposed the moraine material over decametres (between ■ white and II). (■ III) is the frontal moraine of Stadium III; (■ IV) that one of the youngest Late Glacial Stadium IV (Table 1). From the immediate glacier tongue margin (▽ ▽) of this youngest Late Glacial Gar Zangbo glacier, the supraglacial meltwater has accumulated ice marginal ramps (IMR = Bortensander; for further information, cf. Kuhle, 1990a, e) in the form of 8–11° steep gravel floor- (sander-) slopes on the frontal moraine (☐ black, on the right). Today, the edges of the strata of these glaciofluvial gravel sheets outcrop skywards in an up-valley direction (▽). They mostly have been developed at places, where lateral moraines form an inset of medial moraine between two adjacent tongue basins (▽). (The two black ☐ on the left) mark moraine material which has been flushed from the orographic right valley slopes of the Gar Zangbo. (■ black, in front, middle) is an only slightly dissected ground moraine pedestal of a Late Glacial side valley glacier tongue reaching the Gar Zangbo from the NE (Stadia II or III ?) (Figure 2, No. 108). (Photo M. Kuhle.)

← *Photo 146.* Taken at ca. 4400 m (aneroid measurement at high pressure: 4225 m asl), left side of the river, 24 km up-valley the Gar Zangbo (= S source branch of the Indus valley) from the viewpoint of Photo 145, looking into the orographic left-hand valley flank (Figure 2 between Nos. 106 and 109; 32°02′ N/80°07′ E). Direction: facing S (left margin) to W (right margin). (☐) are ground moraine plains of the early-Late Glacial (Stadium I) and High Glacial (LGM = Stadium 0) overlain by glaciofluvial gravel floors of the last-Late Glacial (Nos. 1, 2, 3 = glacier mouth gravel floors of Stadia II, III, IV; see Table 1). (■) mark High- to early-Late Glacial ground moraine sheets (Stadia 0-I) (Figure 2, No. 130). In the glaciation-favouring NE exposition of the hills, where Late Glacial hanging glaciers and névé-shields (Stadia III and IV) persisted in the cirque-like hollow forms (○), the High Glacial ground moraine has been removed and laid down in the form of cones (◁ black) at the exits of the hollow forms. At that time the main valley bottom (☐) was already free of ice. (■ I) shows an orographic left lateral moraine ledge (Figure 2, No. 109), probably developed by the Gar Zangbo glacier during the Late Glacial Stadium I. At that time, too, the highest of the three terrace levels (◀ 4) has been deposited in the form of a glaciofluvial side valley filling, i.e., as a classic kame, against the glacier margin of the Gar Zangbo. Accordingly, the corresponding side valley must already have been free of ice. The incision of the kame-accumulation and the development of the terraces linked to it, took place in three phases during the retreat of the Gar Zangbo glacier. They were interrupted by short-term accumulations, so that three terraces could develop (▲). Since the Holocene until today, High Glacial ground moraine material has been washed down in rills from the upper slopes (second ■ from the left) and as small fans laid down on the highest terrace plain (△ black on the very right). The High Glacial (LGM = Stadium 0) glacier level (– –) ran across the ground moraine-covered hills; here (– –) just its verifiable minimum height has been marked. The debris cones, which are obviously built-up from crumblings after deglaciation (△ white), contain Ice Age moraine cores, showing an only thin cover of residual detritus on its surface. (■ near to the left margin) marks ground moraine, which is about to split into earth pyramids. (◓ white) indicates glacigenic flank- and (◓ black) glacigenic ground polish. (Photo M. Kuhle.)

↑*Photo 149.* At a height of ca. 4430 m (aneroid measurement 4270 m asl at high pressure), ca. 12 km the Gar Zangbo (upper Indus valley) up-valley from the locality of Photo 148, taken facing S (Figure 2 below, No. 112; 31°52′ N/80°11′ 30″ E). Ca. 8–12 m-thick limnic sediments (□) occur in the foot area of the orographic left-hand valley side which have been undercut by the Holocene valley bottom and thus have been exposed. They are located up-valley of the end moraine complex of Gar (Figure 2 between Nos.108/110; Photo 148) in the accompanying Late Glacial glacier tongue basin of Stadium IV (for the exact locality see Photo 148 ↓). After the melting of the glacier tongue, the rhythmically layered stillwater sediments have been sedimentated either by a late-Late Glacial impounded glacier lake on the orographic left, or by a late-Late Glacial to postglacial tongue basin lake. Ground moraine, containing large (a good 1 m-long) erratic granite- and quartzite boulders (○) which are isolated from each other, occurs on the base of the stillwater sediments in the immediate underlying bed. (Photo M. Kuhle.)

↑*Photo 147.* Exposure at ca. 4620 m (aneroid measurement at high pressure: 4470 m asl), on the upper slope of the orographic left lateral moraine in the Gar Zangbo (S source branch of the Indus valley) (Figure 2, No. 109). Locality: see Photo 148 (▼). Direction: facing E. Hills, rounded by the ground scouring of the inland ice (◓) are marked in the background at the same place as in Photo 148 (◓ centre, black). (■ black and white on the right) is ground-, i.e., lateral moraine with polymict boulders, edged as well as rounded at the edges, which 'swim' in a fine matrix. (↗) are two erratic granite boulders. The dark components up to fist-size consist of sedimentary rock. The coarse components have been pressed into the very dense ground mass which, because of the clay- and silt portions, has only a small pore volume. (□) is a 25–60 cm-thick sandy-pebbly overlay spread over the moraine slope; since deglaciation its substrate has been washed out from the moraine surface lying above. (■ on the very left) shows the ground moraine surface on the valley bottom, i.e., at a 225–235 m lower height. (Photo M. Kuhle.)



↑*Photo 151.* Taken at ca. 4700 m (aneroid measurement at high pressure: 4540 m asl), 56 km away from the viewpoint of Photo 150, looking up the Gar Zangbo up to its source area (locality: Figure 2 between Nos. 117, 129 and 119; 31°23′ 30″ N/80°30′ 30″ E), facing SSE (left margin) via WNW (centre) up to NE (right margin) over the area of a flat glacial transfluence pass (Photo 150 left of the centre, background; in Figure 2 on the left of No. 118; Photo 152). In this region the slightly 'rolling' or undulating surface is made up by ablation moraine or so-called 'glacial-cover-sand' which has been glaciofluvially washed during the thawing-out of the inland ice (□). (◓ white) are round-polished

← *Photo 150.* At ca. 4450 m (aneroid measurement at high pressure: 4295 m asl); locality: in the centre of Figure 2 between Nos. 110/113; 31°48′ N/80°15′ E; 9 km up-valley (SE) from the locality of Photo 149. Panorama taken facing NE (left margin) via SE (centre) up to SW (right margin). (■ in the foregound) is washed ground moraine with a surficially clotted fine material matrix. (■ black, half-left in the background) marks a Late Glacial (perhaps Stadium IV, Table 1) dumped end moraine. (▲) are fan forms into which dislocated moraine material has been deposited, rich in fine material. This dislocation is the result of Late Glacial mudflows, triggered by the meltwater of persisting glacier remnants and snow patches from the hills above. The prehistoric origin of these fans becomes clear by its dissection which took place during the Holocene through to the present time (right of ▲). (◓) are hill- and mountain ridges rounded by the ground- and flank polishing during the High Glacial (LGM = Stadium 0). (– –) indicates the minimum surface height of the High Glacial inland ice, derived from the relief forms. (△) mark alluvial fans which during the Late Glacial have been accumulated by the meltwater of the hanging glaciers located in the two side valleys above; i.e., these fans are glacier mouth gravel floors (sander). Even today their material is fluvially transported by the temporary discharge of meltwater and precipitation. Above (△), on the root of these fans (on its proximal part), post-High Glacial (i.e., Late Glacial to Holocene) V-shaped valleys have been cut into the glacigenic flank- and ground polish forms (◓) which are arranged transversely (from left to right) to them. (↑) these working edges document that they are younger than the glacier polishing. (9) are mountains rising to a height of up to 6239 m, which are still glaciated (cf. Photo 151). (Photo M. Kuhle.)

mountain ridges, i.e., classically developed roche moutonnée forms (◓ white on the left). (▲) mark exaration rills and -stripes gouged out by the overflowing ice. These rock ridges are covered by ground moraine (the two ■ on the very left) which, as a decimetres- to metres-thick overlay of loose material, has been incised by Holocene to modern microfluviatil rills (▽ white). (△ black) marks a flat Holocene to modern form of an alluvial fan, built up from washed ground moraine since deglaciation. (◓ black) are further, higher mountains rounded by the inland ice and glacigenic flank polishings on the orographical left side. (■ white and black in the background) show the ground moraine covers from their lower slopes as far as their middle-high slope areas. (○) are cirque forms and short valley heads (-backslopes), shaped by cirque- and short valley glaciers during the late-Late Glacial (probably during Stadia III-IV; see Table 1). Up to present-day perennial snow patches exist on the summits of these mountains (at ○ white; date of the exposure: September 2). The landscape development and overall shaping of these mountains is an immediate reminder of the Scandinavian fjells (in the Swedish and Norwegian Scandes), which concern old plain landscapes formed by an at least Pleistocene inland ice, as well. (9) marks up to 6239 m high glaciated mountains. These are the same mountains as shown in Photo 151 (9). (– –) is the minimum surface height of the High Glacial (LGM = Stadium 0) inland ice, the run-off of which followed the Gar Zangbo down to the Indus main valley to the NW (towards the middle of the panorama). (Photo M. Kuhle.)

➞ *Photo 152.* At ca. 4780 m (aneroid measurement at high pressure: 4615 m asl) looking from the transfluence pass (Figure 2 left of No. 118; 10 km E from the viewpoint of Photo 151; 31°21′ N/80°36′ E) facing SE (left margin) via S up to W (right margin). (The two ◓ on the right) are fell-like mountain ridges or 'glacially streamlined hills' polished by the inland ice forming the SE continuation of the mountains shown in Photo 151 (towards the left margin). Here – at a subtropical latitude – perennial snow patches are visible (above ◓ in the centre) as well as in Norway. They are located at heights about 5400 m asl (ca. 600–700 m above the viewpoint). (◓ large, on the left) is an abraded rock ridge in the form of a very flat, broad roche moutonnée which, as well as its environs, is covered by ground moraine (■). Decimetres- to metres-deep microfluviatil rills are cut into its ground moraine mantle (▲). This ground moraine cover as well as the moraine trains which occur on both ends of the hills, i.e., in their flow shadow, put these forms in a genetic relationship with drumlins (Figure 2, Nos. 118, 119). Erratic granite boulders 'swim' in the ground moraine; they are rounded at the edges and facetted (○). Sedimentary bedrock occurs in the underground. The sedimentological condition of the ground moraine matrix can be drawn from Figures 29 and 5 (diagram 02.09.96/1). (**– –**) indicates the minimum surface height of the Ice Age inland ice sheet covering the relief, deduced from the glaciogemorphology shown here. (Photo M. Kuhle.)

← *Photo 153.* From ca. 4640 m (aneroid measurement at high pressure: 4490 m asl), ca. 5 km SE from the locality of Figure 29 and Photo 152, SE of the transfluence pass from the upper Gar Zangbo to the NW source branch of the Langchu Ho valley (Figure 2, No. 118; 31°19′ 30″ N/80°38′ 30″ E). Exposure on a fluvially undercut moraine (■) on the orographic right (SW) side of the northwestern source branch of the Langchu Ho valley, 23 km up-valley of the settlement of Menshih (ONC 1:1 000 000 H-9). In its uppermost 2-4 m the moraine material shows the characteristics of ablation moraine which, as a rule, shows a less dense and at the same time coarser fine material matrix. In addition, a fluvial (glaciofluvial) washing-out occurred in places (□). (○) mark polymict boulders, so, e.g., far-travelled granite boulders (○ white). (Photo M. Kuhle.)

➞ *Photo 155.* At ca. 4380 m (aneroid measurement 4230 m asl) from a viewpoint 13 km SE of the locality of Photo 154, looking across the confluence area of the two source valleys of the Langquen-Zangbo (Langchu Ho valley) and the valley chamber of the settlement of Menshih (Figure 2, No. 121; 31°12′ N/80°48′ E). Direction: facing NW (left margin with the other source branch of the valley coming down from the NW (□ black, on the left) where Photos 153 and 154 have been taken) via N to NW (right margin). In this confluence area, in which the settlement of Menshih (left, just outside of the panorama section) is situated on the river (▲) in the thalweg, ca. 50 m-thick limnic, i.e., glaciolimnic sediments are exposed (□ black). They have been deposited in the late Late Glacial (Stadia III and IV), when an ice-dammed lake occupied the confluence area. This lake had been dammed-up by a remnant of a glacier- or inland ice complex, which blocked the Langqen-Zangbo valley (Langchu Ho, i.e., Xiangquan He) (Figure 2, below No. 129 in the region of Toling). For its sedimentation some hundreds, or at most a few thousands years, were available. The glaciolimnic sediments (□) cover the High Glacial to early-Late Glacial ground moraines (Stadia II, I and 0; Table 1) which overlie the valley bottom. Marginally the ground moraines (■) plunge under the limnic sediments. In parts the main river (▲) and the tributaries adjusted to its level (▽) have removed (□ white), i.e., dissected (□) the limnic sediments. (◓) is a glacigenically abraded triangular-shaped slope, developed from a back-polished 'truncated spur', which has been polished earlier, i.e., for the last time during the High Glacial (LGM). (**– – 0 – –**) is the minimum surface height of the High Glacial (LGM = Stadium 0) inland ice. (Photo M. Kuhle.)


↑ *Photo 154.* Taken at ca. 4500 m (aneroid measurement at high pressure: 4355 m asl), 9 km SE from the viewpoint of Photo 153, from the orographic right side of the NW source branch of the Langqen-Zangbo or Langchu Ho (valley) (12 km NW of the settlement of Menshih; Figure 2 between Nos. 118/119; 31°15′ 30″ N/80°41′ 50″ E), looking over the valley bottom (□ white, centre). Direction: facing NNW (left margin) via N up to NE (right margin). The SW-sloping valley is mainly covered by two types of accumulation. These are Late Glacial lateral- and end moraines of Stadium IV (■) as well as glaciofluvial gravel bodies of Late Glacial meltwater activities of the Glacier Stadia III and IV (□ 1 and 2) (cf. Table 1). The gravel fields of the glacier mouth sanders No. 1, which belong to the youngest Late Glacial ice margin positions (Stadium IV), have been superimposed upon the older deposits of the High Glacial ground moraines (Stadium 0 = LGM) and Late Glacial end moraines of Stadium III, covering them over large parts (□ black and white; Figure 2, Nos. 118/119). No. 2 is a remnant of a glacier gravel floor (sander) of the somewhat older Late Glacial Stadium III (see Table 1) on the base of which gravel floor No. 1 has been accumulated to a thickness of ca. 9–15 m, so that only 5–7 m of No. 2 have remained above (2). During the Holocene the postglacial river system has cut the current valley bottom (□ white, centre) into the youngest Late Glacial gravel floor (□ 1). As a result this gravel floor terrace landform has been developed. (△) is the present-day arm of the main river. The Tibetan nomads with their tents and the yak herd may serve to compare the dimensions of the geomorphological landscape elements described. (○) shows exemplarily one of the S- to SW-exposed hanging valley heads and cirque backslopes from which the late Late Glacial (Stadia III and IV, Table 1) hanging glaciers flowed down to the valley bottom in the middleground (■ IV). (◓) are the glacigenically rounded mountain ridges and valley flank slopes, which at the same time are back-polished mountain spurs ('truncated spurs'). During the High Glacial (Stadium 0 = LGM) they have been formed by the ground- and flank polishing following the valley axis of the relief-covering inland ice. (– – 0) is the minimum surface level of the inland ice derived from the geomorphology of the mountain land. (Photo M. Kuhle.)

