*Polarforschung 71 (3), 79 – 95, 2001 (erschienen 2003)*

# Reconstruction of Outlet Glacier Tongues of the Ice Age South-Tibetan Ice Cover between Cho Oyu and Shisha Pangma as a further Proof of the Tibetan Inland Ice Sheet

by Matthias Kuhle[1]

**Abstract:** The author has been engaged in the reconstruction of the Ice Age glaciation and snow line depression carrying out over 20 expeditions and research trips to Tibet and its surrounding mountains since 1976. From the field observations made in 1996, two outlet glaciers were reconstructed: the ca. 75 km long Bo Chu- and the ca. 100 km long Kyetrak Chu glacier. Their sources were not in the Himalayas, but further north of its main ridge in S Tibet. From this location they flowed down through the Himalayas to the south slope. Their past existence and run-off over the local water divide in S Tibet (for the Bo Chu glacier) and the Himalayas (for the Kyetrak Chu glacier) provide evidence of important ice masses on the Tibetan plateau (cf. Fig. 1 complex I3 between Shisha Pangma and Mt. Everest).

**Zusammenfassung:** Seit 1976 hat der Verfasser zur Rekonstruktion der eiszeitlichen Vergletscherung und Schneegrenzdepression über 20 Expeditionen und Forschungsreisen nach Tibet und in seine Randgebirge durchgeführt. Die hier vorgelegten Feldarbeitsbefunde von 1996 rekonstruieren zwei Auslassgletscher, den ca. 75 km langen Bo Chu- und den ca. 100 km langen Kyetrak-Gletscher, welche nicht vom Himalaya, sondern nördlich seines Hauptkammes von Südtibet ausgegangen und durch den Himalaya hindurch bis in dessen Südabdachung hinabgeflossen sind. Ihre vorzeitliche Existenz und ihr Abfluss über die lokale Wasserscheide in Südtibet - was den Bo Chu-Gletscher betrifft - und über die des Himalaya - was den Kyetrak-Gletscher betrifft - liefern den Beweis für bedeutende Eismassen auf dem Tibetplateau (vgl. Abb. 1 Inlandeiskomplex I3 zwischen Shisha Pangma und Mt. Everest).

## PROBLEM

The author has been working for the last 27 years on the question of the extent of glaciation of the Himalaya, Karakorum, Kuenlun, Quilian Shan and Tibet during the Pleistocene Ice Age which is gradually being answered by information gained from Quaternary-geological und geomorphological key locations. A suitable area for investigation is the south margin of Tibet where the upland lies adjacent to the Himalayas which are 3000 m higher (Fig. 1, 3). Due to the southerly position at 28°N, the snow line (ELA) runs the highest here - nowadays and probably also during the LGM. Of all the plateau areas, southern Tibet is therefore furthest away climatically from glaciation now and in past times. If even southern Tibet was covered by ice, then this must have been true also for central and northern Tibet because, for planetary reasons, the snow line dips towards the north. The idea is feasible because the Central Plateau which lies north of south Tibet is at the same height above sea level or higher. It is therefore hypsometrically closer to past glaciation.

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Manuscript received 26 March 2001, accepted 12 March 2003

Present-day glaciers flow down from the highest summits of the Himalayas in all directions. On the north slopes, their tongue ends reach down to the level of the plateaus and into the high valleys of south Tibet, such as Yepokangara glacier on Shisha Pangma, Rongbuk glacier on Mt. Everest and Kyetrak glacier on the NW-side of the Cho Oyu (Fig. 12 below No. 1). The large transverse valleys lying between such mountain glacier areas which run down from Tibet and divide the Himalayas into separate massifs, are not glaciated at present (e.g. Tamur valley, Arun valley, Bote Chu, Marsyandi Khola, Thak Khola, Bheri Khola and Alaknanda valley). An important question is: Were these valleys glaciated during the Ice Ages?

In contrast to the weak traces of glaciation in high lying areas which are difficult to prove, the work of past valley glaciers can clearly be recognized. This difference is due to the following factors: Upland ice is cold based glacier ice, because the level of the upland runs about or even above the snow line. As in the Antarctic or parts of Tibet, it has overlain permafrost. Cold based ice usually freezes permanently to the ground. If, because of the shearing strain, it sometimes suddenly moves, it does not leave a smooth surface like warmer glacial ice resting on glacier meltwater but rather roughnesses which cannot be distinguished from weathering traces left by frost.

In the valleys, in contrast to the uplands, the flow velocity of the ice is higher due to reduction of the cross-profile of the outlet. Furthermore, the valleys lead down to lower areas which are far below the snow line and permafrost limit. Their glacier filling therefore consisted of warm based ice. Such fast flowing glaciers running over a film of meltwater leave the rocks round and smooth with polishing. Evidence of this are features such as roches moutonnées, polished rocks and glacier striations.

In contrast to the upland ice, which is found at the altitude of the snow line and in the nourishment area and therefore has mainly an erosive effect, the lower parts of the valley floors and flanks are covered by ground moraines. Their increasing thickness can be explained by the progressively positive mass balance of moraine material below the snow line in the direction of the lowest ice margins. Such ground moraine covers preserve the polished forms of the rocks. The polishings are only visible and can only be proved beyond doubt on those rocks which were just recently relieved of the overlying moraine, i.e. have not yet been destroyed by weathering.

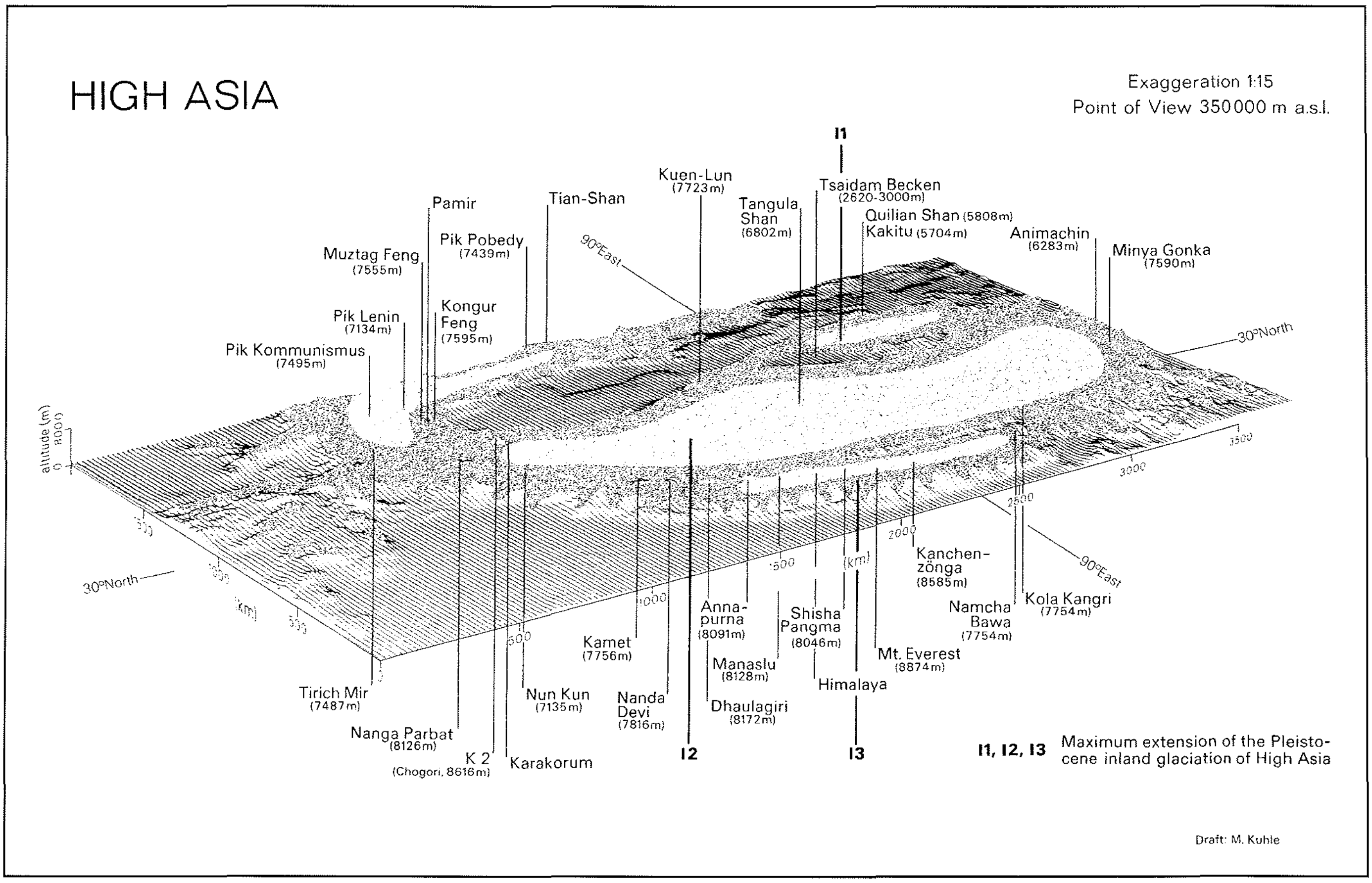



**Fig. 1:** The high glacial Tibetan ice had an extension of more than 2.4 million km². The three centres of glaciation I1, I2 and I3 were separated from each other by the Tsaidam lake and the Tsangpo valley.

**Abb. 1:** Das über 2,4 Millionen km² ausgedehnte hocheiszeitliche tibetische Inlandeis hatte drei kuppelförmige Zentren I1,I2 und I3. Diese waren voneinander durch den Tsaidam-See und das Tsangpo-Tal getrennt.