→ *Photo 156.* At ca. 4600 m (aneroid measurement at high pressure 4455 m asl), 15 km W from the viewpoint of Photo 155 (Figure 2, No. 128; 31°08′ 10″ N/80°55′ 40″ E) facing NNE (left margin) up to E (right margin) looking at the orographic right flank of the large valley or excavation area NW of the Langa Co and Mapam Yumco or Manasarowa. This valley falls away to the NW (left) and forms the orographic left source branch of the Langquen-Zangbo (cf., Figure 2, No. 122 to below 119). (■) are the local Late Glacial (Stadium III–IV; Table 1) end moraines shown in Figure 2 at No. 128, transported by local SW-exposed valley glaciers from the short, steep hanging valleys or from larger trough valleys (◡) and deposited below cirques, i.e., short trough valley heads (○). (□) marks the ground moraine on the main valley bottom, which simultaneously, i.e., during the Late Glacial, has been washed and reworked by the glaciofluvial meltwaters and covered by gravel floors (sanders). First the glaciers described here and flowing down from the tributary valleys, have accumulated the gravel floor plain (□) outside and then – after the back-melting – also inside the tongue basins which now were free of glaciers. Thus, on its base, the end moraines (■) have been buried by the rising sander gravels. The in parts up to metre-sized granite boulders (●) are washed-out moraine boulders. Owing to the meltwater, which emerged from the glacier mouths of those Late Glacial tributary glaciers concentrated into a 'high energy flow', they might have been transported over a distance from several hundred metres to few kilometres. Corresponding to the late Late Glacial glacier retreat, the meltwater streams have cut into the glaciofluvial gravel floor sediments up to a depth of over 10 m (▽). The still glaciated summits of the mountain chain in the background, reaching up to a height of 6100 m, are hidden by clouds. (**I**) marks a massif, the actual glacier feeding area of which is visible (despite the clouds). (◓ black) are orographical right glacial flank abrasions originating from the time, when the entire excavation area was filled with a large Ice Age glacier flowing down from right to left (from Stadium 0 = LGM to ca. Stadium I; see Table 1). (– –) is the minimum surface height of the High Glacial (LGM) inland ice probable according to the classically rounded mountain ridges (◓ white). (Photo M. Kuhle.)

← *Photo 157.* Taken from ca. 4590 m (aneroid measurement at high pressure 4445 m asl), ca. 14 km up-valley, i.e., SE from the viewpoint of Photo 156 (Figure 2, No. 122; 31°03′20″ N/81°03′ E), facing SW (left margin) via W and N (centre) up to E (right margin). The 20 km-broad excavation area which belongs to the uppermost orographical left (SE) catchment area of the Langquen-Zangbo, is shown here. (**– –**) is the minimum surface height of the glacial inland ice (Stadium 0, Table 1), i.e., the mountain ridges have been polished by the ice, in places causing very heavily- rounded forms (⏶). The trough forms (◡) of the larger cross-valleys (antecedent transverse valleys) partly preserved in a classically-geomorphological clearness, provide evidence for a heavier High- to early-Late Glacial (Stadia 0–II; Table 1) ice flow. (○) is one of the cirque-like hollow moulds, frequently preserved on this SW slope. During the late-Late Glacial (Stadia III–IV; Table 1) glaciers flowed down from these hollow moulds as well as from the adjacent slopes and from the trough valleys (◡) as far as into the middleground, depositing end moraines (■ ■) at about 4650 m asl. Between these two end moraine complexes (■ ■) the glacier tongue end with the glacier mouth was located. The meltwater stream having its source there, has undercut and removed parts of a frontal moraine lying immediately in front of the tongue basin, and has shifted its material as a gravel floor into the further glacier forefield (□). The 'high energy flow' of the meltwater has accumulated sander ridges (on both sides of □ right) with partly metre-long boulders (**I I** white). (△) are 2–5 m-high gravel floor terraces, developed by slight cutting-processes of the meltwater. (▲) is an alluvial- and mudflow fan, laid over Late Glacial (Stadium III–IV) ground moraine. It consists of displaced moraine- and youngest gravel floor material (sander material) which has been deposited from the tributary valley ending above. (**I** black) is an over 6000 m-high massif, currently still glaciated. (Photo M. Kuhle.)

↓*Photo 159.* Taken from ca. 4700 m (aneroid measurement at high pressure: 4550 m asl), 4 km SE from the viewpoint of Photo 158 (Figure 2 between Nos. 122/123; 31°00′ N/80°09′20″ E) towards the ENE (left margin) via E up to SE (right margin), looking across the southern foreland of the Kangrinboqé-Feng chain (Kailash chain). All of the glacigenically-polished, rounded hills and slopes marked with (⏶) are covered by a similar ground moraine (■ background) as it is shown more detailed in the foreground (■). (▾) marks – as one example of numerous flat incisions in the vicinity – microfluvial rills inset from the Holocene until today. Here, the small-scale down-flowing precipitation water has cut decimetres- to few metres-deep into the loose and only slightly resistant material of the ground moraine. (▽) show flat spring pits, developed by processes of saturation in the moraine material below the exit of the spring water. Saturation flows such as these are especially favoured by the great soaking capacity of the ground moraine matrix and the related swelling ability. (**– –** 0 **– –**) is the glacio-geomorphogically deduced minimum surface height of the Ice Age (Stadium 0 = LGM) inland ice, which has almost completely covered the relief. Only the high summits (**I**), undercut at their margins by the glacigenic lateral erosion of the inland ice and thus sharpened to a glacial horn, towered above the inland ice level. This concerns the over 5700 m-high mountains (**I**) which are still glaciated. (Photo M.Kuhle.)


0
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← *Photo 158.* Taken from ca. 4680 m (aneroid measurement at high pressure 4535 m asl), 7 km SE from the viewpoint of Photo 157, about 21 km NW of the Langa Co (31°01′30″ N/81°07′E; Figure 2 on the right above No. 122), looking towards the SW (left margin) via N (centre) to E (right margin) across a ground moraine plain (■) with decimetres-long erratic granite boulders (○). (◓) mark round-polished glacigenic triangular-shaped slopes and back-polished mountain spurs ('truncated spurs') as well as an almost perfectly-rounded roche moutonnée (◓ white, left). The latter is covered with an ground moraine overlay (◓ black on the left), into which microfluvial rills (▼) have been incised by the rainwater running down from above. The much flatter roches moutonnées in the middleground are also mantled by a ground moraine sheet (■ black and white at the back in the middle and half-right). (– – 0 – –) is the geomorphologically reconstructed minimum surface height of the Ice Age inland ice (LGM = Stadium 0; see Table 1), which must have been at least 1000 m-thick here. (**I**) is the position of an over 6000m-high glaciated massif of the at maximum 6660 m-high Kangrinboqé Feng- or Kailash-chain. (Photo M. Kuhle.)

↓ *Photo 161.* Taken from ca. 4575 m (aneroid measurement at high pressure: 4430 m asl), 3 km SE from the viewpoint of Photo 160 (Figure 2 halfway between Nos. 122/123; 30°51′50″ N/81°26′30″ E) facing ENE (left margin) via S with the Gurla Mandhata (1, left of the centre) and WSW (the mountains lie right of the centre) up to NW (right margin) with the Kangrinboqé (Kailash) (2). (■) are ground moraine- and ablation moraine sheets on glacigenically round-polished mountain slopes (◓) and roches moutonnées (◓) in the background as well as on the valley bottoms, i.e., lowest plains of the Tibetan plateau in the foreground. (□) shows drift-cover-sand, i.e., ablation moraine ('ablation till') (developed from out-melted internal moraine), which in the postglacial period has been subaerially washed by sheet floods and therefore presents an accumulation of pebbles as denudation pavement. (△ △) is an orographical left lateral moraine terrace and kame form developed by a side valley glacier flowing down from the N. During the Late Glacial (Stadium III; cf. Table 1) this tributary glacier emerged from the side valley (III), diverging hammerhead-like in the mountain foreland below the side valley exit. (0 – –, – –) indicates the minimum surface height of the High Glacial inland ice (LGM = Stadium 0). The 6660 m-high Kangrinboqé (Kailash) (2) pierced the inland ice surface and towered a few hundred metres above. (Photo M. Kuhle.)


← *Photo 160*. At ca. 4580 m (aneroid measurement 4435 m asl), 28 km SE of the viewpoint of Photo 159 (Figure 2 between Nos. 122/123; 30°53′ N/81°24′30″ E), facing W (left margin) via NW up to NNW (right margin), looking across the SSW foreland of the Kangrinboqé-Feng chain (Kailash chain). This is the decakilometres-broad plain (□) between Kangrinboqé or Kailash in the N, and Gurla Mandhata in the S (Figure 2, between Nos. 127 and 126). (□) shows a glaciofluvial gravel floor (sander) which has been seasonally increasingly reworked by snow- and glacier meltwater since the late-Late Glacial glacier retreat (since ca. Stadia III–IV; see Table 1) through to the present time. Its gravels are shifted and tranported by anastomising streamlets (▽) and – during high water in summer – in the manner of 'braided rivers'. The material primarily available for this process were the uppermost overlays of ground moraine, i.e., ablation moraine or drift-cover-sand, still existing in the underlying bed of these covering gravel floors (□). (▲) is a flat fan form, the underlying bed of which consists of ground- and ablation moraine of a Late Glacial tributary glacier, filling the side valley below the Kangrinboqé (Kailash) (W of the settlement of Dartschen; the valley leads towards the NNE, up to the over 5500 m-high Doelma La (pass)). The surface of the fan is built-up from glaciofluvial gravel floor (sander material). (■) mark the zone where the ablation- and ground moraine cover as well as the drift-cover-sand on the slopes emerges to the actual surface, that is on those mountain slopes on which glaciofluvial gravel covers naturally are absent. These glacial sheets of loose material lie on the glacigenically-rounded orographical right flanks (☗) of the upper Langqen-Zanbgo valley. (○) is a S-exposed cirque-like hollow mould still glaciated in the late-Late Glacial (Stadia III–IV). During the High Glacial (LGM = Stadium 0) the relief-covering inland ice attained a minimum surface height approximately indicated at (0 – –). (Photo M. Kuhle.)


↑ *Photo 164*. Taken at ca. 4800 m (aneroid measurement at high pressure: 4620 m asl), 9.5 km SW from the viewpoint of Photo 162 (Figure 2, No. 125 between the lakes Langa Co and Mapam Yumco = Manasarowa or Mafamut Thso according to ONC 1:1 000 000 H-9; locality: 30°48′ N/81°22′ E) facing NW (left margin) via E and SSE (centre, towards the Manasarowa lake) via SSW (1 = Gurla Mandhata) up to WNW (right margin). The viewpoint is on a ground-, medial- and end moraine complex which, compared with its environs, is at least 170–225 m higher. It consists of separate hills which are several km apart from each other (■ in the fore- and middle ground). (□) is the Manasarowa lake dammed-up in a Late Glacial tongue basin; a further Late Glacial tongue basin lake is the west-adjacent Langa Co (located behind the moraine ridges indicated by the first three (■) in the middleground, seen from the right margin of the panorama). (– –) indicates the minimum surface height of the High Glacial (LGM = Stadium 0) inland ice; the summits of Kangrinboqé Feng (2) (=Kailash, 6660 m-high; cf. Photos 163/165) and Gurla Mandhata (1) (7739 m; cf. Photo 166) towered above it. From these mountains local valley glacier streams flowed down

→ *Photo 162.* At ca. 4575 m (aneroid measurement 4430 m asl), 1 km W from the viewpoint of Photo 161 (Figure 2 between Nos. 122/123) taken towards the WNW (left margin) via NW (**I**) up to NE (right margin) across the SSW slope of the Kangrinboqé (Kailash-) chain. (□) are the ablation moraines with their glacial drift-cover-sands and -silts primarily preserved in the underlying bed. Their surface has first been glaciofluvially washed and then – during the Holocene until to the present time – by the precipitation water as well. (◓) are round-polished glacigenic triangular-shaped slopes developed from back-polished mountain spurs between the side valley mouths. They are covered with ground moraine material (the two white ■ in the centre). (■ III) is an orographic left-hand lateral moraine of a Late Glacial (Stadium III, Table 1) side valley glacier tongue, which has left the side valley and spread hammer-head-like in the foreland (cf. Photo 161 △ III). (▲) are glaciofluvial gravel floor fans deposited through these side valley exits since the retreat of the side valley glacier tongues. They can be described as cone sanders. (– –) is the minimum surface height of the High Glacial (LGM) inland ice which - with the exception of the several hundred metres higher Kangrinboqé (**I**; the 6660 m-high summit is hidden by clouds) has completely covered the relief. (■ black) are end moraine deposits of tributary glaciers which are shown more exactly in Photo 163. (Photo M. Kuhle.)

to the inland ice mass – especially from the 40x40 km extended Gurla Mandhata massif with its several summits. During the early Late Glacial (Stadia I and II, Table 1) the inland ice has melted down and transformed into an ice stream network. Later, during the middle- to late-Late Glacial (Stadium III) it has been resolved into separate foreland glaciers flowing down from the Kangrinboqé Feng-chain and the Gurla Mandhata-massif. These piedmont glaciers which were adjusted from the mountains down to the plateau, have scoured the tongue basins of the Manasarowa lake (□) between the end moraine ridges (the two ■ III in the centre) and Langa Co (lake) W of the end moraine ridges (■ III on the right) into the High- to early-Late Glacial ground- and ablation moraine covers. (■ II) is the ablation moraine surface, i.e., the overlay of drift-cover-sand which, with the back-melting of the ice stream network of Stadium II and the complete deglaciation, has been sedimentated on this ground moraine ridge. For the condition of this ablation moraine see Figure 29 and Figure 5, diagram 02.09./2. (◓) are rock slopes and hills round-polished by the glacier ice, in many places covered with metre-thick ground moraine. (Photo M.Kuhle.)


➞ *Photo 165.* Detail of the panorama shown in Photo 164, taken from the same perspective. Direction: facing NNW to the SSW-slope of the Kangrinboqé- or Kailash-chain. The 6660 m-high summit is its highest mountain (2), rising ca. 800 m above the present-day ELA. (■ II, foreground) marks the ablation moraine, i.e., the drift-cover-sand (between Mapam Yumco and Langa Co; Figure 2, No. 125; see Photo 164 ■ II), sedimentated by deglaciation during the Late Glacial Stadium II (see Table 1). (■ white) is the High Glacial (LGM = Stadium 0) ground moraine plain the surface of which during the Late Glacial to Holocene up to the present time has been glaciofluvially and fluvially washed and at some places has also been buried by gravels. (■ black in the background) are High Glacial ground moraine remnants which remained on the slopes and so are without a gravel cover. These are accumulations which are not to be mistaken as local Late Glacial end moraines – upthrust by valley glaciers of the Kangrinboqé chain –, because they are not located in the valley exits but in a spur-position on the slopes falling away to the mountain foreland (■ black in the background). (◓) are High Glacial flank roundings and glacigenic triangular-shaped slopes (truncated spurs) at many places also mantled with a decimetres- to metres-thick ground moraine sheet. (– –) marks the minimum surface height of the inland ice (LGM = Stadium 0). Several of the lower summits and crests have been sharpened later, i.e., after the deglaciation of the inland ice, by Late Glacial cirque glaciers in the cirque depressions (○). (Photo M.Kuhle.)



⟵ *Photo 163.* A section of the SSW slope of the 6660 m-high Kangrinboqé (2 = Kailash) (shown in Photo 162 from approx. the same direction), built up from flatly-lying, very coarse conglomerate with large gravels (Figure 2 between Nos.125/127). In this exposition its summit superstructure is covered with flank ice up to a height of 5600 m asl. Below – but not visible from this perspective – a glacier tongue flows down half-right from the summit. (■ black, centre and IV) is an end moraine system (also shown in Photo 162 ■ black in the background) which has been upthrust by a side glacier from the glacigenic trough valley (◡). It belongs to the late-Late Glacial (Stadium IV; see Table 1). (■ white) is the ground moraine plain of the mountain foreland overlain by earlier Late Glacial (probably Stadium II) drift-cover-sands and ablation moraine. (◓) show rock roundings and smoothings created by glacier ground- and flank polishings during the High- to early-Late Glacial (Stadia 0-I), on which ground moraine remnants (■ black, right) in some places can still be observed. On the steep rock slopes the prehistoric smoothing is covered by a veil of residual debris which has been developed in situ (above ◡) during the postglacial period. The postglacial precipitation water has eroded flushing rills of a maximum depth of 2–3 m (↗) into the outer slopes of the end moraines. (– –) is the minimum surface height of the LGM inland ice (Stadium 0). (Photo M. Kuhle.)



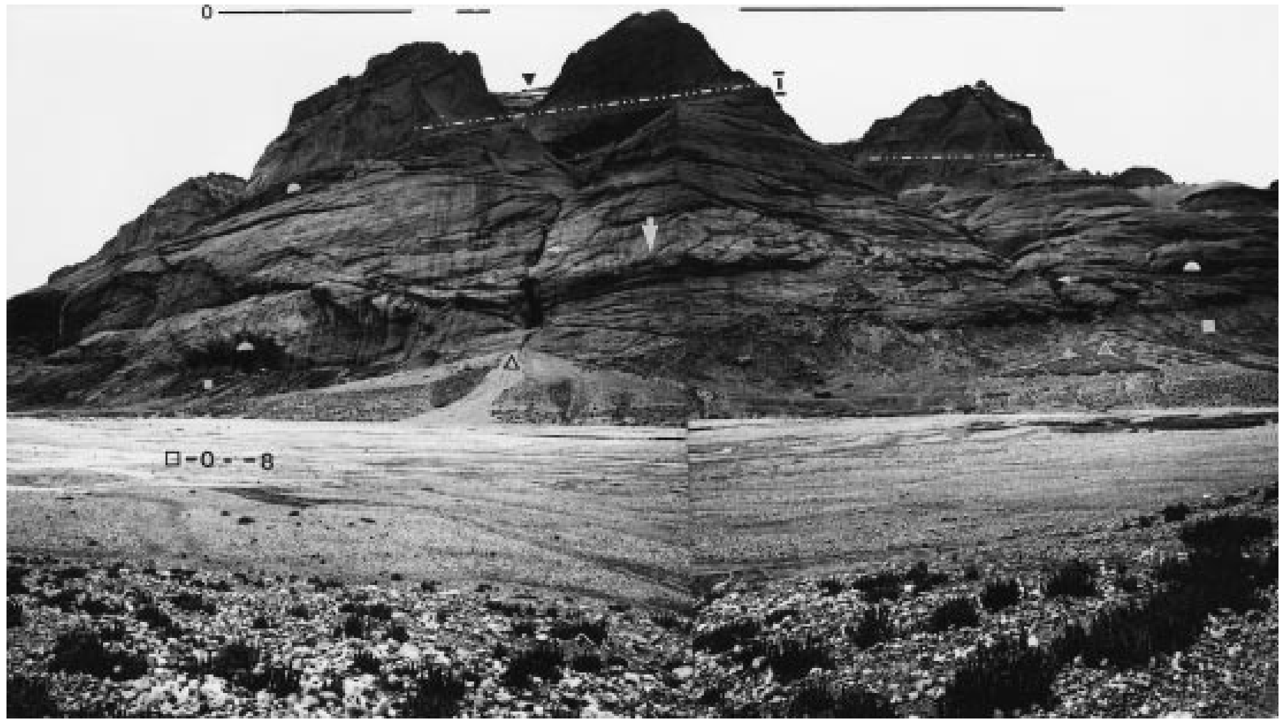

← *Photo 166.* Taken at ca. 4757 m (aneroid measurement at high pressure: 4480 m asl) from the NW shore of the Mapam Yumco, i.e., Manasarowa lake. According to the ONC map 1:1 000 000 H-9 the lake level runs at 4727 m asl (= 15,510 feet). Locality: 30°45′ N/ 81°22′E; direction: NE. (□) is the limnically reshaped ground moraine plain, washed out by the surf of the lake. The lake basin is a late-Late Glacial (Stadium III, Table 1) tongue basin into which the late-Late Glacial to postglacial moraine lake has been filled. It has a NS-extent of 25 km and a WE-extent of 20 km. In this bay its waves were able not only to erode the High- to Late Glacial (Stadium 0 to Stadium III) ground moraine (□ right), but also to develop a shore platform with a gravel cover derived from the moraine, which near to the water line has been accumulated to a lake shore rampart (□ on the left). Where the end moraine ridges and -hills of Stadium III (■ III) fall away to the lake, the shore line has underwashed the moraine, developing a cliffed coast in it (▲ on the left) (Figure 2, No. 125). (▽) are washing-rills, which in a typical manner have been eroded by the rainwater into the loose rock surface of the moraine. (■ black) shows a ground moraine-mantled hill, the moraine cover of which has also been undercut by the lake shore (◀ on the right). (– – and – – 0) is the minimum surface height of the High Glacial (LGM = Stadium 0) inland ice reconstructed with the help of the relief roundings and moraine overlays. (– – 0) marks at the same time the approximate thickness of the ice transfluence over the relief saddle, i.e., a transfluence pass. (○) is one of the cirque forms lined up side by side and flatly set into the summit located to the N, which have been scoured by hanging glaciers since the early-Late Glacial (Stadium 1, Table 1) after the inland ice level has dropped under their level. (Photo M. Kuhle.)

↓ *Photo 167.* From approximately the same viewpoint (shifted 50 m to the S) as in Photo 166, looking to the SE with the lake Mampa Yumco, i.e., Manasarowa (□) at 4727 m, via S (■ white, left of the centre) up to W (right margin). On the very right in the foreground the walls of a monastery are visible, constructed from sedimentary rocks. (■ III) is late-Late Glacial (Stadium III, see Table 1) ground moraine, into which old (subrecent, probably historic) shore lines with a few decimetres-high lake shore ramparts (▼) have been worked. (⋁) is the postglacial course of a stream, developed after deglaciation, which has been eroded into approximately the same ground moraine cover. (○) marks a cattle kraal of yak semi-nomads, made up from air-dried ground moraine bricks. (◓) shows hills of sedimentary bedrock which are abraded and polished by the inland ice. This rock took on the form of a cliff through subglacial undercutting in a meltwater tunnel (⇧). (■ ■) are High- to Late Glacial ground moraine sheets. During the thawing-out of the ice (late Stadium III), the glacier meltwater has worked horizontal lineaments into them, shaped like glaciofluvial erosion ledges (▽). Up to now it cannot be ruled out that these are traces of late-Late Glacial (Stadium IV, see Table 1) lake level positions lying ca. 18–30 m above the current lake level. (– –) points to the minimum surface height of the High Glacial (Stadium 0 = LGM) inland ice. (Photo M. Kuhle.)


← *Photo 169.* At ca. 4630 m (aneroid measurement 4500 m asl) from a viewpoint 5 km further to the NW than that of Photo 168 (31°02′30″ N/81°08′50″ E) also looking to the S in the direction of the Gurla Mandhata (1; Figure 2, No. 126). (■ black and ■ III– IV) is an end moraine (an end moraine outer slope) of the late-Late Glacial Stadia III–IV (see Table 1) bearing large metre-long boulders (○), which has been deposited through the valley coming down from W of the Kangrinboqé leading to the S (Figure 2 between Nos. 122/123:II-IV; see Photo 170). (■ middleground, centre) are the High- to Late Glacial ground- and ablation moraines as well as drift-cover-sands (LGM = Stadium 0 to Stadium III) in the environs of the late-Late Glacial tongue basin lake Langa Co (□). (↗) show stadial end moraines of the late-Late Glacial Stadium III, upthrust from the S by a piedmont glacier of the Gurla Mandhata (1) over the round-polished mountain ridge (◓ centre). (■ in the background on the right and left) are late-Late Glacial moraine accumulations and dislocated material in the form of mudflow fans on the mountain foot and in the foreland of the U-valley exits (∪) of the Gurla Mandhata massif. The shifting of the moraines and the build-up of the mudflows has been caused - and still is - by the meltwaters of the glaciers which still are 7 km-long. (▷) marks an early-Late Glacial moraine remnant at a height of 5700 m (probably Stadia I–II). (◓ ◥) are triangular-shaped slopes ('truncated spurs') back-polished or at least smoothed by the High Glacial (LGM) inland ice (Figure 2, No. 126). (– –) indicates the minimum surface height of the inland ice (Stadium 0 = LGM) reconstructed with geomorphological methods. (Photo M. Kuhle.)

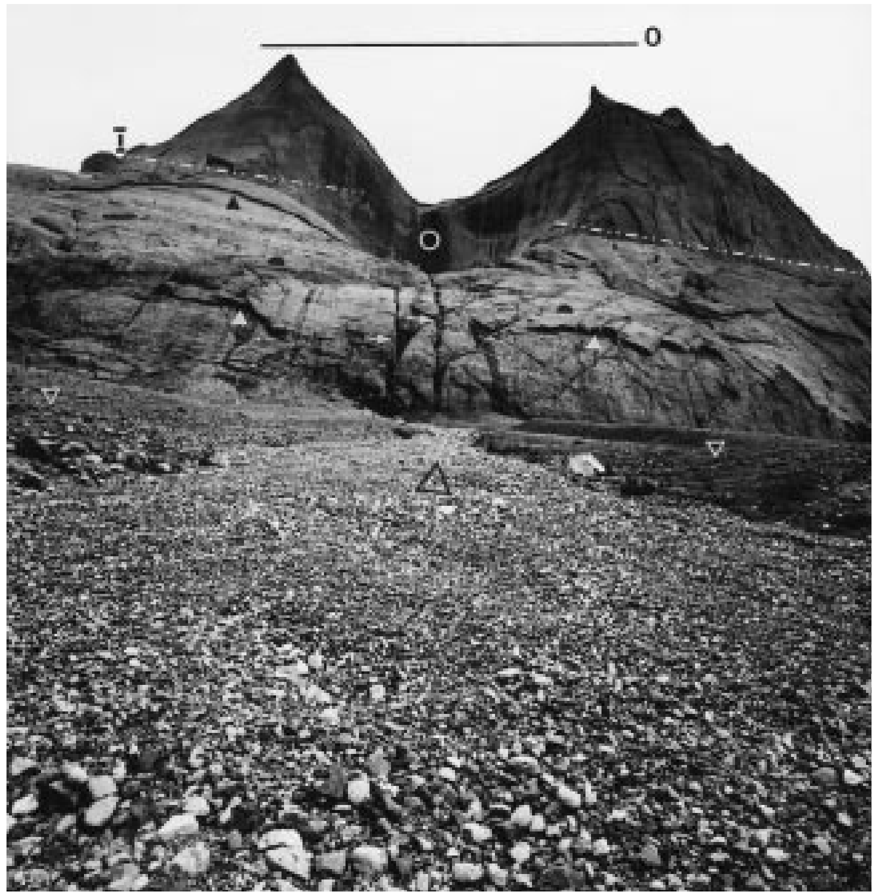


← *Photo 168.* At ca. 4600 m, view from the settlement of Dartschen on the SSW-foot of the Kangrinboqé Feng (Kailash-)chain (31°01′ N/81°11′E; centre of Figure 2 between Nos. 122, 123, 127) facing S to the Gurla Mandhata (1=7739 m; Figure 2, No. 126). From the fore- to middleground extends the here 54 km-broad S Tibetan plateau area, where the lakes Mapam Yumco (Manasarowa lake; see Photos 164, 166, 167) and Langa Co (light stripe below ■ III-IV) are located. The plateau is covered over large parts by High- (Stadium 0 = LGM) to early-Late Glacial (Stadium I and II; see Table 1) ground moraine and an overlay of ablation moraine, i.e., drift-cover-sand (■). (◓ right) is a mountain ridge of slightly metamorphosed sedimentary rock, rounded by the inland ice, also covered with glacigenic sediments of such sort (■). The upper, youngest cover of moraine accumulation, formed by garland-like bulges and ramparts, has been laid down after the melting of the inland ice by a late-Late Glacial (Stadia III–IV, cf. Table 1) piedmont-glacier (■ III–IV) flowing down from the S, i.e., from the Gurla Mandhata massif. This foreland glacier overflowed the roche moutonnée (◓ right) from the S, overlapping it by a number of flat glacier tongues lined up side by side. Their tongue forms can approximately be reconstructed with the help of those ground- and end moraine bulges and -ramparts (■ III–IV). Of course, postglacial reshapings by solifluction covers over permafrost had a modifying and blurring effect as well, but also as a convergence phenomenon. (↗) are microfluvial rills eroded by recent precipitation water, as they are typical of sloping prehistoric moraine plains. (∪) is one of the still glaciated U-valleys leading to the N, from which the late-Late Glacial piedmont glacier substreams – which coalesced in the foreland – had flowed down. (✓) are medial- and lateral moraine remnants developed during Stadium IV (IV) which have been fluvially modified during the postglacial period. (△) show glaciofluvial mudflow fans built up from the late-Late Glacial up to the present time (Stadia IV to XII; Table 1). They consist mainly of late-Late Glacial moraine material which has been washed by the meltwater, reshaped and dislocated. (○) are dislocated late-Late Glacial (Stadium IV) metre-sized moraine boulders as well, laid down in a fan form on the SSW margin of the Kangrinboqé massif. The two (◓) on the left are typical glacially triangular-shaped slopes (‘truncated spurs’; Figure 2, No. 126). (– –) marks the minimum surface height of the High Glacial (LGM) inland ice, above which the Gurla Mandhata main peak (1) has towered ca. 1800 m. (Photo M. Kuhle.)




↑ *Photo 170.* At ca. 4700 m (aneroid measurement: 4575 m asl), taken in the foreland and at the exit of the valley (in the following named 'Kailash-NW-valley') which, – directly NW of the Kangrinboqé Feng (Kailash) – , leads down from the NNE from the southernmost mountain chain of the Gangdise Shan (Figure 2 No. 127) to the SW (31°02′50″ N/81°08′30″ E). Direction: facing S (1 = Gurla Mandhata; cf. Figure 2, No. 126) via W (centre of the panorama) and NNE, up the "Kailash-NW-valley" (◡) up to NE to the lower SW-exposed slopes of the Kailash (Kangrinboqé) (right margin). (■ white) are end moraines of the last-Late Glacial glacier position, i.e., Stadium IV (see Table 1), which have been thrust from the 'Kailash-NW-valley' (◡) to the SW as far as into the mountain foreland. The moraine ramparts are made up from up to metre-long polymict boulders of clay schist, silt- and sandstone, granite as well as from a Kailash-conglomerate containing fist-sized gravel components of a multifarious petrography (○) and a pelitic ground mass. Despite their comparatively young age of ca. 13–14 Ka, several of these round-edged to rounded boulders are split by central radial cracks owing to a weathering in situ (○ right of the centre). (■ black on the right) is the most up-valley and thus youngest stadial remnant of dumped end moraine of this late-Late Glacial Stadium IV. It is adjusted to the glaciofluvially washed ground moraine plain (□) on the bottom of the older Stadial of Stadium IV (accompanying ice margin ■ IV). (↖) is moraine which has been undercut by the actual meltwater river and exposed (below is ground moraine, overlain by ablation moraine as a variant of a dumped end moraine). (■ left, black, in the background) is an older Late- to High Glacial (Stadium III-0) ground- and later lateral moraine complex, the development of which is part of the thawing-out of the overall glaciation of the mountain foreland, i.e., of these lowest plateau areas of S Tibet. (◓ ◤) are mountain ridges rounded by the High Glacial to early-Late Glacial inland ice (Stadia 0-I); this glacigenic rounding occurs on the flanks of the 'Kailash NW-valley' in flatly-lying Kailash-conglomerates (see above) in a structure-dependent stepped form (◓ ◤ right half of the panorama). (◡) is the High- to Late Glacial classic trough form of the 'Kailash NW-valley'. (– –)indicates the minimum surface height of the inland ice during the LGM. (Photo M. Kuhle.)