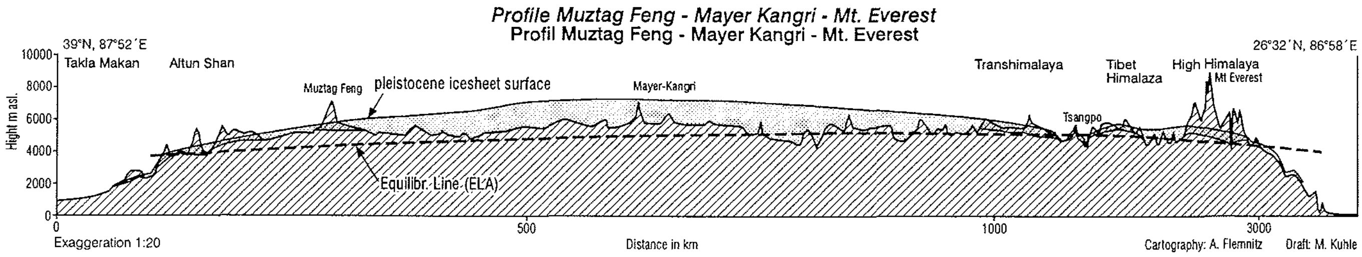



**Fig. 3:** Cross-profile of the Pleistocene inland glaciation of Tibet according to KUHLE (1998). This older reconstruction is supported in this paper by the observations regarding the southern margin of Tibet, which are evidence of the transfluences of the outlet glaciers through the Kyetrak Chu (valley) and the Bo Chu (valley) west of Mt. Everest over the watershed of the Himalaya and into its southern slope.

**Abb. 3:** Querprofil des pleistozänen Inlandeises in Tibet nach KUHLE (1998). Diese ältere Rekonstruktion wird durch die in dieser Arbeit vorgestellten Daten vom Südrand Tibets gestützt. Die Untersuchungen beweisen die Transfluenz von Auslassgletschern, welche dem Verlauf des Kyetrak Chu (Tal) und des Bo Chu (Tal) westlich des Mt. Everest über die Wasserscheide des Himalayas bzw. in seine südliche Abdachung folgten.

As for the empirical proof of a former ice cover the search for traces of a past glaciation in these transverse valleys is highly promising. For this reason it must be established whether local glacier ice from the Himalayan mountains or far-travelled ice from the Tibetan plateau flowed through them. In the latter case, these would have been typical outlet glaciers which arose from a Tibetan inland ice cover at the southern edge of the plateau and then flowed down through the Himalayan transverse valleys. To provide evidence of the existence of such an outlet glacier, the most interesting factor would not be the former glaciation of the valley but rather the glaciation at its source somewhat north of the Himalayas. Only a glaciation of the valley head would confirm Tibet to be the glacier catchment area and not the higher Himalayas which continue down-valley. The plateau region of Tibet with an altitude of about 5000 m would, in this case, have been above the Ice Age ELA - naturally not as high above it as the summits of the Himalayas but instead extended over a wide area. A plateau that rises above the snow line has the type of relief which can accumulate the most snow to feed a glacier. Since it does not slope or, at most, only slightly, the ice flow is held back until a thickness of at least a few hundred metres is attained. The secondary increase in height due to such a plateau ice furthers the feeding of the glacier by lowering the annual surface temperature. This is accompanied by an increase in the annual snowfall. Thus, owing to its much larger area, the feeding by such a plateau glaciation exceeds that of 2000-3000 m higher summits by far.

The idea that from the southern edge of the Tibetan plateau antecedent transverse valleys have come down through the Himalayas is highly simplified. Strictly speaking, the valleys start from local water divides between the Himalayan south side and the Tibetan drainage system. Because the internal drainage in south Tibet takes place along shallow valleys, we are not talking about a plateau area in a strictly geometrical sense. Actually, it is a slightly dissected upland that might have been covered by an ice sheet. If so, the past outlet glaciers must have flowed down over transfluence passes.

In order to prove the existence of glaciers which arose from the ice of a Tibetan plateau which in its turn was also the prerequisite for the nourishing of the glaciers, two examples have been chosen.

## CHOICE OF TEST VALLEYS ON THE MARGIN OF TIBET AND APPROACH TO INVESTIGATIONS

Two valleys between Shisha Pangma and Mt. Everest (Fig. 1) were chosen, the axes of which cross the Himalayas from Tibet in a southerly direction. One is the Bo Chu (Bote Chu; Pa Ho on the ONC map 1:1,000,000, H9, 1978) which runs across the main ridge of the Himalayas between Shisha Pangma und Chomolung Kang from Yagru Xiong La (Fig. 2, No. 25) to Dram (Zhangmu) (Fig. 2, No. 1). The second valley is the Kyetrak Chu between Chomolung Kang and Cho Oyu which rises from the settlement of Ting-Jih (Fig. 2, above No. 39) in a south direction to Nangpa La (No. 31). Its axis continues south of this glacier pass in Nangpo Dzangpo to the settlement of Thame on the Himalayasouth-slope. If the northerly extension of the valley axis of the Bo Chu over the Yagru Xiong La (pass) into the Xaga Chu is considered, the courses of the two valleys show fundamental similarities. Both of them cross local passes and water divides on their way out of south Tibet. Here, the special topographical conditions mentioned in Section 1 are realized: the valleys lead out from the dissected Tibetan upland right across the Himalayas and slope steeply down to the lowland (cf. density of the topographic contour line and altitudes of the top section of Figure 2 with those of the bottom section). One difference between them (which, however, can be neglected in this context) is that the Kyetrak valley is still partly glaciated whereas the Bo Chu is not. The present-day Kyetrak glacier flows from the Himalayas (Cho Oyu 8201 m) for 10 km in a northern direction into Tibet (Fig. 2, No. 31-32).

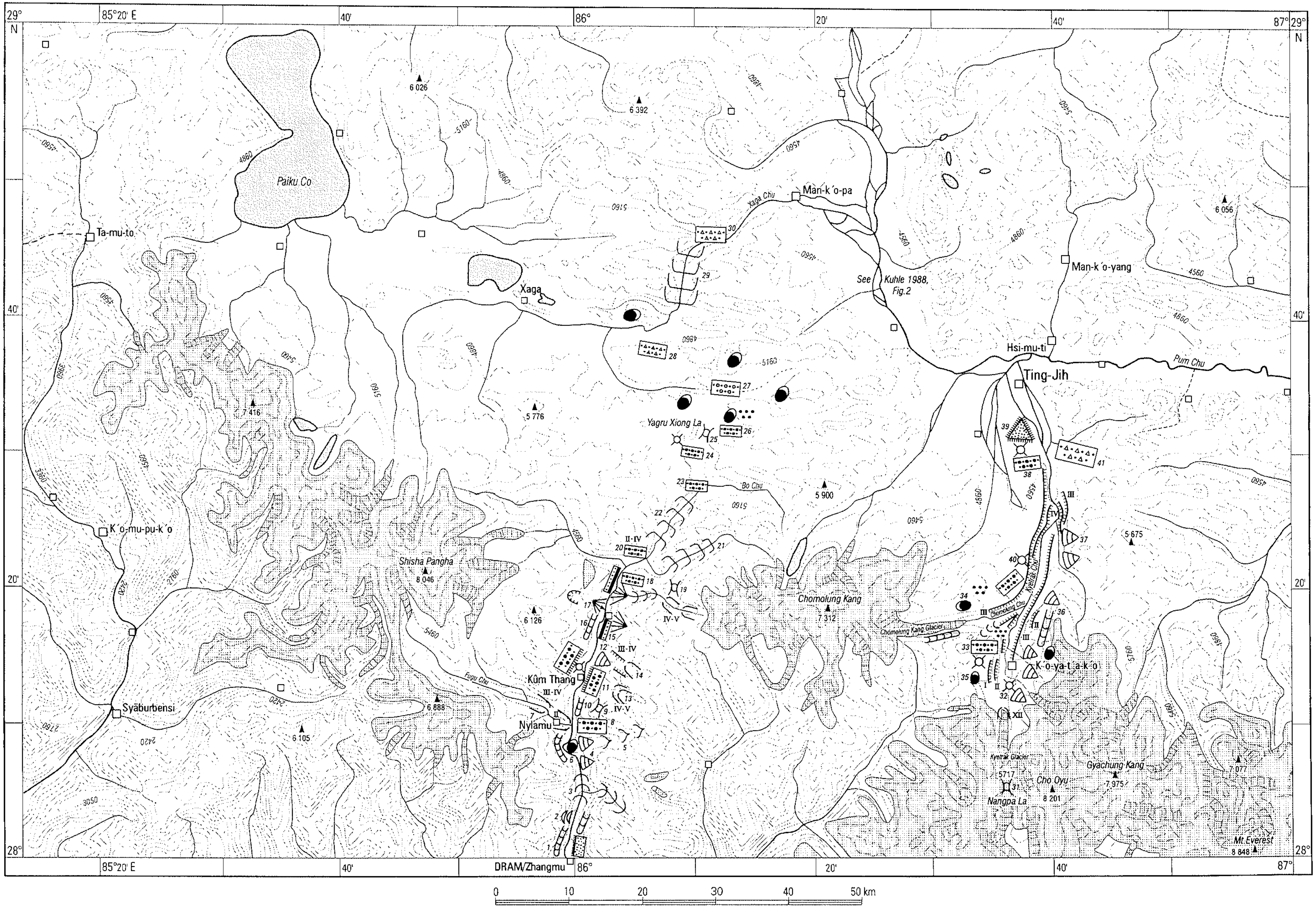
In accordance with the problem presented in Section 1, the following questions were to be answered: (i) Was Bo Chu glaciated, i.e. what indications prove or disprove a past glaciation of the valley? (ii) If Ice Age glaciation can be evidenced, did its glacier come down from Tibet or was it only local ice from the still glaciated Himalayan mountains? (iii) Are there any indications that the Kyetrak glacier might not have existed in its present form, thickness and flow direction? Could there possibly be evidence of a much more important ice stream of the type "outlet glacier" which might have filled the Kyetrak valley from Tibet? If so, such an ice accumulation would have flowed in the opposite direction to the present-day Kyetrak glacier over the present ice divide of the Himalayas (over the Nangpa La: Fig. 2, No. 31) in a southerly direction.

## EVIDENCE OF A PAST GLACIATION OF BO CHU (ALSO BOTE CHU; PA HO OR SUN KOSI KHOLA), PROBABLY FROM THE LAST ICE AGE (LGM)

### *Indications of glaciation in the lower Bo Chu*

In the valley section of Lamosango (27°40-48'N, 85°45-55'E), the talweg of the Bo Chu runs at 700-900 m a.s.l.. Here, 3-4 m long, erratic augen-gneiss boulders from the Shisha Pangma (for the petrography of the Shisha Pangma cf. KUHLE 1988: 483, Fig. 43) were found. They lie on outcropping schists and metamorphic silt-stones. Many of these boulders are rounded. Others show subglacially formed potholes. Some of them can be found in the matrix of the morainic fine material. A further indication that the Bo Chu glacier tongue reached all the way down to the valley chamber is the occurrence of Pleistocene lateritic red weathering which sets in abruptly and over large parts, down-valley. Up-valley from the settlement of Barabise, rochemoutonnée-like glacier polishings are preserved up to at least 250 m above the talweg. They are proof of corresponding minimum thicknesses of ice in the valley. In the slope-depressions lying between them, glacigenic layers of boulder clay metres- to decametres-thick, next to covers of autochthonous slope debris have been preserved. Based on this evidence, it is certain that at the time of its greatest length, the Bo Chu glacier ended in this valley chamber between 700 and 900 m a.s.l..

In the next valley section which stretches in an upward direction to the junction with the Chaku Khola, glacigenic flank polishing occurs on both slopes. This is proved by the clear roundings of the outcropping edges of the strata. The following valley section upwards in direction of the settlement of Jhirpu presents two closely interlocking valley cross-profiles. The higher one shows the broad U-profile of the glacier bed, whereas the other one is set into the valley bottom in the form of a narrow V-profile due to subglacial erosion from the melting ice. The latter is typical of Ice Age glacier tongues which have flowed downwards as much as 3000 m below the ELA. Therefore, this V-profile has also been observed in other Himalayan transverse valleys (KUHLE 1982). Further up, the valley crosses the main Himalayan ridge so that the slopes are much higher and longer than they are in the lowland of the Himalayas. This causes a more intensive reshaping of the past glacigenic flank polishings by present-day flushing-out. For this reason, postglacial breakages of the rock interrupt the glacigenic polishings in some places. In this part of the Bo Chu, moraines are only to be seen as remnants. They have been eroded by monsoon-induced torrents. In many places, their substrate has been dislocated by linear mudflows and finally completely removed at the bottom of the valley by the Sun Khosi river.



29° N
85°20' E
40'
86°
20'
40'
87°
28°
Paiku Co
Ta-mu-to
Xaga
Xaga Chu
Man-k'o-pa
See Kuhle 1988, Fig.2
Man-k'o-yang
Hsi-mu-ti
Pum Chu
Ting-Jih
Yagru Xiong La
Bo Chu
K'o-mu-pu-k'o
Shisha Pangha
8 046
Chomolung Kang
7 312
Chomolung Kang Glacier
Kyetrak Chu
K'o-ya-t'a-k'o
Kûm Thang
Fugu Chu
Nylamu
Syäburbensi
Kyetrak Glacier
Nangpa La
Cho Oyu
8 201
Gyachung Kang
7 975
7 077
Mt.Everest
8 848
DRAM/Zhangmu
6 026
6 392
6 056
7 416
5 776
5 900
5 675
6 126
6 888
6 105
0
10
20
30
40
50 km

- *Glaziärer Flankenschliff* / glacial flank polishing and abrasion
- *Kerbförmiger oder schluchtförmiger glazigener Trog* / V-shaped or gorge-like glacigenic trough
- *Rundhöcker und ähnliche glaziäre Schliffformen* / roches moutonnées and related features of glacial polishing and abrasion (glacially streamlined hills)
- *Glaziäre Dreieckshänge* / glacially truncated spurs (triangular shaped)
- *Endmoränen von Talgletschern* / terminal moraines of valley glaciers (former ice margin)
- *Schwemmschuttfächer, Schotterflurfächer* / outwash fan, gravel fan
- *Schutt-und Murkegel* / debris- and mudflow cone
- *Heutige Gletscher* / present glaciers
- *See, Fluß* / lake, river
- *Nachbrüche an glazigen beschliffenen Felsflanken* / spallings on glacially polished rock flanks
- *Grundmoräne mit großen erratischen Blöcken* / ground moraine with big erratic boulders
- *Grundmoräne mit großen nicht erratischen Blöcken* / ground moraine with big non-erratic boulders
- *Sedimentproben, Altersbestimmungen* ($C_{14}$, *TL*) / samples of sediment, age determinations ($C_{14}$, TL)
- *Ufermoräne, Endmoräne* / lateral moraine, terminal moraine (former ice margin)
- *Transfluenzpaß* / transfluence pass
- IV-V *Riss-, Hoch-Würm-zeitliche, spät- u. neoglaziale bis historische Gletscherstände* / Riss-(pre-LGM), Würm-i.e. High-(LGM), Late-, Neo-glacial and historical glacier positions
- 26 *Lokalität* / locality
- *Siedlung* / settlement
- *Kar* / cirque
- *Glazialer Trog* / glacial trough
- *Glazialer Trog mit Schottersohle* / glacial trough with gravel bottom
- *Große Blöcke (erratisch und nicht erratisch)* / big boulders (erratic and non-erratic)
- *Grundmoräne ohne große Blöcke* / ground moraine without big boulders
- *Kames- Terrasse* / kame terrace
- *Gletschertor-Schotterflur-Terrassen* / glacier mouth- gravel floor terraces
- 7 975 *Gipfelpunkt* / peak

*Kartographie* / Cartography: *E.Höfer* *Entwurf* / Draft: *M.Kuhle*

**Fig. 2:** Quaternary-geological and glaciogeomorphological map of south Tibet with Shisha Pangma- and Cho Oyu-group (locality: Fig. 1, 13 between and N of Shisha Pangma and Mt. Everest). The geomorphologic signatures follow the courses of the two outlet valleys which lead from Tibet in a northern direction through the High Himalaya and in its south-slope. They formed two southern drainage tracks of the Ice Age Tibetan ice sheet.

**Abb. 2:** Quartärgeologische und glaziogeomorphologische Karte von Südtibet mit Shisha Pangma- und Cho Oyu-Gruppe (Lokalität: 13 in Fig. 1, zwischen und nördlich von Shisha Pangma und Mt. Everest). Die geomorphologischen Signaturen folgen dem Verlauf der beiden Auslasstäler, die von Tibet nach Norden durch den Hohen Himalaya und in dessen Südabdachung führen. Sie bildeten zwei südliche Abflussbahnen des eiszeitlichen Tibet-Inlandeises.

One such mudflow (July 1996) brought down morainic material originating from the westerly tributary valley, Jangbo Khola. The mudflow completely destroyed the settlement of Lartza at 1300 m a.s.l. at the bottom of the Bo Chu (45 people were killed). Far-travelled granite and augen-gneiss boulders, 3 x 4 x 5 m in size, were incorporated into the mudflow which derived from the massifs of the Shisha Pangma and Rolwaling Himal, that is from the upper catchment area of the Bo Chu. The clayey-loamy matrix of the mudflow is typical moraine matrix which was also taken up and displaced.

The largest moraine boulder transported by mudflow in this valley section of the Bo Chu is 6.7 x 11.3 x 17.7 m in size. It lies 6 km downstream from the settlement of Kodari, a few metres above the talweg. XU DAOMING (1988) also describes this boulder as a displaced moraine component. According to his investigations, the boulder was transported by two mudflows (from the region depicted in Fig. 2, No. 3-5) caused by outbursts of moraine lakes in the Rolwaling massif in 1964 and 1981.

Glacigenic flank polishings occur also on both sides of the Bo Chu between Lartza and Dram (also Khasa or Zhangmu). On the orographic right side opposite from Dram there is a particularly important indication of a valley glaciation during the Ice Age (Fig. 2, No. 1). It is an extensive glacial flank polishing up to 400 m above the talweg which is well developed in the resistant metamorphic rocks of the Khumbu and Kathmandu covers (KU 1-3; KN 2, 3 according to HAGEN 1969: 129). It proves that the surface of the Bo Chu glacier must, at one time, have been at 2400 m a.s.l.. The smoothly polished rock surfaces, darkly striped from the influence of water, have been roughened by late-glacial and Holocene to present-day crumblings (Fig. 2, No. 2). Spallings cause small overhangs under which the rock has not been darkened by water. They can therefore be seen very clearly as large, light roughnesses in the rock, several square metres in size.

The transverse valley profile in the Bo Chu between Dram and the junction with the Fuqu Chu also provides evidence of a past valley glaciation. In the middle of its course it is U-shaped (at 28°02'N, 85°59'E, 2700 m a.s.l.; Fig. 2, No. 3). In some sections it shows the characteristics of a gorge-like trough, i.e. of a V-shaped valley, the flanks of which have a slightly concave form caused by abrasion of a valley glacier (for details of this valley type cf. KUHLE 1982). The neighbouring side valleys (Fig. 2, No. 5 and a further side valley to the right of No. 3) also show both of these types of glacial valley cross-profiles.

Further evidence of an important Ice Age valley glaciation is given by the glacially truncated spurs between the junctions with the side valleys. Triangular-shaped slopes such as these form parts of the flanks of the Bo Chu (Fig. 2, No. 4).

At 3680 m a classic "riegel" mountain has been polished by the glacier and shaped into a roche moutonnée (Fig. 2, No. 6). At its culmination there are erratic augen-gneiss boulders (see above). At the junction with the Fuqu Chu end moraines have been deposited from the two Shisha Pagma south glaciers, presently separated (Fig. 2, No. 7). Because of their brownish weathered surfaces and their calculated ELA-depression compared with the present snow line of ca. 600-800 m, they must belong to the last Late-glacial period, i.e. they are somewhat older than 13000-14250 yr BP (as for the chronological classification of the ELA-depressions see KUHLE 1997 Tab. 1 stage III-IV).

The Ice Age glaciation of the lower Bo Chu dealt with so far could possibly have arisen exclusively from the Fuqu Chu. One argument in favour of this would be its connection to the very highest glacial catchment area of the Bo Chu, i.e. the 8046 m high Shisha Pangma (cf. Fig. 2). This is, however, not the case, because the middle part of Bo Chu was also filled with ice.

*Indications of a past glaciation in the middle Bo Chu*

The following discussion deals with the 23 km long section of the main valley between the two large orographic right-hand side valley junctions. These valleys join the Bo Chu from the Shisha Pangma massif. The southern valley is the Fuqu Chu (Fig. 2, No. 7), whilst the northern has no name (No. 20).