↑ *Photo 172.* At ca. 4790 m (aneroid measurement 4635 m asl), 0.7 km up-valley from the viewpoint of Photo 171 (31°05′20″ N/ 81°11′50″ E) looking into the orographic right flank of the 'Kailash NW-valley' towards the NW (centre of the panorama). (◓) marks the almost completely preserved flank smoothings up to the level of (– –I), i.e., up to the Late Glacial glacier surface level of Stadium I. During the High Glacial (Stadium 0 = LGM) the minimum surface height (which cannot be recognized from here, but has been reconstructed with the help of the upper polish line on the orographic left (opposite) valley flank) ran even higher (about ca. 400–500 m), namely above the rock knobs and spur peaks (0– –). Above (– –I) the surfaces of the rock faces are markedly rougher, i.e., more heavily destroyed by weathering and crumbling, so that a glacigenic flank polishing is not clearly identifiable. Below (– –I) the same bedrock of coarse-bedded and -grained 'Kailash conglomerate' is preserved in a glacially rounded form which obviously contrasts to the one above (– –I). This can be deduced from the rounded edges of pre- or subglacial crumblings (↓). (⟵) marks sharp gorge-like ravines or gullies. Since deglaciation of the main valley ('Kailash NW-valley') they have been incised by the meltwater of the cirques, which between the Late Glacial Stadia II and IV up to the Holocene neoglacial glacier Stadia V to VII were still glaciated (with regard to the ELA see in detail Table 1). Even today perennial snow patches (▼) do exist in these cirques, so that the gorges (⟵) have been further deepened. (△) are the gravel floor cones accumulated from both gorges, consisting of dislocated and washed moraine material from the cirques. (■) is ground moraine, pressed by the main valley glacier as far as beneath the partly even overhanging and scoured cavettos. (□ –0 to –8) shows the gravel floor which the glacier meltwaters since deglaciation of the valley bottom after the late-Late Glacial Stadium IV have successively deposited in the valley receptacle during Stadia V to XII (neoglacial to historic). Accordingly, it belongs to the glacier mouth gravel floor (sander) Stadia –0 to –8 (see Table 1). (Photo M. Kuhle.)

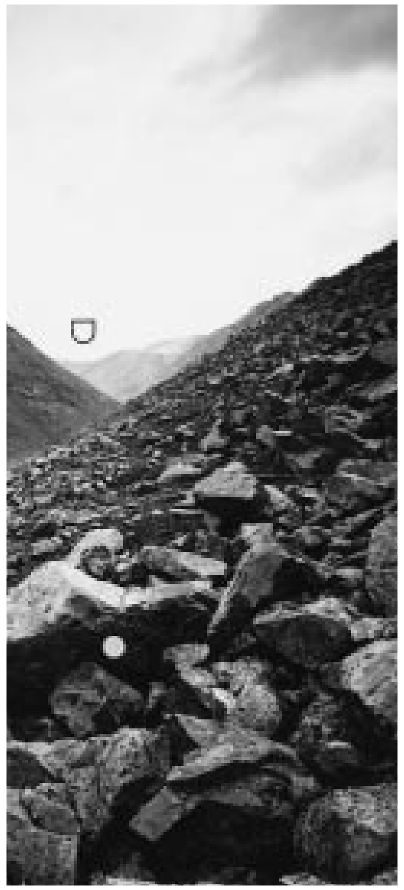

← *Photo 173*. At ca. 4800 m (aneroid measurement 4650 m asl) from approximately the same viewpoint as in Photo 172, looking to the SE into the orographic left flank of the 'Kailash NW-valley'. (◓) indicates the nearly horizontal trough wall, polished by the Late Glacial valley glacier as well as by the inland ice, which in the dip line is convex and consists of coarse Kailash conglomerate. (→) mark the direction of the polishing which accidentally took place in the direction of the edges of the strata of the conglomerate. Since deglaciation the polished rock surfaces are already broken down over large parts: (▲) marks the edges of the breakages. This breaking-off took place scale-like and concordantly to the prehistoric glacier polishings. Thus, even after the breakages, the softly-rounded glacigenic flank form has remained. (→) point to two meltwater gorges, cut vertically to the polish surface into the valley flank. (○) is the NW-exposed cirque from which the glacier- and then the snow meltwater has flowed down from the late-Late Glacial (Stadium IV) up to the early- Neoglacial (Stadium V; cf. Table 1) as far as recently. (→left) shows the focussed stream of a waterfall. (△) is the related actual, temporary stream bed and at the same time a mudflow. Presently the water of the waterfall seeps away on its root. The stream bed, i.e., the mudflow has been developed on a moraine core existing in the underlying bed. (▽ white) is the ground- and lateral moraine material of the Late Glacial valley glacier (Stadia III–IV), which during the Neoglacial has been surficially-washed and removed with the mudflows. (– –I) was an early-Late Glacial glacier level of Stadium I, which has undercut the higher summit walls. During the Holocene (Stadium 0 = LGM) these summits were covered by the inland ice as well (– –0). (Photo M. Kuhle.)

← *Photo 171.* Taken from ca. 4770 m (aneroid measurement 4620 m asl) from the right flank of the 'Kailash NW-valley' (Figure 2 between Nos. 125 and 127), ca. 6 km up-valley from the viewpoint of Photo 170 (31°04′40″ N/81°11′20″ E). Direction: looking from facing SW down-valley (left margin) via NW into the orographic right valley flank (centre) up to NE (right margin) up-valley. The lower slope areas are covered with Late Glacial ground moraine (■) upon which local debris from the valley flanks has been deposited since deglaciation (△). Both the moraine surfaces (■), as well as those overlying debris bodies, are built-up from large portions of coarse boulders (○ ○) as they are typical of the relief energy of this steep high mountains. The up to metre-long boulders (to compare the size see the yak caravan on the very left) consist of local 'Kailash conglomerate' outcropping on the two valley flanks visible, but also from granite components transported over a distance of at least 17 km from the NE source area of this trough valley (◡). Not only the classic trough valley cross-profile (◡), but also the High- to Late Glacial (Stadia 0-III; see Table 1) glacigenic flank polishing (◤ ◥) can clearly be recognized on the rock surfaces of coarse conglomerate. The but thin valley glacier filling of the late-Late Glacial Stadium IV could only abrade the lowest rock surfaces, which are currently covered with loose material over large parts, so that these rock smoothings are not verifiable. (▼) is a typical crumbling on which the structure-independent glacial polishing – since deglaciation without abutment – has vanished because of cleft-controlled rock falls. This crumbling process is accelerated by the characteristic effect of flank polishing which oversteepens the lower slope of the trough valley. (△) are mudflow cones and -fans of glaciofluvially displaced moraine material from hanging valleys and cirques (↓) the glaciation of which persisted because of their height. Up to now they are built-up by snow meltwaters and deposited in the Ice Age trough. (☐ –0 to –8) are glaciofluvial gravel floors, i.e., valley bottom accumulations which are still in the process of development. Since the neoglacial (Holocene) Stadium V they have been acculumated by the meltwater of the glaciers which successively retreated well into the historic time (historical Stadia VII–XI) (see Table 1). They are composed of sands, pebbles and gravels. (– –) indicates the minimum surface height of the inland ice (LGM = Stadium 0) which completely covered the relief visible here. (Photo M. Kuhle.)



↓ *Photo 174.* Taken at ca. 5230 m (aneroid measurement at high pressure: 5070 m asl) from the tongue of the Kailash-NE-glacier (31°06′20" N/81°16′20" E) in the highest valley source area of the S Gangdise Shan (Kangrinboqé Feng-group; Figure 2 in the middle between Nos. 120/123). (●) is the ice of the glacier tongue, mantled by a thin nightly cover of freshly-fallen snow. The tongue is dissected into up to 10 m-high ice pyramids. These ablation forms resulting from the subtropical insolation alternate with ice faces overlain by debris of surface moraine. (○) is the valley head below the 6660 (or 6656) m-high Kangrinboqé (Kailash) (2), where the over 3 km-long valley glacier sets in. (☐ black) is a complete cover of medial- or lateral moraine (with some fresh snow), lying on an orographic left-hand, marginally active glacier component. (■ white, large) is lateral moraine on marginal dead ice, i.e., ice without an actual glacier movement and contact with the current glacier feeding area. Up-valley its surface passes into the inner slope of the lateral moraine (■ VII-X) of the historical Stadia VII- X. (X white) is the relevant end moraine remnant with an age of ca. 180-76 years (= 30 before 1950) (cf. Photo 175; see Table 1). The upper crest of this lateral moraine belongs to moraine (■ VII). (☐ –7) is the glacier mouth gravel floor of Stadium XI, created between ca. 1920 and 1950. It continues under the ice cover of the stream (–7) as far as the glacier end. (■ IV) is a representative late-Late Glacial ground moraine filling (Table 1) of the 5000 m-high trough valleys (◡). (▼) are ground-, i.e., lateral moraine ledges of the main valley crossing from right to left. They also belong to Stadium IV. (◓) are glacigenic roundings of the High- to early-Late Glacial inland ice cover (Stadium 0-I), preserved in a just punctiform manner. Still rarer are correspondingly old, high-lying moraine remnants (■ white, small). (– –0– –) is the minimum surface height of the maximum inland ice cover (0 = LGM). (Photo M. Kuhle.)


← *Photo 175.* Taken at a height of ca. 5100 m (aneroid measurement 4970 m asl) from the valley bottom of the 'Kailash-NE valley' (viewpoint: Photo 174 behind (X) white; 31°07′ N/81°17′ E) towards the SW looking up-valley to the Kailash-NE glacier. (2) is the 6660 m-high Kangrinboqé Feng (Kailash). (– –) indicates the High Glacial (LGM) minimum surface height of the inland ice, which the Kailash-summit (2) has pierced by several hundred metres. (◖ ◗) are remnants of High- to Late Glacial (Stadium 0 to II or III) glacigenic flank polishings which here, i.e., in the vicinity of the actual glaciation, are in particular sparsely preserved. (■) are steep ground moraine slopes. (■ VII) is ground moraine which belongs to the orographic left historical lateral moraine of the 'younger Dhaulagiri Stadium VII' (cf. Table 1). (VIII–X) marks the inner slope of a lateral moraine of the ca. 400–76 years old 'younger Dhaulagiri Stadia VIII, IX and X'. Thus, it belongs to the 'Little Ice Age'. (▽) is the upper margin of this moraine generation, which has been placed in apposition to the older ground moraine (■ VII). (X) is the outer slope of a frontal moraine remnant of Stadium X, which was about 180–76 years ago. (▲) show dead ice complexes on both sides of the active recent glacier tongue, covered by surface moraine. (*l*) marks a supraglacial meltwater stream on the glacier tongue end, which points to its lack of crevasses and runs in a gully between two of its substreams. (□) is a small, ca. 1–3 m-thick gravel floor (sander) of the historical stage, spread by the meltwater over the ground moraine on the valley bottom. (○) are angular rock boulders, which have moved down from the orographic right valley flank since this valley cross profile has been deglaciated. (Photo M. Kuhle.)



← *Photo 176.* At ca. 5150-5200 m (aneroid measurement 5030 m asl) from the exit of the 'Kailash-N-valley' (Figure 2 below No 127; 31°07′10″ N/81°15′50″ E), taken from facing S (left margin) to the N-face of the Kangrinboqé (Kailash; 6660 m) (2) via NW (centre) up to the NE (right margin). (X) is the outer slope of the end moraine rampart, which has been classified as belonging to the 'younger Dhaulagiri Stadium X' (see Table 1) of the Kailash-N-glacier. Accordingly it belongs to the 'Little Ice Age'. (▲) are debris cones which, since the deglaciation of this valley cross-profile formed by the lateral moraine X, have been deposited into the orographic left lateral valley. As can be clearly observed in the foreground, substantial portions of the older, mostly neoglacial (see Table 1) moraine sheets in the area of the side valley inflow into the main valley, consist of up to several metres-long, mainly angular granite boulders (block volume > 50%) (●). This is local moraine from the adjacent rock slopes (◥ ◓). (■) indicate Late Glacial ground moraine remnants on the valley flanks, which contrast markedly with those moraine materials through important proportions of fine material matrix. (△) are mudflow cones which have removed the Late Glacial ground moraine, rich in fine material. They emerge from flat, funnel-shaped, cirque-like forms (○) which, during the late-Late Glacial (Stadium IV), still contained cirque glaciers and in the Neoglacial (Stadia V–'VII) had névé patches, surviving far into the year. Today they hold important masses of winter-snow. The resulting meltwater supply was the cause of the build-up of the mudflow cones (△). (□ black) are ground moraine areas which the meltwater has washed; (□ –0 to –2) is the main valley bottom, covered by a neoglacial gravel floor (sander). The valley cross-profiles show more or less typically glacigenic trough forms (▽). They have been rounded by the Late Glacial ice stream network (Stadium I-III) and High Glacial inland ice as far as the mountain ridges (◥ ◓). (– –) is the minimum surface height of the LGM-inland ice deduced from these glaciogeomorphological indicators. (Photo M. Kuhle.)

↑ *Photo 177.* At ca. 4940 m (aneroid measurement: 4785 m asl) from the orographic left side of the upper 'Kailash-NE-valley' (31°08′ N/81°15′E; Figure 2 below No. 127), panorama taken from facing SW (left margin) down-valley via NW (centre) up to NE (right margin) up-valley. This is a totally glacigenically formed high valley landscape with U-, i.e., trough-shaped valley cross- profiles (▽), polishing bottoms and -flanks (◓ Figure 2, No. 120) and back-polished mountain spurs ('truncated spurs'), located between the side valley exits (◓ left of the centre and further left on top). The black (◓) lying farthest to the right, shows a glacial transfluence (pass) to a valley system adjacent to the E. (■) are Late Glacial- and on its base also High Glacial ground moraine overlays (Stadium 0 to Stadium IV; see Table 1). (▽) mark mudflow fans, which since deglaciation reshape the ground moraine covers from the Holocene up to the present time. (○) are round-edged to facetted, over 0.7 m-long moraine boulders of granite. (□ –0 to –2) is the actual stream bed, running on the glacier mouth gravel floors No. –0 to –2 (see Table 1), accumulated during the Neoglacial (Stadia V–′VII). Despite the in general significant glacier retreat, there are no important dissections up to date. These are the sanders of the side valley glaciers, from which in the Neoglacial existed a larger number, i.e., which were then more extended (see, e.g., Photos 174, 175). (– –0– –) is the minimum surface height of the Ice Age (LGM = Stadium 0) inland ice, derived from the geomorphology. (Photo M. Kuhle.)



↑ *Photo 179.* Taken at ca. 4490 m (aneroid measurement at slight high pressure: 4370 m asl), 10 km NW of the settlement of Menshih, i.e., 2 km SE from the viewpoint of Photo 154 (Figure 2 between 118 and 128; 31°14′50″ N/80°43′40″ E), from the NW source branch of the Lanquen Zangbo. Direction: facing WNW (left margin) up-valley via N (centre) up to NE (right margin) slightly diagonally down-valley. (◓) are up to 5400 m-high round-polished mountains similar to Scandinavian fjells, which the High Glacial (LGM or Stadium 0) inland ice (▬ ▬ = minimum surface height) has covered and reshaped. This summit (○ white) reaches a height about 5600 m asl and has probably pierced the inland ice surface (but this could have also happened only in the Late Glacial), so that is has been sharpened. (◡) are trough valleys, still filled with glaciers during the late-Late Glacial (Stadium IV; see Table 1). (■ IV and ■) mark the accompanying end moraines on the main level of the Tibetan plateau (stretching up to the foregound). (○) are cirques in a S-exposition, which at the same time have been filled with hanging glaciers. (□ 1) are the glaciofluvial gravel floors (sander) No. 1 of the 'glacier mouth gravel floor'-type, belonging to the ice margins (■ IV). At the time of the late-Late Glacial glacier retreat, the dissection of these gravel fields into 15–17 m-high gravel floor terraces has set in (□ 1). Meanwhile this dissection has been brought to an end, since the current river (△) branches out and meanders over a several hundred metres-broad gravel bottom (□ black). (□ white, foreground) is an only 1.2 m high subrecent (historical) terrace remnant with willow vegetation. (Photo M. Kuhle.)