Directly opposite the junction with the Fuqu Chu, the smoothly polished surfaces of the orographic left-hand main valley slope (Bo Chu) are covered by ground moraine several metres thick, containing erratic boulders (Fig. 2, No. 8). Wherever this cover of lodgement till is missing, glacial polishings on relatively rapidly weathering rock faces are preserved. This is evidence of quite a young main valley glacier. A rather important ice thickness of at least 500 m is proved by the glacigenic rounding of the valley flank up to its culmination. At the top there is a glacigenic transfluence pass (Fig. 2, No. 9).

From the Fuqu Chu junction upwards in direction of the Bo Chu, between 3670 and 3800 m, another well-preserved example of glacial polishing by the main valley glacier (No. 10) was found. On the main valley floor between the settlements of Nylamu and Kum Thang, a ground moraine from the maximum glaciation (LGM) (3700-4120 m a.s.l., 28°15'20"N, 86°00'30"E; Fig. 2, No. 11) has been observed. The moraine contains isolated, far-travelled granite- and augen-gneiss boulders, sometimes up to one metre in length. These rocks occur as bedrock in south Tibet (KUHLE 1988, Fig. 43). The moraine was first washed out superficially by meltwater of the late-glacial glacier. Later it was reshaped glaciofluvially into today's terraces. The clay peak and bimodal grain-size distribution (Fig. 4) documents the moraine character of the fine material matrix. The conspicuously large proportion of middle sand (41 %) on the moraine surface is evidence of fluvial reshaping. A proportion of 0.18 % calcium carbonate is proof of incorporation of only a small amount of bedrock from the underground. The 200 $SiO_2$ grains analysed microscopically (Tab. 1, Fig. 5, 21.8.96/1) show a predominance of 62.5 % of the group glacially crushed/freshly weathered, typical of ground moraine. The 37.5 % quartz grains included in the morphoscopic group dull (aeolian) /lustrous (fluvial) are proof of the late-glacial glaciofluvial and Holocene cold-arid reshaping of this ground moraine terrace. The flanks of this valley section have been polished back to a trough. The widening of the valley cross-profile was glacigenic as can be recognized from the glacially truncated spurs between the orographic left-hand junctions of the tributary valleys (Fig. 2, No. 12) which are covered with remnants of ground moraine.

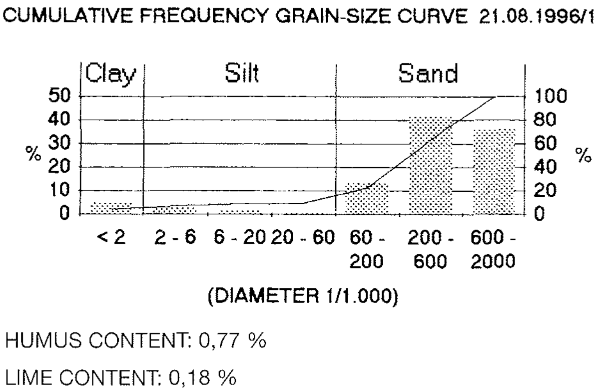



**Fig. 4:** Sediment sample taken from a depth of 0.15 m at 3835 m a.s.l. on the orographic right side of the Bo Chu near the monastery of Milaripa. Locality: Fig. 2, No 11; moraine matrix of a high to late glacial ground moraine to lateral moraine terrace which has also been reworked glaciofluvially (cf. Tab 1, Fig. 5, 21.08.96/1). A large part of the moraine is built up by erratic augengneiss substrate, resulting in a coarse-grained matrix and a low peak of the fine grain in the clay.

**Abb. 4:** Sedimentprobe in 3835 m ü.M. orographisch rechts im Bo Chu nahe dem Kloster von Milaripa aus 0,15 m Tiefe entnommen. Lokalität: Fig.2, Nr. 11; Moränenmatrix aus einer hoch- bis spätglazialen Grund- bis Ufermoränenterrasse, welche auch glazifluvial überarbeitet worden ist (vgl. Tab. 1, Abb. 5, 21.08.96/1). Die Moräne ist großteils aus erratischem Augengneisssubstrat aufgebaut, weshalb die Zwischenmasse grobkörnig und der Feinkorn-Peak im Ton niedrig ausgefallen sind.

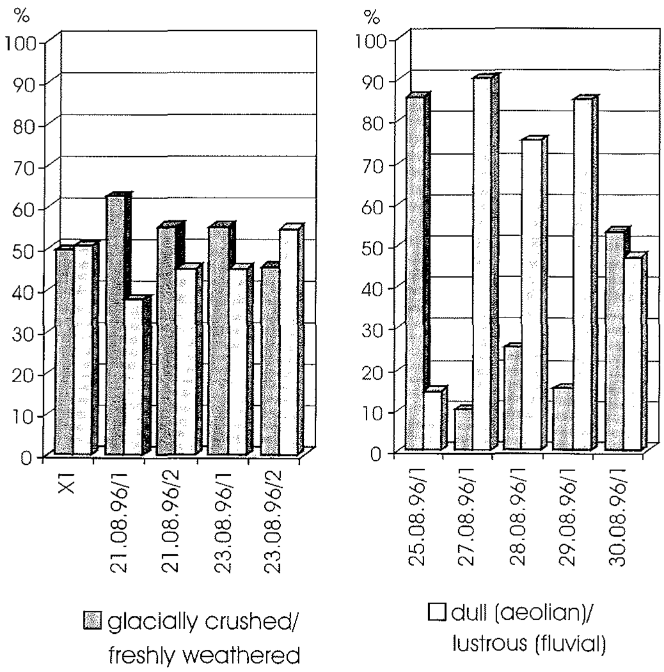



**Fig. 5:** Morphometric quartz grain analysis of 10 representative samples from south Tibet (cf. Tab. 1 and Fig. 2, 4, 6-9).

**Abb. 5:** Morphoskopische Quarzkorn-Analyse von 10 repräsentativen Proben aus Südtibet (vgl. Tab. 1 und Abb. 2, 4, 6-9).

The fact that the reshaping of the Last Ice Age ground moraines in this middle part of the Bo Chu was caused by meltwater from late-glacial up to neoglacial glaciers can be proved by relatively young end moraines in the side valleys, because these are evidence of the typical late-glacial to neoglacial ice margins. Two of the end moraines come down to 4100 m a.s.l. in an orographic left-hand tributary valley (Fig.

| *Sample No./ date*<br>Probennr./ Datum | 0,2 - 0,6 mm counted quartz grains<br>*0,2 - 0,6 mm ausgezählte Quarzkörner* | glacially crushed/ freshly weathered (in situ)<br>*glazigen-gebrochen/ frisch (in situ) verwittert* | dull (aeolian)<br>*äolisch mattiert* | lustrous (fluvially polished)<br>*fluvial poliert* | remarks<br>*Anmerkungen* |
|---|---|---|---|---|---|
| XI | 201 | 49.6 % | 26.8 % | 23.6 % | fluvial reworking more distinct than aeolian - Fluviale Überarbeitung ausgeprägter als äolische |
| 21.08.96/ 1 | 200 | 62.5 % | 10.0 % | 27.5 % | 90 % quartz portions (eg. citrine), feldspars – *90 % Quarzanteil (u.a. Citrin), Feldspate* |
| 21.08.96/ 2 | 142 | 56.3 % | 10.6 % | 33.1 % | all transition forms exist; slightly fluvial reworking of the glacially crushed/ freshly weathered material; small portion of quartz - *alle Übergangsformen vorhanden; leichte fluviatile Überarbeitung des glazigen gebrochenen/ frisch verwitterten Materials; geringer Quarzanteil* |
| 23.08.96/ 1 | 210 | 52.1 % | 38.0 % | 9.9 % | c 80 % quartz - *ca. 8 0% Quarz* |
| 23.08.96/ 2 | 180 | 45.5 % | 37.8 % | 16.7 % | heterogeneous sample, partly important degree of rounding; transition from glacially crushed/ freshly weathered into fluvially rounded; varieties of quartz are predominant (citrine, milky quartz) – *heterogene Probe, teilweise hoher Zurundungsgrad; Übergang von glazigen gebrochen/ frisch verwittert zu fluvial gerundet; Varietäten des Quarz vorherrschend (Citrin, Milchquarz)* |
| 25.08.96/ 1 | 140 | 85.7 % | 14.3 % | - | very sharp crests/ fresh fracture surfaces, freshly-edged material - *sehr scharfe Grate/ junge Bruchflächen, Material kantig-frisch* |
| 27.08.96/ 1 | 50 | 10.0 % | 80.0 % | 10.0 % | difficult analysis, since nearly no quartz does exist, much muscovite (mica) and brown-red aggregates - *schwierige Analyse, da kaum Quarz vorhanden; viel Muskovit (Glimmer) und braun-rote Aggregate* |
| 28.08.96/ 1 | 100 | 25.0 % | 55.0 % | 20.0 % | slight polishing of the fresh fracture surfaces - *leichte Überpolitur der frischen Bruchflächen* |
| 29.08.96/ 1 | 33 | 15.0% | 85.0% | - | sample with a very small portion of quartz - *Probe mit sehr geringem Quarzanteil* |
| 30.08.96/ 1 | 155 | 53.0 % | 20.7 % | 26.3 % | heterogeneous sample, last way of transport but clearly pronounced - *heterogene Probe, letzte Transportart jedoch deutlich ausgeprägt* |

**Tab. 1:** Morphometric quartz grain analysis of 10 representative samples from south, central and west Tibet (cf. Fig. 2, 4, 6-9). Laboratory analysis (microscopy): O.A. Bauer 9/10/97; sampling: M. Kuhle.

**Tab. 1:** Morphoskopische Quarzkorn-Analyse von 10 repräsentativen Proben aus Süd-, Zentral- und Westtibet (vgl. Abb. 2, 4, 6-9). Laboranalyse (Mikroskopie): O.A. Bauer 9/10/97, Probenentnahme: M. Kuhle.

2, No. 13). Their ramparts enclose two glacier tongue basins. They belonged to a west-exposed high valley glacier which has now completely melted. It came down from a massif southwest of Chomolung Kang, presently unglaciated. The end moraines are considered as being from the late-glacial up to neoglacial stages IV to V because of the ELA-depressions of at least 300 m to maximally 700 m compared with the present snow line, calculated for their ice margins. This indicates an age of ca. 5500 to 13500 yr BP (as for the chronological classification of the ELA-depressions see KUHLE 1997, Tab. 1, stage IV-V). Lateral and end moraines also occur six kilometres to the north, at a junction with another parallel tributary valley at an altitude of 4100 and 4280 m a.s.l. (Fig. 2, No. 14), suggesting an age of c 14250 to 13000 yr BP (stages III to IV) (ibid.). 11 km up the main valley (Bo Chu), in a third orographic left-hand tributary valley, two further end moraine lobes from the late-glacial to the Holocene (neoglacial) periods have been mapped (Fig. 2, IV-V below No. 19). The upper catchment area of this west-exposed valley belongs to Chomolung Kang (7312 m) and, because of its considerable altitude, it is still glaciated.

From the settlement of Kum Thang (Fig. 2, No. 11) 10 km up the Bo Chu (up to No. 15), a glacial valley extends, which is typical of south Tibet. A late-glacial to Holocene glacier-snout-gravel-floor has been filled in to form the valley bottom. This valley bottom consisting of outwash debris is divided into gravel terraces with 3 to 5 terrace steps, each only a few metres high (No. 15). Some 25 m higher, ground moraine terraces run along both flanks of the valley (No. 11. see above). On the orographic right-hand flank of this broad trough valley, which because of its post-High Glacial (post-Last Ice Age or post-LGM) gravel floor has a box-shaped profile, glacial rock polishings have been preserved (Fig. 2, No. 16) in the form of roundings and smoothings. However, an upper ice scour limit which enables the maximum thickness of the Last Ice Age Bo Chu glacier to be recognized has not been preserved. According to our measurements in summer and autumn 1984 (KUHLE & JACOBSEN 1988), here at 4000-4400 m a.s.l. freezing and thawing occurs more than 200 times per year. The daily fluctuation in the rock surface temperatures is 30 to 50°C. Under these thermal conditions an intensive post-glacial weathering of the rock must have resulted. The glacial polishings could only remain in positions long protected by lodgement till covering.

Again, the valley slopes are incised by short side valleys, so that here, too, the main valley flank consists of the mountain spurs lying in between, which have been truncated by the main glacier. This unambiguous sequence of forms, which cannot be mistaken for convergence phenomena, provides evidence of a parent glacier many hundreds of metres in thickness, marked by important flank abrasions. The connected side glaciers flowed down from high depressions or flat cirques in an east-exposure (No. 17). These days, outwash and mudflow fans emerge from them (No. 17). The fans are much too small to correspond to the excavation volume, i.e. to have accumulated in the course of the entire Pleistocene without a break in accumulation due to any evacuating glaciation. They include dislocated ground moraine material. Judging from the angle of repose, the ground moraine material may have originated to a certain extent also from the main valley flank. Corresponding post-glacial fans consisting of displaced lodgement till deposited on top of the ground moraine of the main valley and interlocked with glaciofluvial gravel can also be found on the left-hand side of the valley (Fig. 2 between No. 15 and 18). Their key position as a direct indication of former glacial landforms is explained for High Asia in detail by ITURRIZAGA (1999). Generally, a former glaciation is the most important factor for the development of such debris fans. It provides the loose material in the form of ground and lateral moraines on high slope positions. The side valleys contribute to displacement of material forming fan shapes due to their concentrated water flow. Accordingly, the most northerly of these fans contains a scattering of erratic gneiss and granite blocks (Fig. 2, No. 18).

Approximately 3 km away from this fan up the Bo Chu, there is a covering of ground moraine, metres to decametres thick. It stretches from the talweg 300 m up the orographically left slope. Its surface has almost horizontal, parallel exaration rills (28°19'N, 86°04'E at 4100 m a.s.l.). On the glacigenic roundings of the opposite (right-hand) valley flank there are remnants of ground moraine up to just as high a level. Above these, between 4800 and 5000 m, there are high depressions in east-exposures. From their small vertical distance to the modern orographic snow line at 5600-5700 m, it can be concluded that they contained small glaciers or firn shields even during the late late-glacial period (stage IV according to KUHLE 1997, Tab. 1). Their meltwater drainage caused sander-like outwash fans and debris cones to occur on the already ice-free Bo Chu valley floor.

The two left-hand side valleys (Fig. 2, No. 21 and below No. 18) between which an Ice Age transfluence pass (No. 19) is interposed and which, therefore, during the LGM had a very thick glacier, are trough valleys with or without gravel floor. The narrower and steeper valley (below No. 18) has an almost classically U-shaped cross-profile with no flat bottom, which during the post-glacial period (Holocene) has been filled with gravel. The valley with the box-shaped trough cross-profile (No. 21) was already proved to have been formerly glaciated and shaped by the glacier ice in 1984 (cf. KUHLE 1988: 488, Fig. 48).

Halfway between the junctions of these two left-hand tributary valleys, a large orographic right-hand side valley joins the Bo Chu (Fig. 2, No. 20). It leads down from the east side of the Shisha Pangma massif which is still highly glaciated. At the junction with this side valley, the main valley bottom is covered by ground moraine at 4120 m a.s.l.. Its thickness of probably several decametres can be concluded from the great width of the valley floor filled with moraine. Here it is more than 300 m thick. The ground moraine contains erratic boulders of augen-gneiss about one metre in size. The parent rock of these erratics crops out 15-20 km away on Shisha Pangma (for information on augen-gneiss petrography see KUHLE 1988: 483 and Fig. 43). Thus, at least the surface of the sediment originated from a local moraine which was transported here by the corresponding local side glacier from the Shisha Pangma massif. This came from a glacial catchment area at an altitude of up to 8000 m (Fig. 2, Shisha Pangma left of No. 20). In the catchment area further up the Bo Chu main valley (to the north) such an altitude is not nearly reached. Therefore, the glacier tongue of this side glacier must still have reached the valley bottom of the Bo Chu, when the northerly Bo Chu main glacier coming from Tibet (from Fig. 2, No. 25) - if it ever existed - had already melted. If it existed, then most probably during the LGM; perhaps even just at the time of the earliest Late-glacial stage (stage I according to KUHLE 1997, Tab. 1), i.e., when the ELA had decreased by somewhat more than 1000 m compared with the present-day level. For this reason, the local ground moraine we are talking about must be geomorphologically dated as a milddle or late late-glacial deposit (Fig. 2, No. 20, II-IV = stages II-IV, c 15000-13000 yr BP). Should this northerly main valley glacier have existed, its ground moraine would be underneath this young cover of ground moraine. Otherwise, in the case of a non-existent main valley glacier from Tibet, down from the 5060 m high Yagru Xiong La (No. 25), Ice Age alluvions (gravel floors) would have to lie beneath it.

Some 2.5 km further up the Bo Chu, an orographic left-hand side glacier (No. 21) from the 7312 m high Chomolung Kang, might, in an analogous fashion, have reached the Shisha Pangma east glacier even later than the Bo Chu parent glacier.

The methodologically most important information in this chapter is as follows: Just like a large side valley glacier from the Fuqu Chu coming down from the south flank of Shisha Pangma could have built up the lower Bo Chu glacier, the side glacier from the east of Shisha Pangma could have built up the middle Bo Chu glacier. In both cases, the high catchment areas would be the strongest argument in favour of such a glacial feeding. However, the precipitation from the windward side in the south towards the Shisha Pangma east slope is already noticeably decreasing. On the other hand, on the east slopes, the lower amount of incoming radiation favours formation of the glacier. Accordingly, the main question that now must be answered is whether the northerly upper Bo Chu was ever glaciated. Its glaciation could only have taken place from Tibet.

*Indications of a past glaciation of the upper Bo Chu and its connection to the plateau ice from Tibet*

Up-valley from the junction of the side valley from Shisha Pangma (Fig. 2, No. 20), the Bo Chu has a classic glacigenically-shaped box cross-profile (No. 22) over a distance of more than 20 km. It has been developed from a broad glacial U-shaped valley because of the sedimentation of loose material like ground moraine and, after deglaciation, gravels at its bottom. Nine kilometres up-valley from the junction of the left-hand side valley which comes down from Chomolung Kang (No. 21), a ground moraine cover metres to decametres thick was mapped on the orographic right-hand slope (28° 28'N, 86°09'50"E, 4310 m a.s.l., Fig. 2, No. 23). It lies on top of smoothly polished outcropping sedimentary rocks, whose surfaces show a pattern of parallel, horizontal striations. This is characteristic of a valley glacier which due to its movement and the boulders of the subglacial moraine frozen to its bottom and edges ploughs through its own, partly already consolidated, ground moraine. At the slope foot the moraine mantle was undercut by the lateral erosion of the Sun Kosi river. Here, eroded rills and earth pyramids, typically associated with them, developed. These were formed from more consistent material between the rills, i.e. residually. The material which can, therefore, only be approached as ground moraine is also preserved on the orographic left-hand slope. It reaches on both sides of the valley to c 400 m above the present valley floor. This proves a minimum altitude of the glacier trimline of c 4700 m a.s.l.. Glacigenic flank polishings, however, come up to the culminations of the valley flanks.

The valley cross-profile under discussion is situated at the true head of the Bo Chu valley. Here, the two source branches of this main valley meet at an obtuse angle of 105°. The orographic left-hand branch is still called the Bo Chu. The right-hand one is the Yagru Chu. In the triangle they form is the Yagru Xiong La (also Sho La or Lalung La; Fig. 2, No. 25). Up there at 5060 m, the steep slope on the south edge of the Tibetan plateau begins.