← *Photo 178.* At ca. 4850 m (aneroid measurement 4700 m asl), ca. 2 km down-valley from the viewpoint of Photo 177 in the 'Kailash-NE-valley' (31°07′ N/81°13′30″E; Figure 2 right of No 120), looking downwards. Direction: facing ESE (left margin) via SW (centre) directly down-valley via W up to NNE (right margin) diagonally up-valley. (□ and ■ white) are Late Glacial ground-, i.e., ablation moraines (Stadia III-IV), which by mudflow activities and the meltwater discharge have been surficially dislocated and washed, i.e., modified. (■ IV) is an orographic left-hand lateral moraine ledge of the "Kailash-NE-valley glacier" from the late-Late Glacial Stadium IV. During the Holocene it has partly been integrated into a rock glacier (↓) and dislocated. In this N-exposition at 5000 m asl, the rock glacier (⇩) documents the Holocene orographic minimum height of the permafrost. (△) are active mudflow fans in glacial moraine material, the damp mass movements of which are favoured by the seasonal snow meltwaters. (○) is a flat cirque glacier with the character of a névé shield. Since the Late Glacial deglaciation its meltwater has cut a V-shaped valley profile (▼) into the valley flank, round-polished by the main glacier (◓ black and white on the very left). (●) is a NNE-exposed somewhat larger hanging glacier, the meltwater of which has incised a short, steep gorge (↓) and today still builds-up a glaciofluvial mudflow- and alluvial fan (□ –7 to –8). Accordingly, it has to be classified as sander or gravel floor No. –7 to –8 (cf., Table 1), i.e., as subrecent to contemporary. (□ –0 to –2) is the glaciofluvial gravel floor of Stadia V to ′VII (Table 1) in the area of the main valley thalweg, which has been accumulated during the Neoglacial. (◓) are glacigenic flank polishings in the granite bedrock (◓ on the very left and on the very right) as well as in the 'Kailash conglomerate' (◓ centre and half-right). They extend as far as into the summit area. (– – 0 – –) is the minimum surface height of the inland ice (0 = LGM) deduced from these and also more large-scale glaciogeomorphological arrangements of the positions. (▲) are rounded moraine boulders of granite up to the size of 4.5 × 6 m, lying on the ablation moraine (yak caravan for comparison). (Photo M. Kuhle.)



↓ *Photo 180.* At a height of ca. 4700 m (aneroid measurement: 4570 m asl), 11 km NW from the viewpoint of Photo 179 (23 km NW of the settlement of Menshih; 31°19′30″ N/80°38′ E), SE of the transfluence pass shown in Photo 152 (Figure 2 between Nos. 118/119). Direction: the panorama ranges from facing WNW (left margin) via N (approx. in the centre) up to E (right margin). Ground moraine landscape (■) in the area of a high valley bottom running upwards to a transfluence saddle (left). (■) the ground moraine cover contains erratic granite boulders some decimetres (○ white) to over one metre in length (○ black) which are rounded at the edges to facetted; there are bedrock sedimentary rocks in the underground. The two (◓) on the right are classic roches moutonnées, the flatter luff slopes of which are mantled by several metres-thick ground moraine (■ on the very right). (■ behind, on the left) is a long ground moraine ridge, following the valley incline from the left to the right. This was the final direction of the ice run-off. On these plains the ground moraine (■) shows nearly no overlay of ablation moraine and drift-cover-sand. According to its form and condition, it must have been still covered extensively by glacier ice during the early-Late Glacial (Stadia I and II; see Table 1). (▼) is the only 0.4 m-deep stream bed, which since deglaciation drains the ground moraine plain. (◓ from left to half-right) are glacigenic erosion forms, genetically related to the Scandinavian fjells, which have been rounded by the inland ice. (0 – –) is the minimum surface height of the High Glacial (LGM = Stadium 0) inland ice. (Photo M. Kuhle.)

↑ *Photo 182.* Taken at ca. 4550 m (aneroid measurement: 4415 m asl), 20 km NW of the locality shown in Photo 181 (31°32′ N/80°24′ E), facing N (left margin) via NNE up to E (right margin), looking across the valley bottom into the orographic right flank of the upper Gar Zangbo (Figure 2, Nos. 114/117). The valley bottom consists of glaciofluvial gravel-, pebble- and sand material (☐ white). (▼) is a corresponding late-Late Glacial to postglacial gravel terrace of the same age, into which the current river has cut as far as 4–5 m-deep (below ▼). (■ and■ II) are the Late Glacial end moraines of the tongue basin (II-IV) located to the ENE (see Figure 2 by No. 115. (**/ /**) mark the ca. 15°-steep outwash (sander) slopes or 'Bortensander' (ice marginal ramps = IMRs after Kuhle, 1990a, e) accumulated by the meltwater, which either flowed over the end moraine hills or seeped through it. These are outwash (sander) slopes from washed moraine material, the development of which is connected to the seasonal supraglacial meltwater. (☐ black) are flatter, somewhat older cone sanders which – at a more extended ice margin, lying nearer to the current river course – have been deposited by the meltwater through the glacier mouths. The somewhat younger IMRs are adjusted to their surface. (◁) is a Late Glacial to postglacial alluvial fan, made up of removed moraine- and gravel floor material, which today is dissected (not visible from here). (**– –**0**– –**) is to indicate – in a shifted perspective – a uniform minimum surface level of the inland ice sheet covering the entire relief (Stadium 0 = LGM). (Photo M. Kuhle.)

← *Photo 181.* At ca. 4670 m (aneroid measurement: 4540 m asl), taken 7 km NW of the 4780 m-high transfluence pass shown in Figure 2 on the left below No. 118, which already lies in the upper catchment area of the Gar Zangbo (31°22′ N/80°32′30″ E). Direction: from facing NW (left margin) via NE (centre) up to SE (right margin) looking back to the transfluence pass. (□ black) is a shallow, only a few metres-deep lake in the further high valley area NW of the transfluence pass, which has been developed on the water-retaining ground moraine. (□ white and ■ in the foreground) is ground moraine which, in dependence on the process of down-thawing of the inland ice and the accompanying sorting of fine material by the meltwater, has been covered by ablation moraine, i.e., drift-cover-sand (Figure 2 on the right, below No. 117). (■ background) are end moraines which have been solifluidally rounded and fissured by the precipitation water. From this viewpoint one looks at its outer slopes (■ II–III and ■ on the right). During the Late Glacial (Stadia II or III; see Table 1) they have been upthrust by a local hanging-, i.e., mountain glacier end flowing down from the NE, i.e., from the fjell-mountains (◓). Their material consists mainly of compressed older (Stadium 0 to I or II) ground moraine. (----) is the minimum surface height of the older, i.e., High Glacial inland ice sheet (LGM). (Photo M. Kuhle.)



↓ *Photo 183.* Taken at a height of ca. 4420 m (aneroid measurement: 4275 m asl), ca. 26 km NW from the locality shown in Photo 182, on the valley bottom of the upper Gar Zangbo (31°44′30″ N/ 80°17′ E). Direction: ranging from facing S (left margin) via W (near the centre) up to NNW, looking down the Gar Zangbo valley (right margin). The orographic left valley flank of the Gar Zangbo visible here, consists of mountain ridges, which have been overflowed by the High Glacial inland ice and are thus round-polished (◓). Between these ridges and the glaciofluvial alluvial debris fan on the valley bottom in the foreground (△ black), a 6–9 km broad border of Quaternary moraine- and sander (glaciofluvial gravel-) accumulations (■ and □ white) is located. It forms the current, immediate valley flank. These polyglacial moraines and gravel floors (■ and □ white) have been glaciogeomorphologically remoulded for the last time in the last High- to Late Glacial (Stadium 0 to IV; Table 1). During the High Glacial to early-Late Glacial (Stadium 0 to I) the entire relief was at most covered by the inland ice up to a minimum surface level at (– –0). Thereby the ice body of the Gar Zangbo has reshaped the moraines and gravels of the former ice ages by flank polishing and cloaked them with a ground moraine overlay (■). In the Late Glacial (Stadia I to IV) an ice stream network existed, the tributary glaciers of which were first connected to a Gar Zangbo parent glacier (Stadia I-II) and later (Stadia II-IV) came to an end on the ice-free Gar Zangbo valley bottom (△ black). (■) are three level positions, i.e., surface levels of these tributary glaciers. (▼ black) is the highest of the glacier levels documented here, dammed-up by the Gar Zangbo parent glacier which still existed in early-Late Glacial times (Stadia I–II). (▽ white) is its highest verifiable High Glacial level. The thickness of the parent glacier was already substantially reduced. Accordingly, the meltwater discharge which was adjusted to its surface, has created 6-8°-steep gravel floor ramps, i.e., outwash (sander) slopes (/ \). During the later-Late Glacial (Stadia III-IV) the surfaces of the tributary glaciers have been deepened into these gravel floor- and moraine valleys (for example: ▼ white in the middle – not in the background). (⬀) is an at that time (Stadia III–IV) backward-eroded small meltwater valley. (□ black) show pelite-portions typical of glaciofluvial gravel floors (sander) which, in contrast to pure river gravels, are relatively large. (↑) mark the stillwater sediments shown in Photo 184. (Photo M. Kuhle.)


← *Photo 184.* At a height of ca. 4400 m (aneroid measurement: 4260 m asl), 4 km NW from the viewpoint of Photo 183, looking WNW into the orographic left flank of the Gar Zangbo. Here, the valley bottom of the Gar Zangbo consists of a Late Glacial (Stadia III–IV; see Table 1) glaciofluvial gravel cover (☐ white), deposited over the High- to early-Late Glacial (Stadia 0 to I) ground moraine in the underlying bed. (◁) is an alluvial fan adjusted to this sand plain (☐ white), originating from the glacigenic sediments of the orographic left valley flank (■), which has been developed since deglaciation in the Late Glacial. (▼) mark approximately horizontally arranged lineaments on the ground moraine slopes, created by the flank polishing and abrasion of the Gar Zangbo ice stream (Stadia 0-I) flowing down to the right (NW) (Figure 2 above No. 116). The ground moraine- i.e. ablation moraine cover and the drift-cover-sands (■) lie on polyglacial, older Quaternary (Stadia -I and older; Table 1) loose rocks (= glaciofluvial gravels and moraines), which during the LGM to Late Glacial (Stadia 0 to IV) have been newly reshaped (cf. Photo 183). (↗) are rills, incised by the water of the melted dead ice and the run-off of the precipitation water from the Gar Zangbo glacier since deglaciation. (☐ black) show the rhythmically-layered glaciolimnic sediments, shown in Figure 2 between Nos. 110/112, which are 15–40 m thick. Their overlying layer is partly covered with gravels. The centimetre-fine alternation of beds can be explained by the seasonal fluctuations of the glacier meltwater influx. (☐ black) are the stillwater sediments of either a tongue basin lake in the Late Glacial tongue basin of Gar (Figure 2, No. 108) or of a glacier- and lateral moraine lake, created between the orographic left margin of the Late Glacial Gar Zangbo ice stream – which had dammed it – and the glacier ends reaching down further to the SW (Figure 2, No. 116 and on the left above). (– –0) indicates the LGM minimum surface height of the inland ice. (Photo M. Kuhle.)

→ *Photo 185.* Taken at ca. 4380 m (aneroid measurement: 4240 m asl), 7 km down-valley the Gar Zangbo from the viewpoint of Photo 184 (31°49′30″ N/80°13′30″ E), looking into the orographic left valley flank towards the SW. (☐) are deposits which, because of their rhythmical strata series within a thickness of a few centimetres and the characteristic change from a light-appearing clay fraction to a dark-appearing silt fraction (i.e., change of the depositions during the transitional periods of the year to those at the time of the meltwater maximum in summer), can be considered as being glaciolimnic stillwater sediments. They are nearly horizontal. In the area visible here, the stillwater sediment has been deposited through a side valley (above and behind ⇩) into an orographic left ice-dammed lateral valley lake of the Late Glacial (maximum possible age: Stadium I; youngest age: Stadia II or III; Table 1) Gar Zangbo ice stream. At present, the temporary stream from that side valley has dissected the stillwater sediments (⇩). On the round-polished mountain ridges in the SW background (◓), remnants of ground- and ablation moraine (drift-cover-sands) are located (■). (– –0– –) is the geomorphologically reconstructed minimum surface height of the High Glacial inland ice sheet (Stadium 0 = LGM). (Photo M. Kuhle.)

→ *Photo 187.* Taken at ca. 4350 m (aneroid measurement: 4205 m asl), about 8 km the Gar Zangbo down-valley from the viewpoint of Photo 186, looking into an orographic left side valley towards the W (31°55′ N/80°08′20″ E). Despite the fact, that this is a valley of a structural asymmetry – with the flatter bedding plain slope on the left (left above of ▼) and the steeper slope of the outcropping edges of the strata on the right – the glacigenically trough-shaped cross profile is obvious (Figure 2, No. 109). (⦥) is a classically-concave profile line of a glacigenic cavetto, developed by flank polishing. In addition, the debris cones at the foot of the orographic left flank (△) make the trough valley cross-profile unclear. They show in their core Late Glacial (cf. Stadia III to IV, Table 1) remnants of ground- and lateral moraines, which during the Holocene have been buried by frost debris from the weathering steep wall above (△). (▼) marks the corresponding orographic right late-Late Glacial lateral moraine ledge (Stadium IV = the last Stadium before the final deglaciation of this side valley). On this moraine ledge at the slope foot, slope debris has been accumulated syngenetically (simultaneously with the development of the moraine) as well as in the Postglacial (Holocene) (▼). (◓) are glacigenic rock polishings. (‒ ‒) indicates the deduced local minimum surface height of the relief-covering inland ice (LGM). (■) are remnants of the ground- and ablation moraine overlay. (□ white) marks a 1.8 m-high neoglacial to historic (cf. No. –2 to –5; see Table 1) gravel terrace. (□ black) is the youngest gravel body surface, overflowed in dependence upon the seasons. It contains over 1 m-long polymict moraine boulders which have been fluvially shifted and/or free-washed *in situ* (○). (↓) shows a gorge, incised during the Late Glacial (ca. Stadia I to II) by subglacial meltwater which, due to its hydrostatic pressure and the accompanying cavitation corrasion, has an especially eroding effect. For this an ELA was needed which, compared with the LGM, had already increased by ca. 200-300 m (see Table 1; cf. the ELA of Stadia I and II against Stadium 0). (Photo M. Kuhle.)



← *Photo 186.* From a position at ca. 4420 m (aneroid measurement: 4280 m asl), 7 km down-valley from the viewpoint of Photo 185, looking W into in the orographic left valley flank of the Gar Zangbo (31°52′20″ N/80°10′40″ E). The jeep-road runs over a ground moraine plain rising down-valley, surficially covered with a glaciofluvial polymict pebble- and gravel scatter (□). It leads from the viewpoint to the Late Glacial end moraines (I and III ■) of the tongue basin of Gar (Figure 2, between Nos. 108/110). A characteristic of chronologically-connected ground moraine plains is, that they rise toward the final end moraines in the shape of flat ramps, forming the transition to the actual inner slopes of the end moraines. The hills, which are only in parts clearly glacigenically rounded (◓), have been mantled with ground- and ablation moraine up to at least 250 m above their slope foot level (■). The late-Late Glacial to actual Holocene linear erosion and rill development down the slopes, which - dependent on the down-flowing precipitation water - has been effective only since deglaciation, has chisseled the glacial overlay of loose sediment (↗). (‒ ‒) indicates the minimum surface height of the prehistoric inland ice (LGM). (Photo M. Kuhle.)

← *Photo 188*. From a height of ca. 4340 m (aneroid measurement: 4195 m asl), ca. 10 km down-valley the Gar Zangbo from the viewpoint of Photo 187, looking into the orographic left valley flank (32°00′50″ N/80°08′20″ E). Direction: facing WSW (left margin) via W up to NW (right margin) down the Gar Zangbo. (□ and ■ in the fore- and middleground) are ground- and ablation moraine hills which have been glaciofluvially reshaped since deglaciation in the Late Glacial. They are made up from more or less washed material with substantial portions of polymict, up to 0.6 m-long boulders. Granite boulders are contained which originate from the orographic right Gar Zangbo valley flank. (▽) is a hanging valley with a flat trough cross-profile (Figure 2 between Nos. 106/109). (○) are Late Glacial (cf. Stadium III; Table 1) NE-exposed nivation- and cirque niches. (■ background) marks High- to early-Late Glacial (Stadia 0 to I) ground- and ablation moraine covers as well as drift-cover-sand. (↗) are the characteristic microfluvial rills, set into it during the Holocene. After the glacier ice had left, they have gradually patterned these loose rock overlays in the course of several millennia. (△) show alluvial and mudflow fans, accumulated by the late-Late Glacial to present glacier- and snow meltwaters. They consist of removed moraine (ground-, lateral- and end moraine) and have been laid down on the level of the main valley bottom. (0– –) is the minimum surface height of the prehistoric inland ice (Stadium 0 = LGM), pierced only by the over 5600–5700 m-high summits which are currently still glaciated. (Photo M. Kuhle.)