What is the significance of a glacier thickness well over 400 m (see above), here at the root of the Bo Chu (No. 23)? The ice must have crossed this triangular inset between the two source valley branches directly from the Tibetan plateau. In the Bo Chu main valley which begins here, it then collected to form a south Tibetan outlet glacier. This ice supply from Tibet derived from the ground moraine at the main valley head can be empirically verified all over this triangle of plateau. Here, a ground moraine with erratic granite boulders is also to be found (No. 24). In some places, it has become exposed in young fluvial rills. Sedimentary bedrock is in the underground. In other places, as in subordinate talwegs, the moraine is covered by gravel interspersed with pebbles and sand. These have been washed out from the moraine surfaces of the local catchment areas of those rills and small valleys during the deglaciation and post glacial periods. The ground moraine spreads over the entire surface to far above 5000 m. It uniformly covers the Yagru Xiong La (5060 m No. 25) and also the neighbouring kilometres-wide highland areas of south Tibet (No. 26). The polymictic, mostly erratic boulders are rounded, facetted or have rounded edges. They "float" isolated from each other in a matrix of fine material. This is also clearly morainal due to the bimodal grain size distribution (Fig. 6). The c 9 % clay of the fine grain peak characterizes the moraine as ground moraine, as does the predominance of 56.3 % quartz grains which by morphoscopic microscopic analysis is shown to be "glacially crushed" (Fig. 5, 21.08.96/2). The alternative of convergent material which would also be interpreted as "freshly weathered" can be rejected. The material at the culmination of the pass (No. 25) must, because of the horizontal topography and its erratic composition, be far-travelled substrate. The lack of any dip in the slope hinders even any incorporation of in situ weathered material from the out-cropping rock. Two or three kilometres beyond this culmination, glacially streamlined hills have developed in the sedimentary rock on a basal area at 4800 m a.s.l. (Fig. 2, obliquely to the left above No. 26). They are also covered by ground moraine with erratic granite boulders (No. 26). Further to the north there are roches moutonnées and large streamlined glacigenic erosive forms also in the granite bedrock. These are the source areas for (i) the surrounding local moraine (No. 27), (ii) ground moraine with erratics (No. 26) transported in a southerly direction upwards towards the pass (No. 25) and (iii) isolated large erratic granite boulders without a moraine mantle (above No. 26) but also (iv) far-moraine transported over the Yagru Xiong La into the Bo Chu (No. 23) (see above). The sedimentary loose rocks and also the erosive forms described provide evidence of a complete covering of this region of south Tibet by a former glacier.

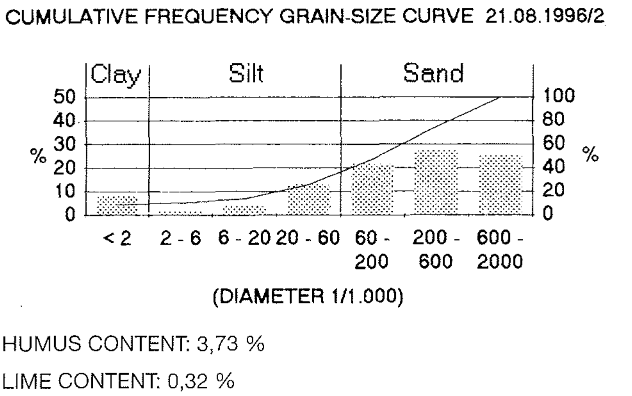



**Fig. 6:** Ground moraine matrix taken from a depth of 0.15 m at 5060 m a.s.l. in the high plateau area of the Yagru Xiong La (cf. Tab. 1, Fig. 5: 21.08.96/2). Locality: Fig. 2, No.25. The characteristic bimodal course of the curve shows a fine grain peak in the clay fraction, typical of ground moraines. Polymict erratic boulders of granite, quartzite and gneiss are incorporated into the humus-containing ground moraine which is slightly weathered on the surface. There are also several limestone components. Metamorphic bedrock occurs in the underground.

**Abb. 6:** In 5060 m ü.M. im Bereich der Hochplateaufläche des Yagru Xiong La aus 0,15 m Tiefe entnommene Grundmoränenmatrix (s. Tab. 1, Fig. 5: 21.08.96/2); Lokalität: Fig. 2, Nr. 25. Der charakteristische bimodale Kurvenverlauf mit einem zweiten Maximum in der Tonfraktion ist typisch für Grundmoräne. Die oberflächlich leicht verwitterte, humus-haltige Grundmoräne enthält erratische polymikte Blöcke aus Granit, Quarzit und Gneis; auch einige Kalkkomponenten sind vorhanden. Im Untergrund stehen Metamorphite an.

Before discussing this result, further field data from south Tibet are to be reported. We are now 15-18 km north of the local watershed between the upper Bo Chu and a few shallow basin-like side valleys which run to the north towards Xaga Chu and into Tibet (No. 28). The gentle slopes (8-15°) down to Xaga Chu are completely covered by ground moraine between c one and several metres thick (Fig. 11) which, typically, consists for the most part of fine matrix. This contains, isolated from each other, polymictic boulders which are fist-sized up to at most head-sized, rounded, facetted or with rounded edges. Among them are also granite erratics. In the underground is sedimentary bedrock. The surface of this lodgement till covering is conspicuously shapeless and smooth (Fig. 11 from ■ to ■ in the back ground). It covers these gentle slopes right up to the towering hills over 5000 m high, south east of Xaga Chu, and even sometimes covers their culminations (Fig. 11 ▲). This provides evidence of their complete former ice covering which can also be diagnosed from their rounded form. From this, the minimum height of the Ice Age glacier surface can be deduced (Fig. 11---). In situ scree slopes which would have been characteristic of a periglacial environment continuing over many hundreds of thousands of years is missing on the slopes (Fig. 11■ on the left). This gives a further indirect indication of Ice Age glaciation. Lastly, the 2-4 m deep rills must be mentioned. They are cut into the lodgement till by the present-day run-off of rain water (e.g. at 28°38'-45'30"N, 86°06'-10'30"E). These new fluvial forms due to the modern climate destroy the former cover of loose rock. This is also proof of a completely different type of morphodynamics during the Ice Age.

A ground moraine exposure deriving from backward erosion of rills (Fig. 2, No. 28; Fig. 11) lies 625 m lower than the water divide on the Yagru Xiong La (No. 25). An only local, small-scale glacier cover would not, on its own, render the thickness of ice (see above) deduced from the shapes of the hills and their moraine covers possible, taking into account such a great difference in altitude. Accordingly, an ice thickness of more than 625 m is necessary. The wide, extensively levelled ground moraine cover which lies over and around the relief of the hills also speaks in favour of this.

A further indicator is the glacigenic trough shape of the Xaga Chu (Fig. 2, No. 29). Its bottom is covered by a layer of gravel made up during the late late-glacial, the neoglacial period and in historical times. The Xaga Chu drains the north side of the Shisha Pangma massif and, therefore, the glaciofluvial gravel floor which is over one kilometre wide and has been developing since deglaciation, can be correlated with the late late-glacial to historical glacier stages IV to c IX (13500-180 yr BP according to KUHLE 1997, Tab. 1) in the Shisha Pangma northern flank (for the glacial history of the Shisha Pangma northern slopes see KUHLE 1988: 468 Tab. 1 and 479-487). Thus, not only the erosive trough shape becomes understandable, but also the later accumulation of gravel due to the more recent glacier history since the LGM. There is no other alternative.

On the trough flanks of the Xaga Chu, the ground moraine described above continues for decakilometres down-valley towards the north-east (Fig. 2, No. 30). As the slopes become steeper, the rills dissecting them become closer. Obviously, these fluvial channels, still shallow for the time being, only started to interglacially reshape the large-scale abrading and also smoothing glacial geomorphology a few thousand years ago. Fluvial geomorphodynamics throughout the whole of the Pleistocene would have left behind a completely different, namely a V-shaped valley landscape divided up into smaller areas.

The glaciogeomorphological results from the southern edge of the Tibetan high plateau and the southerly adjoining upper Bo Chu lead to the following picture. On top of the plateau there was an ice which completely covered the hilly relief. Its thickness was so great that it even filled large valleys north of the water divide, like the Xaga Chu, completely. Large-scale ground moraine covering and the distribution of granite erratics from north of the water divide over the Yagru Xiong La in a southerly direction down into the Bo Chu are evidence of a former ice flow from Tibet. Thus, such a Bo Chu outlet glacier (Fig. 1, right-hand side, or east of Shisha Pangma) arose from a south Tibetan upland ice (Fig.1, I3; cf. also Fig. 3, near the right-hand edge: Tibet Himalaya = south Tibet). It was channelled by the Bo Chu and drained off through the Himalayan breakthrough valley. In the Himalayas, the Chomolung Kang, the Shisha Pangma and the Rolwaling Himal (below Fig. 2) fed this glacier. The glaciogeomorphology of the Man-k'o-pa basin which joins the Xaga Chu in the northeast (Fig. 2, obliquely to the right above No. 30) affects the evidence of a Bo Chu outlet glacier only indirectly. This was described in a previous study (KUHLE 1988, Tab. 1, Fig. 1 and 31).

## EVIDENCE FOR A PROBABLE LAST ICE AGE (LGM) KYETRAK OUTLET GLACIER

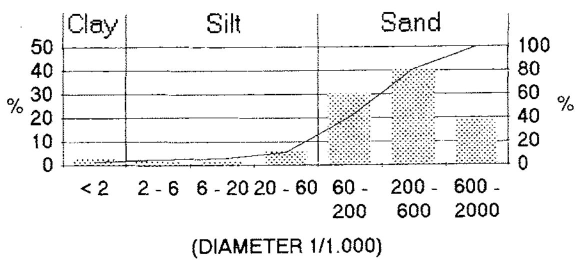
A further glaciogeomorphological key locality is the Kyetrak Chu NNW of the Cho Oyu (Fig. 2). In this context, it is not the present-day direction of descent of the valley which is of importance but rather the direction of its axis. This runs from north to south right through the Himalayas from Tibet. The Kyetrak valley ascends first from the settlement of Ting-Jih to the recent glacier pass Nangpa La (or Khumbu La; Fig. 2, from No. 39 to 31) at an altitude of 5717 m. Beyond the Himalayan water divide (Fig. 2, south of No. 31) the axis continues along the southern Himalayan slopes. There, on the other side of the pass, the valley of Nangpo Dzango and further down the Dudh Kosi valley, run down through the Khumbu Himal. The reconstruction of its maximum Ice Age glaciation has been taking place since 1956. It has led to the consistent result that the lowest end of the glacier must have reached down at least to 1580 m a.s.l. and, therefore, into the valley chamber of Surke in the Dudh Kosi (HEUBERGER 1986: 30; KUHLE 1985, 1987). Where the two tributaries, the Nangpo Dzango glacier from Nangpa La (No. 31) and the Imja Drangka glacier flowed together to form the Dudh Kosi parent glacier (Khumbu parent glacier) (27°53'N, 86°44'E), this had a thickness of at least 600-850 m (KUHLE 1987: 406, Fig. 19: 407/408).

A continuation of the glacier reconstruction south of the Nangpa La is not necessary in this context. Much more important is the question of where the ice came from. Did it flow down exclusively from Cho Oyu, Gyachung Kang and from the neighbouring peaks on the southern side of the Himalayas or did it also come over the water divide from Tibet? In this connection it becomes significant that the Kyetrak valley axis is a direct outlet from south Tibet. At present, it leads down from Nangpa La in a northerly direction (see above), i.e. into the upland (Fig. 2, from No. 31 to 39 and further on towards Ting-Jih). Thus, the problem is the following: Was there a former outlet glacier which flowed over the water divide counter to the slope of the valley? Or, put in another way: Did a thick Tibetan inland ice flow over the bordering Himalayan passes?

*Traces of the maximum former thickness of ice in Kyetrak Chu*

The present-day Kyetrak glacier, 10 km long, flows west of the Cho Oyu (Fig. 12, No. 1) from the 5717 m high Nangpa La (Fig. 2, Fig. 12, No. 31) in a northerly direction along the bottom of the Kyetrak valley (Fig. 12) down to 4800 m a.s.l. (Fig. 2, below No. 32). Investigations of the orographic left-hand, west valley flank have shown that the sedimentary bedrocks (Fig. 12□) are covered with ground moraine. At 5250 m (Fig. 2, No. 33), approximately 600 m above the valley floor (Fig. 12, – 5 on the left), a sample of the matrix of the ground moraine was taken (Fig. 9). The bimodal grain-size distribution and the fine grain peak in the clay (10 %) prove their morainic character. The exposed position of this material on a mountain ridge render an alternative diagnosis of fluvial accumulation impossible. The morphoscopic grain analysis (Tab. 1, Fig. 5, 25.08.96/1) yielded a predominance of 85.7 % glacially crushed/freshly weathered quartz grains typical of ground moraine. They cannot have been generated by fresh weathering in situ for the following reasons: The sample was taken from an earth pyramid which was several metres above the bedrock of the underground (Fig. 12 ➤ ➤). The form "earth pyramid" is proof of far-travelled material. The remains of earth pyramids themselves, as have been studied in the European Alps (e.g. on the Ritten or near Meran at Tirol Castle) and in the Karakorum in classic moraine localities, are evidence of ground moraine as initial material. A proportion of 85.7 % (Fig. 5, 25.08.96/1) of matrix with grains that have been glacially crushed is an extremely high value also for Tibetan ground moraine. The reason for this is the very high relief position which has prevented post-genetic reworking almost completely (cf. below).

CUMULATIVE FREQUENCY GRAIN-SIZE CURVE 23.08.1996/1



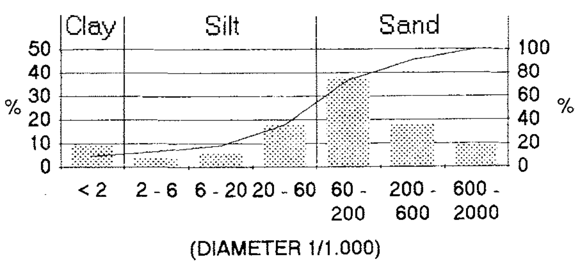

HUMUS CONTENT: 1,89 %

LIME CONTENT: 6,99 %

**Fig. 7:** At 4725 m a.s.l., 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: Fig. 2, No 32. 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 Tab. 1, Fig. 5, 23.08.96/1.

**Abb. 7:** In 4725 m ü.M. im Talboden links der Schottersohle spätglaziale bis historische Grundmoräne im oberen Kyetrak-Tal, 2 km von der Zunge des Kyetrak-Gletschers entfernt, aus 0,1 m Tiefe entnommen. Lokalität: Fig. 2 Nr. 32. Die geringen Ton-Anteile werden auf die bedeutenden Anteile nur wenig transportierter Lokalmoräne zurückgeführt. Diese ihrerseits sind für die enge Tallandschaft des Himalaya, in der sich die Probenlokalität befindet, typisch. S. Tab. 1, Fig. 5, 23.08.96/1.

CUMULATIVE FREQUENCY GRAIN-SIZE CURVE 23.08.1996/2



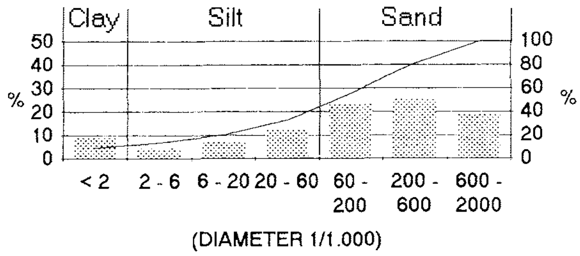

HUMUS CONTENT: 2,58 %

LIME CONTENT: 0,15 %

**Fig. 8:** Sampling at 4730 m a.s.l. from the orographic left-hand late glacial ground moraine- or lateral moraine terrace (Stage III or IV?) c 90 m above the recent gravel floor of the Kyetrak valley. Depth: 0.15 m; locality: 28°22'N, 86°37'50"E, Fig. 2, No. 40. The bimodal course of the cumulative curve, characteristic of moraines, is obvious. The important differences of the carbonate content (cf. Fig. 7, 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 Tab. 1, Fig. 5, 23.08.96/2.

**Abb. 8:** In 4730 m ü.M. aus der orographisch linken spät-eiszeitlichen Grundmoränen- oder Ufermoränenterrasse (Stadium III od.IV?) ca. 90 m über der rezenten Schottersohle des Kyetrak-Tales entnommen. Entnahmetiefe: 0,15 m; Lokalität: 28°22'N, 86°37'50"E, Fig. 2 Nr. 40. Der für Moränen kennzeichnende bimodale Summenkurvenverlauf ist deutlich. Die bedeutenden Unterschiede im Kalkgehalt (vgl. Fig. 7, 9) innerhalb von Moränensedimenten ein und desselben Tales bilden die starke topographische Abhängigkeit des Eisflusses von den Gletschermächtigkeiten unmittelbar ab. S. Tab. 1, Fig. 5, 23.08.96/2.

CUMULATIVE FREQUENCY GRAIN-SIZE CURVE 25.08.1996/1




HUMUS CONTENT: 3,79 %

LIME CONTENT: 17,32 %

**Fig. 9:** At 5250 m a.s.l. sampling of high- to late glacial ground moraine at a depth of 0.1 m on the orographic right-hand flank of the Kyetrak valley, c 600 m above the present talweg. Locality: Fig. 12 ◄; Fig. 13 ▲ right hand, background; Fig. 2 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 Tab. 1, Fig. 5, 25.08.96/1.

**Abb. 9:** Aus 5250 m ü.M. in der orographisch linken Flanke des Kyetrak-Tales ca. 600 m über der heutigen Tiefenlinie aus hoch- bis späteiszeitlicher Grundmoräne aus 0,1 m Tiefe entnommen. Lokalität: Fig. 12 ◄, Fig. 13 ▲ rechts hinten; Fig. 2 Nr. 33. Der bimodale Verlauf der Summenkurve mit dem ausgeprägten Feinkornpeak im Ton ist für den glazigenen Charakter des Sediments kennzeichnend. Die Moräne enthält große erratische Granitblöcke und deckt großflächig anstehende Sand- und Schiefergesteine ab. S. Tab. 1, Fig. 5, 25.08.96/1.

A further proof is obtained with the help of erratic granite boulders in the moraine or on the sedimentary bedrock without any surrounding fine material matrix (Fig. 12 □, ↘↘). These granite boulders and ground moraines (Fig. 12 ↘, ◄; Fig. 13 ○; I) were mapped on the west flank of the Kyetrak Chu over distances of kilometres on slopes, valley shoulders and mountain ridges, covering the reddish silt- and sandstone bedrocks (Fig. 12 □, Fig. 13) as well as the light-coloured limestone rocks (Fig. 2, on the right and diagonally right above No. 33, between No. 34 and 40). Their highest occurrence lies at least 700 m above the level of the valley floor. Thus, the upper level of the past Kyetrak glacier which is indicated by glacigenic accumulations, lay at an altitude of 5500 m. A glacier cannot, however, accumulate moraine and boulders above the snow line. There, glacial erosion and debris transport predominate. At an altitude of 5500 m, we are only 500 m below the present-day snow line (ELA) of the Kyetrak glacier. During the LGM, the snow line was 1000-1200 m lower than it is now, so that these highest accumulations were at least 500 m above the Ice Age snow line (ELA). Therefore, these moraines and erratic granite boulders must have already been a late-glacial accumulation. This also means that the maximum Last Ice Age (LGM) thickness of the glacier cover must have been much greater. Its surface lay much higher than 5500 m, i.e. probably at 5700-5900 m. Geomorphological indications for this conclusion are the mountain ridges and

**Fig. 11:** View from 4435 m a.s.l. (Fig. 2, No. 28; 28°38'N, 86°06'E) into the orographic right-hand flank ot the Xaga Chu facing east. The exposure shows a ground moraine cover (■ foreground) with coarse polymict boulders floating in a matrix wich contains great portions of clay. The boulders (○) consist of granite and quartzite. The granite is erratic, because sedimentary bedrock is in the underground (□). The boulders are rounded at the edges, partly glacigenically facetted (○). The ground moraine sheet (■), part of which is far-travelled, mantles the flat slopes (from the foreground up to the background on the right ■) as well as the steeper foot slopes (■ background on the left) of the mountain ridges rounded by the glacier ground scouring (▲). (----) marks the minimum height of the Ice Age inland ice surface, deduced from the field data. Photo M. Kuhle.

**Abb. 11:** Auf 4435 m ü.M. (Fig. 2, Nr. 28; 28°38'N, 86°06'E) in die orographisch rechte Flanke des Xaga Chu nach Osten fotografiert. Der Aufschluss zeigt eine Grundmoränendecke (■ Vordergrund) mit groben, polymikten Blöcken, die in einer stark tonhaltigen Matrix "schwimmen". Es sind Granit- und Quarzitblöcke (○), wobei erstere erratisch sind, da der Untergrund aus Sedimentgestein besteht (□). Die Blöcke sind kantengerundet, teilweise auch glazigen facettiert (○). Die zum Teil ferntransportierte Grundmoränendecke (■) bekleidet die flachen Hänge (Vordergrund bis Hintergrund rechts) sowie die steileren Fußhänge (■ Hintergrund links) der vom Gletscher-Grundschliff abgerundeten Bergrücken (▲). (----) markiert die Mindesthöhe der eiszeitlichen Oberfläche des Inlandeises, die von den Geländedaten abgeleitet wurde. Foto M. Kuhle.

cupolas above the west flank of the Kyetrak valley - devoid of moraine and/or erratic boulders - which are polished round up to the altitudes mentioned (Fig. 12 and 13 ◓ on the right; Fig. 2, No. 34 and 35).