→ *Photo 189.* At ca. 4250 m (aneroid measurement: 4090 m asl), 33 km down-valley the Gar Zangbo from the viewpoint of Photo 188 (32°16′40″ N/79°59′10″ E), looking into the orographic left main valley flank. Direction: facing NE (left margin) to E (right margin). (□) are sands, interspersed with pebbles, gravels and boulders which, in the form of a cone sander in a late-Late Glacial (Stadia III-IV; Table 1) glaciofluvial gravel floor, have been locally deposited through the valley flank visible. (○) are the accompanying high depressions, cirques and short troughs, containing the glaciers from which the necessary meltwater flowed down. SW-exposed late-Late Glacial hanging glacier tongues have accumulated end moraines of the 'sander root'-type (△). This ramp-like accumulation-type, which on its surface is 8–11° steep, is characteristic of stable ice margins and seasonally supraglacial meltwater discharge. (■) show older ground moraine covers (■ small; Stadium 0) and end moraine complexes of the early-Late Glacial (■large). (⇩) marks veils of wind-blown sand which can be observed at many places. (◓) are glacigenic rock roundings as a result of the ground scouring of the inland ice (Stadium 0 = LGM) (Figure 2 on the left, beside No. 108); and (– –) is the minimum surface height of the ice sheet. (Photo M. Kuhle.)

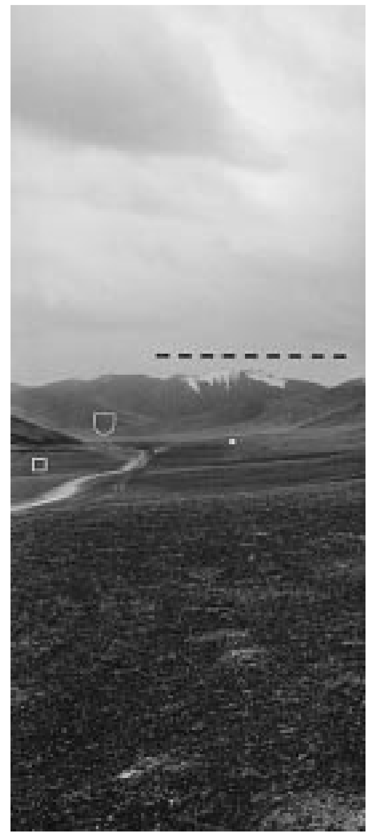
↘ *Photo 191.* Taken at ca. 4260 m (aneroid measurement: 4100 m asl at high pressure) towards the NE, 8 km down the Gar Zangbo valley from the viewpoint of Photos 190/191 (32°19′ N/79°55′30" E), looking into the right flank. Direction: facing N (left margin) up to E (right margin). As shown in Figure 2 left of No. 108, the orographic right flank of this S source branch of the upper Indus valley (Gar Zangbo) is marked by well-preserved glacigenic flank polishing (◓). This concerns ground polishing forms with the characteristics of classic roches moutonnées, i.e., hills with the typical profile lines of roches moutonnées (the three ◓ in the left half of the picture). These roches moutonnées are forms which are combined from three hills with three culminations, separated from each other by slight saddles. They consist of metamorphic sedimentary rocks. (■ black, large, right) is a Late Glacial orographic right lateral moraine, modified to a kame terrace. The remaining smaller (■) show parts of ground- and ablation moraine overlays, deposited during the last-High Glacial (LGM = Stadium 0) up to the early-Late Glacial (Stadium I, Table 1), even at high relief positions. (△) is a fluvial ravine, cut into the ablation moraine after deglaciation. (– –0– –) indicates the minimum surface height of the High Glacial (Stadium 0 = LGM) inland ice, deduced from the glaciogemorphological inventory. (Photo M. Kuhle.)

↑ *Photo 190*. From the same position as in Photo 189, facing N along the orographic left flank of the Gar Zangbo (here also named Kaerh Ho or even upper Indus), looking down-valley. The viewpoint lies on a late-Late Glacial (Stadia III or IV = gravel floor No. 2 or 1; Table 1 gravel field, sander) local orographic right gravel floor fan (□), adjusted to the main valley bottom. (△) are polygenetic accumulations, which on its base cover High- to early-Late Glacial (Stadia 0 to II) ground moraine and contain local lateral- and end moraines (■). The latter have been deposited by local late-Late Glacial, SW-exposed ice cap- and hanging glacier tongues. Their surface forms preserved (△) are kame ramps, which can also be described as end moraines of the 'sander root'-type. They have been left behind by seasonal supraglacial meltwater streams, flowing down from the hanging glacier tongues, in the form of 8° to at maximum 20° steep accumulation ramps. Their surface has been patterned by the course of the streamlets. (◓) are the rock roundings as a result of the High Glacial inland ice- to Late Glacial (Stadium II) ice cap ground scouring. (– –0) is the approx. estimated minimum surface height of the LGM-inland ice, based on this glaciogemorphology. (Photo M. Kuhle.)



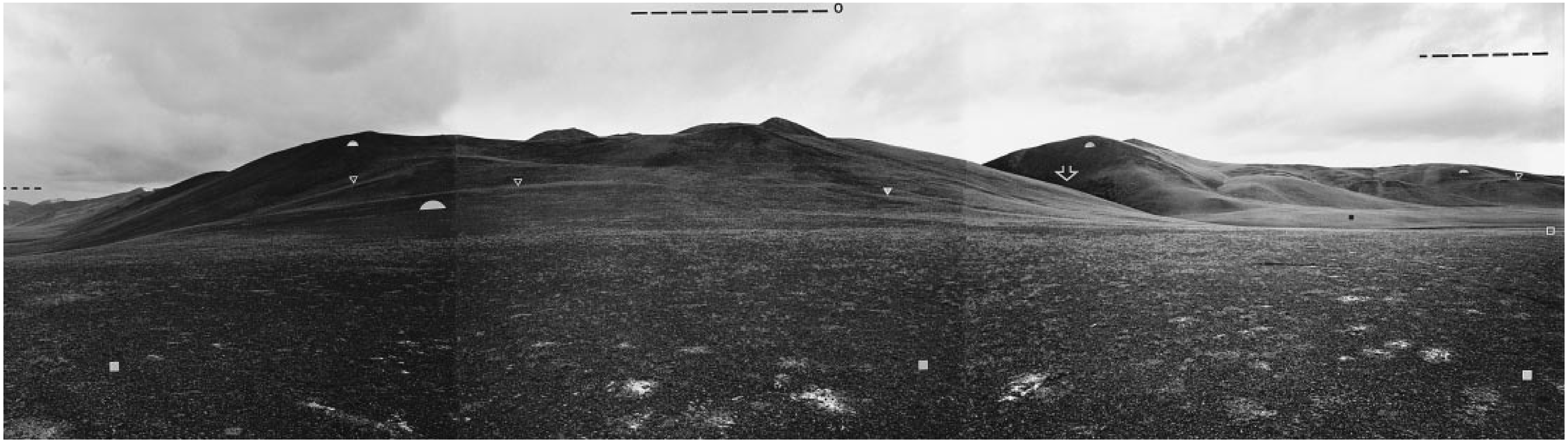
↑ *Photo 192.* At ca. 4220 m (aneroid measurement: 4120 m asl at high pressure; lake level according to ONC 1:1 000 000 G-7: 4218 m), from the easternmost end of the Nako Tso (lake) (33°31′ N/79°55′E; Figure 2 between Nos. 142/143) facing W. During the Ice Age (LGM) the basin of the present-day Nako Tso has been completely filled by glacier ice up to a minimum height of the inland ice surface (– –0– –) at over 5000 m asl - probably even up to ca. 6000 m asl (cf. the Na-K'ot Ts'o area in Figure 32). This is to be evidenced by the round-polished mountains and roches moutonnées (◓) as well as by their ground- and ablation moraine overlays (■) preserved in places. (↗) marks an erratic granite boulder, lying in its formation of ground moraine cover on calcareous sedimentary rocks of the roche moutonnée (◓ white on the left). Since deglaciation the down-flowing precipitation water has cut fresh funnels into the ground moraine material (■), which has been newly deposited in the form of fans at the slope foot (□ left). Limnic undercutting has caused the steepening of the lower slope (■ below). (□ in the foreground) is moraine material, reworked by the lake along its shore line and thus also heavily frost-weathered. The roche moutonnée from limestone in the centre of the photo forms a small island in the lake (◓ white on the right). With its Holocene to current shore line the lake has undercut the soft slopes of this glacially rounded hill (⇧). This confirms that the Ice Age glacigenic morphological regime has been relieved by a postglacial limnic one and the lake is of a postglacial age. (Photo M. Kuhle.)

↑*Photo 193.* 5 km N from the locality of Photo 192, again at the E-end of the lake Nako Tso – located towards Central Tibet, several hundred metres away from its current shore line, this large erratic granite boulder (○) has been deposited by the inland ice. Locality: 4225 m asl; 33°33′ N/79°57′E; Figure 2 between Nos. 142/143. Direction: facing E (left margin) up to S (right margin). Here we are in the lowest (Figure 32: Na-K'ot Ts'o) and most arid area of Central W-Tibet. (↗↙) mark further depositions of erratic boulders on the highest slope sections of the ridge, completely overthrust by the ice (◓ left). They are incorporated into a ground moraine cover (■), lying on metamorphic bedrock (▼), from which the local glacially streamlined mountain ridges (◓) are built up. Late Glacial and postglacial slope gorges (▼) and grooves (▼) have been cut into the bedrock. (△) are small flat fans consisting of ground- and ablation moraine removed after deglaciation. (– – 0 – –) mark the Ice Age (LGM) minimum surface height of the ice completely covering the relief, which probably ran at ca. 6000 m asl (0– – on the right) (cf. Figure 32: Na-K'ot T'so area). (Photo M. Kuhle.)



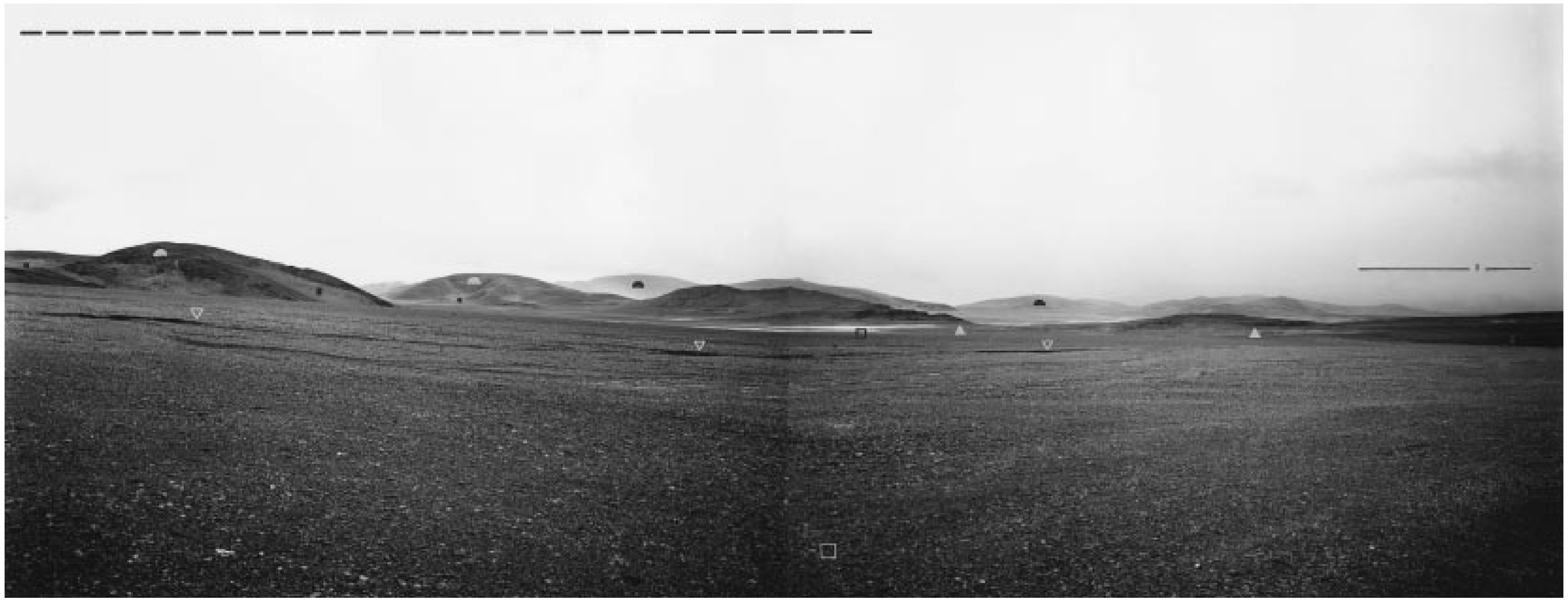
→ *Photo 194.* At ca. 5300 m (aneroid measurement: 5250 m asl) on a first pass 4 km S of the 5350 m-main pass, on the caravan route from Rutog to Haji Langa in the Aksai Chin area, NNE of the E-end of the Nako Tso (locality in Photo 193) which is 159 km away (Figure 2 S of the 5350 m-main pass between Nos. 157 and 155; 34°18′50" N/80°23′E). Directions: from facing S (left margin) via W (centre) up to N (right margin). The solid rocks under the ground moraine 'veil' (■) consist of red sandstone which, as a part of the local moraine, has caused the red colour of the ground moraine matrix. The trough valley leading down to the S (⬡) contains 1–4 m-thick local debris components, washed and sorted by the meltwater, which cover the rock ground as a flatly-inset (thin) glaciofluvial valley bottom (☐ left). Ground- and ablation moraine also takes part in this covering (■ at the back, on the very left). The mountain ridges bordering this pass in the W, have been polished and rounded by the inland ice flowing over them from N (right) to S (left) (◓). The edges and ledges (▽) dependent on the structure of the sedimentary bedrocks have been gouged out and left behind by the ground souring of the ice as a characteristic glaciogemorphologically streamlined interference phenomenon. During the Late Glacial the prehistoric inland ice landscape had already been locally dissected into large grooves ('spill ways') (⇩) by the meltwater under the thawing ice. (☐ right) marks a postglacial fluvial thalweg with a very thin gravel floor, attaining a few decimetres up to ca. 1.5 m. The development of this thalweg has been brought about by an incline out of that 'spill way' (⇩) as a later consequential form. (▼) is a Holocene to historic solifluction tongue. (– –0– –) is the minimum surface height of the prehistoric inland ice (Stadium 0 = LGM); (– – left) shows, that the ice has mantled the 6000 m-high truncated mountain forms, which today are still slightly glaciated or covered with perennial snow patches and fresh summer (monsoonal) snow (in September). (Photo M. Kuhle.)


↑ *Photo 195*. At ca. 5100 m (according to ONC 1:1 000 000 G-7; aneroid measurement: 4985 m asl), ca. 20 km N from the locality in Photo 194, looking across the area of the S Aksai Chin (Figure 2 between Nos. 157/155; 34°28′ N/80°23′ E). Direction: facing SSW (left margin) via NW (centre) up to N (right margin). The ca. 6100 m-high summit (No. 8) still shows hanging- and cirque glaciers in its N to NE exposition. During the late Late Glacial (Stadium IV, Table 1) and Neoglacial (Stadia V–’VII) up to the historic and present time (Stadia VII–XII) its form, rounded during the LGM, has been sharpened by the youngest, i.e., postglacial glaciation. (◓) are round-polished mountain ridges of reddish sedimentary rocks, which have not newly been sharpened by a later glaciation. (The two ■ left) mark a ground moraine veil largely consisting of local moraine. (⇩) shows the upper base of far-travelled, i.e., erratic, light-grey ground moraine, lying on the reddish (darker) bedrock sandstone. Currently it is being shifted solifluidally down this 14°-slope. (■ right) is a ground moraine plain with up to 1.4 m-long granite boulders. The temporarily stagnant water at this place has led to the development of periglacial earth hummocks and related processes of frost-lifting (⌓). (▼) is a V-shape, fluvially incut by subglacial meltwater during the Late Glacial and the thawing of the inland ice. It has been set as a perfect edge into the soft glacigenic ground polishing forms. (– – 0 – –) is the minimum surface level of the inland ice (LGM) derivable from the relief and glacigenic sediments. (Photo M. Kuhle.)

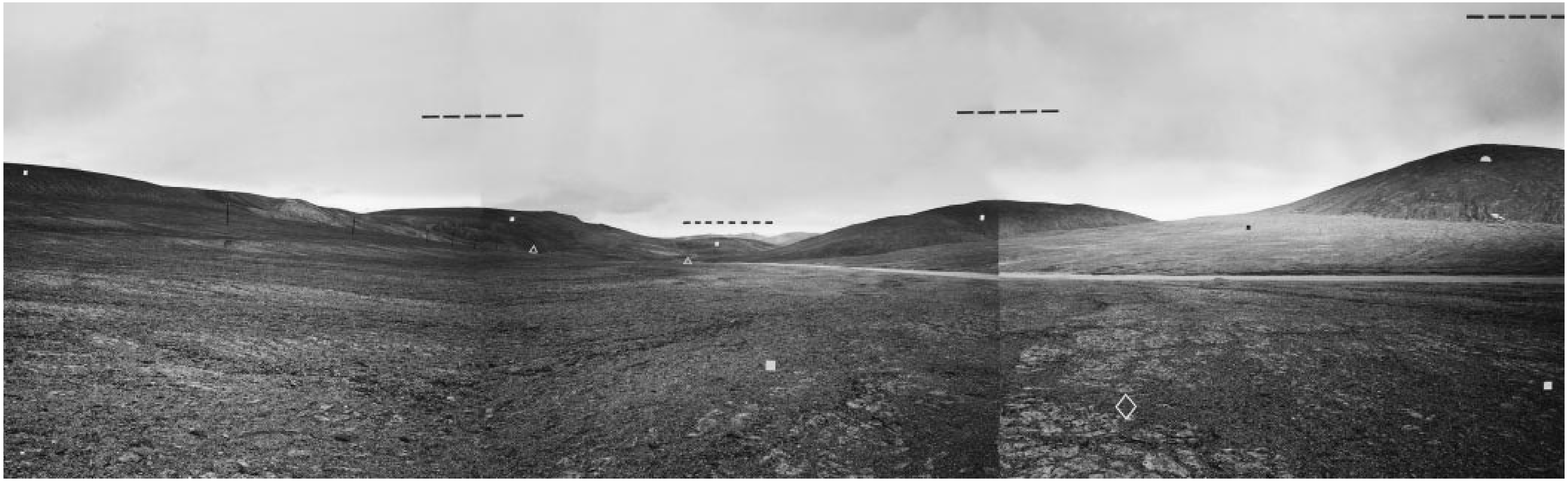


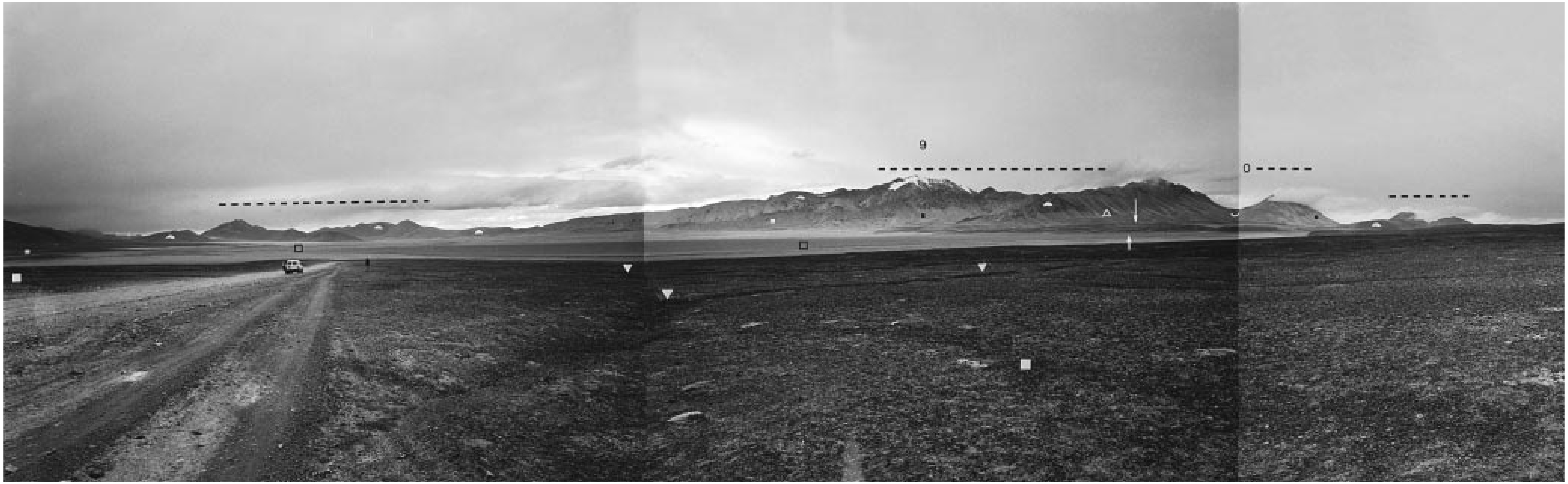
▲ *Photo 196.* At ca. 5250 m (aneroid measurement: 4945 m asl), 9 km N from the locality of Photo 195, looking across the lake basin of the Tso Kaer Hu (ONC 1:1 000 000 G-7) or Longmu Co, which is a 17 km W–E extending residual lake without outlet (☐ black) in the S Aksai Chin area. Lake level: 5218 m (according to ONC G-7) (Figure 2 below No. 159; 34°33′30" N/ 80°23′30" E). Van Campo and Gasse (1993) indicate a lake level at 5008 m asl and a lake surface of 98.7 km$^2$. Directions from a viewpoint above the S lake shore: facing WSW (left margin) via N and E (left and right of the centre) up to SE (right margin). (☐ white) is ground moraine, reshaped by the Late Glacial to late Late Glacial (cf. Stadia III–IV; Table 1) lake. (▼) show the prehistoric lake shore lines, developed up to 130 m higher up. At least five lake level positions can clearly be differentiated with the help of surf terraces: at a height of ca. 5 m and ca. 15 m (▼ black, right of the centre); at ca. 77 m (▼ black, left of the centre), at ca. 90 m (▼ black and white, further to the left) and at ca. 100 m (▼ white on the very left) above the actual lake level. Van Campo and Gasse (1993) have classified the lake sediments of the 100 m-terrace as being from 7290 ± 200 y BP; those of the next lower, 90 m-terrace as being from 7520 ± 400 y BP and those of the – according to the author – ca. 77 m-high terrace as being younger than ca. 6000 y BP. (▽) is a fresh gully created by the recent glacier meltwater of mountain No. 8 in Photo 195, which has been inset at the lowering of the lake level during the Holocene as far as into the historic time. (⏶) are hills and mountain ridges round-polished by the High Glacial to Late Glacial (Stadia 0 to ca. II; cf. Table 1) inland ice on which ground- and ablation moraine is preserved in many places (■). (– –0– –) is the glaciogeomorphologically reconstructed minimum surface height of the inland ice (LGM). (Photo M. Kuhle.)

↓ *Photo 197.* Taken at ca. 5150-5250 m (aneroid measurement: 5005 m asl), ca. 14 route-km NW from the viewpoint of Photo 196, W of the Tso Kaer Hu, looking across the roche moutonnée landscape (⏶) of the central Aksai Chin (Figure 2 below No. 159; 34°38′ N/ 80°19′ E). Direction: facing WNW (left margin) via NNW (left of the centre) up to NE (right margin). (■) are ground moraine remnants left behind in niches of the roches moutonnées (⏶), in the flow shadow of the inland ice. They consist of far-travelled, light material which – even at a distance – can be diagnosed as being erratic, because it overlies much darker sedimentary- and phyllite bedrock (⏶). Accordingly, the material cannot be understood as local slope debris. The ground moraine (■) shows no large boulders here. (☐ white) marks ground- and ablation moraine with substantial portions of pebbly local moraine components, washed out by a prehistoric lake in the area of its shifting shore line. (☐ black) is a small residual lake to which the fresh seasonal streamlets of snow meltwater (▽) lead down. (▲) are at least six distinguishable cliffs, worked into the sedimentary rocks by the late Late Glacial shore lines. Their development and the accompanying limnical undercutting of the older (High- to Late Glacial, i.e., Stadia 0 to II or III) roches moutonnées (▲) were a result of the very intensive frost weathering along the shore line and the horizontal pressure effect of the winter ice cover on the lake. Thus, a very short-term development was possible. (– –0– –) is the approximate height of the inland ice surface needed to explain this relief. (Photo M. Kuhle.)



↓*Photo 198.* At ca. 5400 m (aneroid measurement: 5185 m asl), from the highest pass crossed from S to N by the caravan route over the Aksai Chin, taken ca. 14 route-km NW from the locality of Photo 197 (Figure 2, No. 161; 34°41′50" N/80°14′ E). Direction: from facing NE (left margin) via E and SE (centre) up to SSW (right margin). A landscape of inland ice ground scouring, that is to say here at this hilly relief: a roches moutonnées landscape (◓). The roches moutonnées consist of sedimentary bedrock (sand-, silt- and clay stone). They are in part covered by ground moraine (■ white). Far-travelled moraine material is mixed up with local moraine material. Down-slope towards the depressions, the thickness of the ground moraine increases to a maximum of several metres (■ white foreground and ■ black). (◇) are Holocene to modern periglacially frost-patterned bottoms which have cryoturbately remoulded the ground moraine. Their fine earth beds show the clayey moraine matrix. Vegetation is already completely absent at this altitudinal level of Tibet. (↗ left) are microfluvial rills incut by the seasonal snow meltwater into the ground moraine since the late Late Glacial (ca. Stadia III-IV; cf. Table 1) deglaciation through to the present time. (↖ right) are small mudflows typical of temporarily waterlogged and thus up-swelling ground moraine substrate. (△△) are flat small V-shaped valleys created by the glacier meltwater during the final phase of the late Late Glacial deglaciation. (– –) marks the perspectively staggered minimum surface height of the inland ice, deduced from this relief form. (Photo M. Kuhle.)

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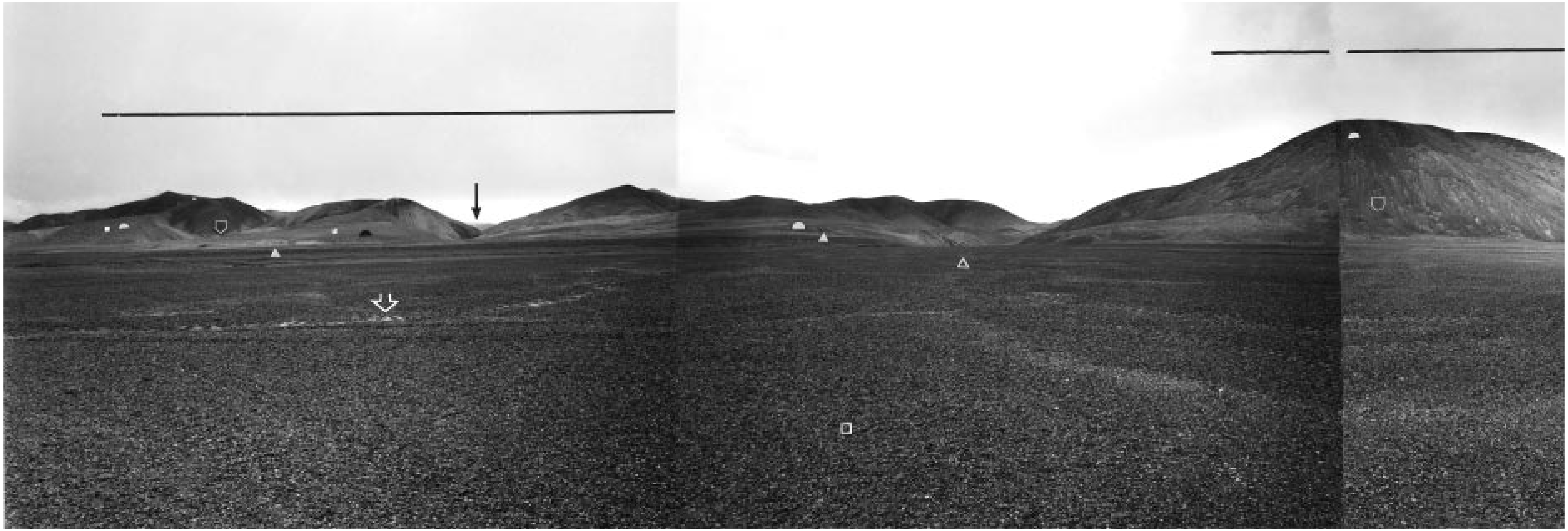

← *Photo 199.* Taken at ca. 5400 m (aneroid measurement: 5230 m asl) from ca. 3 km WNW of the locality of Photo 198, in the area of the ca. 5400 m-pass (Figure 2, No. 161) over the Aksai Chin, somewhat NW of its culmination (34°43′10" N/80°12′ E). Directions: from facing WNW (left margin) via N and E (on both sides of the centre) up to ESE (right margin). (□) mark a lake basin, in which a nearly round lake has remained, being 4 km in diameter (□ right). Behind, a ca. WNW–ESE-stretching mountain massif rises up to 6480 m (No. 9). It is still locally glaciated. During the High Glacial (LGM = Stadium 0) it has been completely covered by the inland ice, the minimum surface height of which (– – 0 – –) is confirmed by the rounding of the mountains (◓) (Figure 2, No. 162). Summit No. 9, however, already towered above the inland ice cover during the Late Glacial (cf. since Stadium I; cf. Table 1) and thus has been sharpened into an approximate glacial horn (Figure 2, below No. 161). (■) is the glacial ground- and ablation moraine sheet preserved from the lake basin as far as up the slopes. (▼) show tundra polygons (frost wedge- or frost crack polygons), i.e., postglacial permafrost indicators. They are typical of the Arctic, mostly developing there in ground moraine as well. (◡) is a classically glacigenic transfluence pass, evidenced by the trough-profile. (↓) are classic indicators of ground scouring in the form of exaration rills gouged into a roche moutonnée. (↑) points to a postglacial cliff, marginally undercutting this roche moutonnée. (△) are cone forms only a few metres-thick, consisting of Ice Age ground moraine shifted down-slope and a thin cover of frost debris. (Photo M. Kuhle.)

← *Photo 200.* At ca. 5200–5250 m (aneroid measurement: 5000 m asl), ca. 4.5 km NW from the viewpoint of Photo 199, from the SW margin of the same up-silted lake basin (Figure 2, Nos. 162-163; 34°44′40" N/ 80°08′30" E). Directions: facing SSW (left margin) via W (left of the centre) up to NW (right margin). This very high Tibetan plateau landscape of the Aksai Chin-Lingzi Thang, where vegetation is completely absent, is marked by rounded mountain- and hill ridges (◓ right) from sedimentary bedrocks (silt- and sandstone). Several of the slopes are lineated by exaration rills or -furrows, arranged crossways to the incline (◓ black and white, centre), as defined for classically glacigenic ground- and flank polishing characteristics. A light erratic ground moraine overlay (■) occurs on the dark bedrock in the underlying bed (⇩). This ground moraine has been exposed by microfluvial rills (▲ right) and fluvial lateral erosion (▲ left). Some slopes have been relieved from the ground moraine by flushing (⇩). Down-slope transport can also be evidenced by solifluction forms (◡). (△) is a flat alluvial fan, developed by a temporary stream through the side valley. It consists of washed and slightly shifted ground moraine. (⇓) shows the clayey ground moraine matrix. (↓) is a late Late Glacial spillway (probably Stadia III–IV). Its V-shape in this rock threshold results from a sudden, very heavy glacier lake outbreak into an adjacent lake basin. (– –) is the minimum surface height of the High- to early Late Glacial inland ice (LGM = Stadium 0 to Stadium I or even II; cf. up-lift of the ELA during this sequence of Stadia), derived from the glaciogeomorphology. (Photo M. Kuhle.)

accumulated at the foot of the valley slope. Not only are smooth, round-polished rock faces of valley flanks covered by this ground moraine, but also rough glacigenic rock areas with slip-off slopes are wearing such a veil-like ground moraine cover. Despite the rinsing, this 'ground moraine veil' has been preserved very well because of the roughness of the underground. As a glacial lubricant it might have even reduced and in part prevented the increased smoothing of the rocks by glacier polishing. Ground moraine covers of this kind have also been mapped on the valley flanks of the upper Yarkand valley as far as 800 and more metres above the thalweg (Figure 2, Nos. 186 and 188).

## 9. Conclusions from the field data presented here with regard to the overall picture of the Ice Age glaciation of Tibet and the surface-efficiency of the ELA depression for this glaciation

The investigation area treated is shown in Figure 1, No. 20. The results of the field work are shown in Figure 2. The glaciogemorphological and glaciogeological indicators Nos. 1–189 provide evidence for an inland glaciation which has completely covered Central- and W Tibet and in many places was more than 1000–1400 m thick. Figures 10, 19, 32 and 35 present cross-profiles of the inland ice with sections of the research area concerned (Figure 1, No. 20). This is area I2 between Mt. Everest in the SE and above the Karakorum in the NW in Figure 12. The inland ice area indicated in Figure 12 as I2, which – according to earlier results from surrounding areas under investigation by the author (Kuhle, 1982–1997b) – has been interpolated as an inland ice sheet, is confirmed by these new field observations. The Central- to W Tibetan Ice Age (LGM) inland ice areas concerned and their extended outlet glaciers which in the S flowed down through the Himalaya, and in the NW from the edge of the plateau into the valleys of the Kuenlun, were situated in the precipitation shadow of the Himalaya and Karakorum. Today they are part of the most arid regions of the whole of Tibet. This suggests, that – in order to develop an inland ice – Tibet must have been either colder and more humid or very much colder than at present.

In order to make clear in which way the build-up of the ice has taken place during the uplift of Tibet, i.e., at the lowering of the ELA against the relief surface, two Central-Tibetan test areas have been chosen (Figures 36 and 37). Figures 36 and 37 concern sections of the investigation areas Nos. 4, 9 and 11 (Figure 1) (cf. Figures 12 and 35). In test area Tibet 8 (Figure 36) the highest summit towering above the Tibetan plateau rises to 6986 m, the one of test area Tibet 12 (Figure 37) is 6928 m high. These are the highest elevations in the glacier feeding areas. The Tibetan high plain extends between 3353 m, i.e., 4542 m asl and those summits in these test areas. ELA = 5700 m (Figure 36) and ELA = 5900 m (Figure 37) are the particular modern snow line altitudes. ELA-893 and ELA-5759 indicate the current surfaces of the glacier feeding areas (in km$^2$), lying above these snow lines. ELA-600 shows the particular increase in the glacier feeding area at an ELA-depression by 600 m relative to present-day conditions, or at an uplift of Tibet (i.e., of the entire relief) by 600 m, and ELA-600: 21146 and 47593 indicate the extent of the feeding areas (in km$^2$), which are pertinent to the particular test areas. ELA-1200 shows the increase in the glacier feeding area at an uplift of 1200 m; the pertinent surface dimensions concern the feeding areas which result from the uplift. The related surfaces of glacier ablation enlarged the total area of the glacier surfaces by ca. half of these feeding area surfaces. In comparison with the total basal surface of the test areas it becomes obvious that at ca. ELA-800 to ELA-1200 the test areas have been completely covered with ice. ELA-600 corresponds to a snow line depression by 600 m and ELA-1200 by 1200 m, compared with the present-day relief. The snow line depression by 600 m occurred for the last time during the late Late Glacial (Stadium IV) and the depression by 1200 m (to 1300 m; see Table 1) during the Last High Glacial (LGM; Stadium 0; Würm) (cf. Kuhle, 1997b, Figure 45, p. 119).

## 10. The global-climatic importance of the Tibetan Ice and its function as a trigger for the Quaternary Ice Ages – an Ice Age hypothesis (in a very simplified and schematized way)

In consequence of the subduction of the Indian subcontinent under the Eurasian plate, Tibet has been uplifted above the snow line and completely glaciated step by step for the first time during the early Pleistocene (maximum as in Figure 12) (Kuhle, 1987d, 1988). This process of glaciation becomes understandable with the help of Figures 36 and 37 by way of the test areas under investigation here. The uplift of Tibet as one of the great events of the earth's history coincides with the onset of the Ice Age 5.5 to 2.5 million years ago (Flohn, 1988, pp. 181f). It has triggered the build-up of the Nordic lowland ices by the initial glaciation of Tibet and in consequence the true High Glacial. The névé surfaces of the Tibetan ice reflected 85% – in part even more than 90% (measurements at 6500–6650 m asl on the Mt. Everest N slope after Kuhle, 1987d, 1989; Kuhle and Jacobsen, 1988) – of the incoming radiation energy, whilst debris surfaces transform 80–85% of this global radiation into long-wave heat-radiation, heating the atmosphere. Therefore the absolute amount with which a given ice surface intervenes in the heat balance of the earth is the greater, the nearer it is situated to the equator and the higher its altitude lies above sea level. At an incoming radiation of 1000–1300 W/m$^2$ (on average 1180 W/m$^2$) at 6000 m asl and 30° N (Mt. Everest N slope), the negative effect on the heat balance is at least four times that of a glaciation at 60° N at sea level (Kuhle, 1987d, 1989). Thus, the Tibetan inland ice with an extent of ca. 2.4 million km$^2$ (Figure 12) and a surface reaching altitudes of 5000 to 7000 m asl (Figures 10, 19, 32 and 35) between 27 and 40° (the position of the N Sahara and the Mediterranean Sea), has caused an albedo-dependent energy loss of considerable dimensions (Kuhle, 1985c–1994b). Out of the albedo-dependent energy loss of the earth-atmosphere of at least 10% of the global radiation, calculated for the worldwide total area of the Last Glacial (LGM) glaciers, already 32% (i.e., one third of the total loss) falls to the loss that was induced by the uplift of the Tibetan inland ice (Bielefeld, 1993, pp. 99ff). According to the discontinuing relationship between the depression of the ELA into the relief, i.e., uplift of the relief above the ELA and the resulting glaciation area, every topography has a characteristic graph of its glaciation potential (Figures 38, 36, 37). With regard to the Tibetan upland and its marginal mountain ranges, the following exponential course of the graph is derived: according to an ELA depression of 1400 m – as it is the case at present – into the existing high mountain relief, which towers above the surfaces of the plateau, a catchment area of only 6% has been developed, whilst an additional ELA depression by only 200–300 m (250 m) raises the increase in surface to 13%, i.e., by the factor 5.8. At a further depression by 300 m are already obtained 24%, and at an ELA of −1000 m compared with today (according to a decrease in temperature of ca. −5 °C) 54% of the total area become a catchment area (the rate of the increase in surface per 100 m ELA depression increases from 0.4 to 3.7 (−600 m) recently as far as 6.3 (−1200 m) (cf. also Figures 36 and 37). Supposing that the present Tibetan plateau will be uplifted by further 250 m (isostatically, see below) (at a recently confirmed amount of uplift of 1 cm/yr this could be attained within approx. 25 000 years), 7% of additional surface would primarily be obtained as glacier catchment area owing to the climatic change with altitude. At an advance of the glaciation, following this process, and a self-increase of the glacier surface by several 100 m – 200 m are to be expected here as a minimum – this corresponds to a real extent of the catchment area of ca. 22% and thus, at a ratio of 2:1 of feeding- to ablation area, to a glaciation surface of 33%, i.e., one-third of the total area of Tibet would be covered with glaciers. In this case the high effect of the albedo, caused by subtropical values of the incoming radiation at a high sea level, would already mean an absolute loss of 1% of the global energy balance and in consequence lead to an increase of the Nordic glaciation processes. At a feed-back loop like this, a further climatically-induced ELA depression into the topography must be assumed, combined with an exponential surface increase and albedo-dependent losses in energy (Figure 38, graph I). This means, that the albedo-effective position of the Tibetan glaciation was possibly an important trigger of the worldwide cooling phase. For the Tibetan plateau and its surrounding marginal mountain ranges a completely covering glaciation in the form of an inland ice sheet is documented by geomorphological indicators (Figure 1 and especially Figure 2). In the central plateau areas and depressions its average thickness of 1500 m increased as far as 3000 m (Figures 10, 19, 32, 35) (Kuhle, 1987d, 1989, 1994b). Analogous to the Fennoscandian glaciation area, a glacioisostatic lowering by 600–700 m is supposed to be probable (Kuhle, 1989, p. 276; 1993c, p. 146). From that result the following consequences: an isostatic reaction can only be expected in delay, i.e., under the pressure of a maximum ice burden. An average lowering by 650 m (Figure 38, graph III) according to a relative rise in temperature of ca. 3 °C, actually led to a reduction of the glaciation, but – under glacial climate conditions of absolutely at least −5 °C and an extent of the catchment area of 68% – the total area remained glaciated and the absolute loss in radiation continued. However, a local additional warming up of the climate by 2 °C (i.e., a rise of the ELA by 400 m, for instance by the orbital variations (Croll, 1875; Milankovic, 1941) was able – in contrast to Phase I – to bring about a destabilization and thus a breaking apart of the inland glaciation into autochthonous mountain glaciations, i.e., a removal of the secondary ice increase, and thus a return of the glaciation to the real topographic situation. In consequence, an abrupt deglaciation took place with the result that the Tibetan plateau again became the most important heating surface of the earth's atmosphere. Assuming here, as in the initial stadia (see above), an ice thickness of at least 200 m at the snow line altitude, this would correspond – with regard to the remaining postglacial −3 °C – to a surface of the catchment area of only 12%, i.e., under recent climatic conditions (−0 °C) of 5%. This means that the glaciation would be less than at present, where nearly 2/3 of the isostatic lowering has already been rescinded (Figure 38, Graphs II and III).

During the Pleistocene, the schematized sequence of the Ice Age-triggerings by the Tibetan High Plateau and the cyclical interglacial re-warmings up to the current level of temperature, was as follows: (1) Tibet has been uplifted above the snow line (ELA) and glaciated. (2) The resulting reflection of the incoming subtropical radiation energy back into space led to the cooling-down of the atmosphere, to the depression of the snow lines and to the build-up of the Nordic inland ices. These lowland ices, located with their centres between 50° and 70° N, which were less energy-effective, obtained an extent of altogether more than 26 million $km^2$. (3) During the Quaternary a re-warming by ca. 2–3 °C (mainly in the northern hemisphere) took place, caused by the orbital variations (Croll, 1875; Milankovic, 1941), from which derived a global rise of the ELA by ca. 400–600 m. (4) In Tibet this rise of the snow line first led only to the melting of the marginal low outlet glacier tongues, whilst the inland ice remained on the plateau, so that the cooling continued. However, in the area of the Nordic inland ices, where the inclination of the surface was only insignificant up to its edges, the rise of the ELA caused a decisive and very important loss in the glaciation area amounting to many millions of $km^2$ (cf. Kuhle, 1987d). In consequence, the connected loss in albedo and the global gain in energy amplified the re-warming of the atmosphere. (5) Now this re-warming also gave rise to an increasing melting of the Tibetan ice. However, its complete melting was only possible because, during every glacial period, the plateau has again been pressed by the glacio-isostatic lowering (Figure 38) into a lower and warmer level. In the other areas of glacial inland ice (Andrews, 1970, and others) the glacio-isostatic lowering has also led to an accelerated interglacial melting-down and has thus contributed to the re-warming.

This study is to be brought to an end with the following objective consideration: supposing that Tibet has never

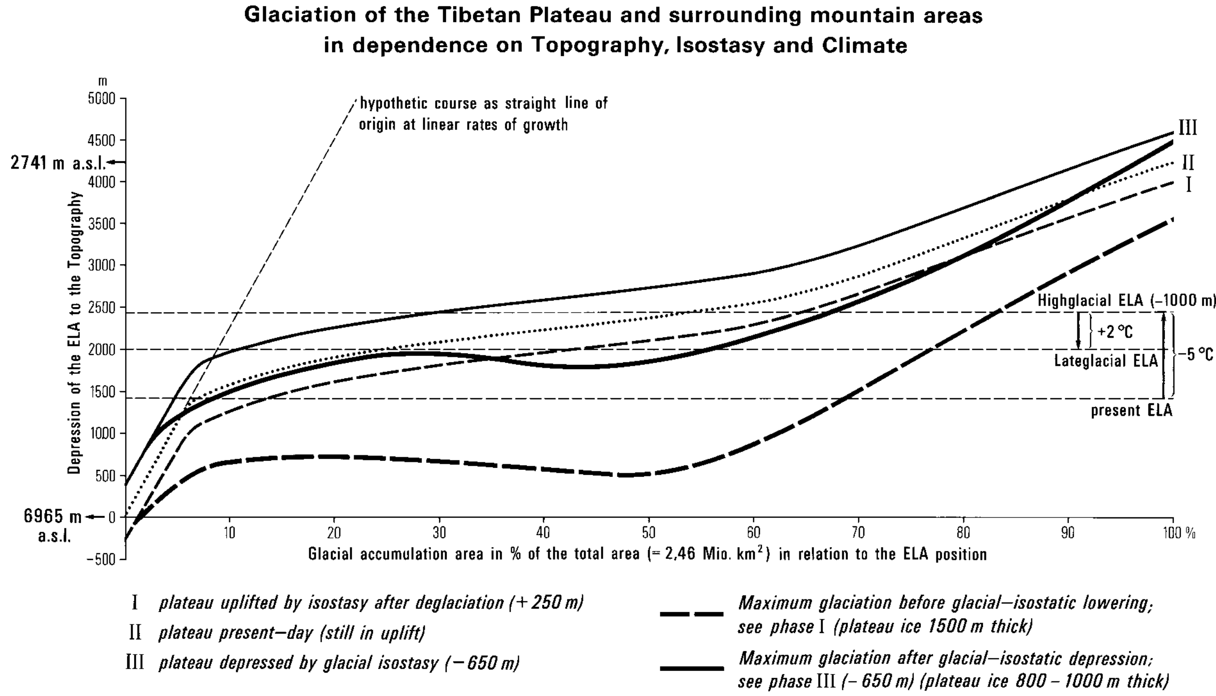


*Figure 38.* Topographically-controlled rates in surface increase of the glacier catchment areas in dependence of the relative amount of the snow line (ELA) depression. I: at an orogenic-isostatically uplifted plateau (+250 m); II: at the recent position of the plateau surface; III: at a glacio-isostatic lowering of the plateau surface (−650 m). The diagrams concern a total surface of 2 464 121 km$^2$, which for the calculation has been subdivided into 29 areas. The key points of the recent surface diagram concern the average maximum summit height (6965 m asl) and minimum height (2741 m asl) respectively, of the 29 areas.

been more extensively glaciated than at present – an interpretation which numerous authors have followed without any reservations up to only a few years ago – its current uplift of ca. 1 cm/yr (Chen, 1988) would raise the plateau within the next 60 000 years – even without a cooling as a result of changing parameters of the earth's orbit – over the modern snow line to such an extent that it might become totally glaciated. Thus, something would only happen in the future that the author already suggests for the past. But can something which is supposed to be probable in the future be improbable in the past? Or will we have totally to exclude the complete glaciation of Tibet as being proved to be physically impossible?

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