On the opposite east flank of the Kyetrak valley, classic flank polishings have been preserved up to the same altitude (5700-5900 m). This concerns characteristic forms of glacigenic flank abrasion, such as rochemoutonnée-like ridges situated high up (Fig. 12 ◓ directly below No.4 and 8; Fig. 2, between No. 32 and 36), back-polished glacially truncated spurs with rounded edges and rock crests (Fig. 2, No. 37, left above No. 36 and on the right to diagonally right above No. 32; Fig. 12 white left) and a striped flank polishing due to exaration. Its lineation traces the outcrops of the strata. (Fig. 12 ◓ on the very left; Fig. 2, diagonally left below No. 36). In many places, the two forms (outcrop and polishing) are combined and interfere with each other. In the Kyetrak valley, this so-called "Schichtkopfstreifenschliff" (outcrop strip polishing) (cf. VON KLEBELSBERG 1948/49) has marked the triangular-shaped slopes of back-polished spurs with a pattern of lineation towards the south (Fig. 13 ◓ on the left).

Only in a few places is the upper east valley flank, characterized by removal, covered with remains of moraine (Fig. 12 ▲▲). Their decametres-thickness is recognizable from afar due to the earth pyramids and the rills between them. Here, late-glacial ground moraine material is concerned. It was left by local eastern side glaciers which joined the Kyetrak glacier north of Cho Oyu and Gyachung Kang (Fig. 12, No. 1 and 2). The assumption that there were junctions is based on the very high positions of the moraines at the exits of the side valleys, several hundred metres above their valley floors. The upper border of the flank polishings on the eastern slopes of the Kyetrak valley allows the diagnosis of a continuous polishing limit, falling slightly away from north to south (Fig. 12 ----0 0----, Fig. 13 ----0). This can only be the minimum altitude of the Ice Age (LGM) trimline of the Kyetrak glacier. The maximum ice level was probably only reached for a short time and is, therefore, geomorphologically hardly discernible - which is why its late-glacial and post-glacial complete obliteration is probable and any remaining signs of it improbable.

The Kyetrak valley was, therefore, filled by a glacier at least 1000 m thick during the Last Ice Age whose surface (Fig. 12 and 13:----0 0----, ----; 0) was inclined counter to the inclination of the valley floor. This means an ice drainage direction at that time towards the south over the Himalayan water divide,


**Fig. 13:** Taken at 5300 m a.s.l. from the orographic left-hand flank of the still very wide Kyetrak Chu (valley) (Fig.2, right of No. 34) to the south. There are erratic granite boulders, partly well-rounded, in the foreground (O, sitting person for scale). They lie on surficially weathered reddish bedrock sandstones. Angular local moraine boulders of limestone, moved only a little, are also preserved on sandstone. (■ below ----0; I, II, III and IV) are ground moraines and lateral moraines of the LGM to late-glacial. I ■ ◓ on the right is shown in detail in Figure 12. ( ◓ ) 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 outcropping edges of metamorphic sedimentary rocks ( ◓ on the right). (----0) indicate the minimum height of the High Glacial glacier levels, deduced from this geomorphology. Photo M. Kuhle.

**Abb. 13:** Foto aus 5300 m ü.M. von der orographisch linken Flanke des noch immer sehr breiten Kyetrak Chu (Tal) (Fig. 2 rechts von Nr. 34). Erratische Granitblöcke, teilweise gerundet, sind im Vordergrund zu sehen (O, sitzende Person als Größenvergleich). Sie liegen auf anstehenden, oberflächlich verwitterten, rötlichen Sandsteinen. Auch eckige lokale Moränenblöcke aus Kalk sind auf dem Sandstein erhalten. ( ■ unter ----0; I, II, III and IV) sind Grund- und Ufermoränen vom Hochglazial (LGM) bis Spätglazial. I ■ ◓ rechts ist in Abbildung 12 detailliert abgebildet. ( ◓ ) markiert vom hochglazialen Gletschereis gerundete Bergrücken, welche auf der orographisch linken Talseite ohne Ausnahme in Schichtköpfen von metamorphem Sedimentgestein ausgebildet sind ( ◓ rechts). (----0) bezeichnet die von dieser Geomorphologie abgeleitete Mindesthöhe der hochglazialen Gletscherstände. Foto M. Kuhle.


**Fig. 12:** At 5250 m a.s.l. from the mountain 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: Fig. 13: I on the right below 31; Fig. 2, right-hand of No. 33. In the background is the Himalaya main ridge with 1 = Cho Oyu 8201 m, 2 = Gyachung Kang 7975 m, 3 = Nuptse 7879 m, 4 = Changtse 7580 m, 5 = Cho Aui 7352 m, 6 = 7296 m peak, 7 = 6907 m peak, 8 = Tongqiang peak 6901 m. (□) are the bedrock schists on which erratic granite boulders have been deposited (↘ ↘). Further up the erratics are embedded in the ground moraine matrix (■ 0); (cf. Fig. 9 and Fig. 5, 25.08.96/1). (⅄ ⅄) are earth pyramids from high- to late glacial moraine material (stage 0 to I, possibly even younger?). The erratic granite boulders (■ 0) reach up to a height of 5500-5600 m and thus c 700 above the valley bottom of the Kyetrak Chu (on the left – 5). They are the highest accumulative prehistoric glacier traces and have therefore been marked as 0 (Last High Glacial, Würm, LGM). Probably, however, they are even younger, so that their deposition belongs to a late glacial snow line which had already increased. The High Glacial (LGM = Stage 0) snow line (ELA), on the other hand, had descended to c 5000 m or even some hundred metres lower. (▲ ▲) are significantly higher traces of Ice Age glaciaerosion: the mountain ridges are polished and thus rounded by the ground polishing. (----0, 0----) mark the minimal height of the ice surface of the maximum past glacier cover, belonging here to the Kyetrak Chu outlet glacier, which flowed down from the south Tibetan ice stream network to the south over the watershed of the Himalaya (Fig. 3). (■ I, ■ II, ■ III) are late-glacial ice levels. (▲) are earth pyramids in morainic material. Photo M. Kuhle.

**Abb. 12:** Foto aus 5250 m ü.M. vom Gratrücken zwischen Kyetrak Chu (Tal; links) und Chomolung Chu (rechter Talhang; Name entsprechend der Information tibetischer Yak-Nomaden, August 1996). Lokalität: Fig. 13: I rechts unter 31; Fig. 2 rechts von Nr. 33. Im Hintergrund der Himalaya Haupt-Kamm mit 1 = Cho Oyu 8201 m, 2 = Gyachung Kang 7975 m, 3 = Nuptse 7879 m, 4 = Changtse 7580 m, 5 = Cho Aui 7352 m, 6 = 7296 m peak, 7 = 6907 m peak, 8 = Tongqiang peak 6901 m. (□) ist anstehender Schiefer mit aufliegenden erratischen Granitblöcken (↘ ↘). Weiter aufwärts sind die Erratika in Grundmoräne gebettet (■ 0) (vergl. Fig. 9 und Fig. 5 Diagramm 25.08.96/1). (⅄ ⅄) sind Erdpyramiden aus hoch- bis spätglazialem Moränenmaterial (Stadium 0 bis I, vielleicht jünger?). Die erratischen Granitblöcke (■ 0) sind bis in eine Höhe von 5500-5600 m anzutreffen, d.h. bis 700 m über dem Talboden des Kyetrak Chu (links – 5). Es sind die höchsten akkumulativen, vorzeitlichen Gletscherspuren, weshalb sie mit 0 (Letztes Hochglazial, Würm, LGM) bezeichnet worden sind. Wahrscheinlich sind sie aber jünger, d.h ihre Ablagerung gehört bereits zu einer weiter angestiegenen späteiszeitlichen Schneegrenze. Die hochglaziale (LGM = Stadium 0) Schneegrenze (ELA) hingegen war auf ca. 5000 m gesunken, vielleicht auch noch einige hundert Meter tiefer. (▲ ▲) sind sogar deutlich höhere Spuren eiszeitlicher Gletscher-Erosion: Die Gebirgskämme sind geglättet und gerundet durch Grundschliff. (----0, 0----) ist die minimale Höhe der Eisoberfläche der maximalen vorzeitlichen Gletscherbedeckung, die hier zum Kyetrak Chu Auslassgletscher gehört. Er floss vom südtibetischen Eisstromnetz über die Wasserscheide des Himalaya nach Süden hinab (Fig. 3). (■ I, ■ II, ■ III) sind spätglaziale Eispegelniveaus. (▲) sind Erdpyramiden in Moränenmaterial. Foto M. Kuhle

flowing between the Cho Oyu massif and Peak No. 7 (Fig. 12 between No.1, 6, 5, 7) through its main ridge. This, however, can only be true for surface ice, a few hundred metres thick. Only surface ice could have flowed over the rock saddle which still today lies underneath the ice of the modern Kyetrak glacier on Nangpa La (Fig. 2, 12, 13: No. 31). The lower ice layers are dammed up by the rock saddle up to its own level. The exact height of the rock saddle is unknown, but can be approximated. The present-day Nangpa La pass lies at 5700 m a.s.l. on an almost horizontal glacier surface the size of 700 x 700 m. Looking down in the longitudinal direction of the glacier, the top of the pass is a very flat area of 3.5-4 km in length with a surface of firn and ice at a gradient of hardly 1°. The valley glacier transverse profile thereby constructed allows a glacier thickness of 500 m to be concluded for the pass. The rock threshold would, therefore, lie at a height of c 5200 m. At times, the Ice Age Kyetrak outlet glacier could have flown at about the same thickness over the rock threshold into the Himalayan southern slopes. The past polishing line (see above) sloping towards the south is an indication for this because of the fact that - coming to an end - it joins, approximately on the Nangpa La, the present- day glacial surface (Fig. 12, 0---- up to No. 31, Fig. 13 ----0).


The existence of a former Kyetrak outlet glacier has been proved by the shown thickness of the ice and the associated glacier level which must have been several hundred metres above the rock threshold on the Himalayan water divide.

*Reversal of direction of drainage of the Kyetrak glacier by 180°*

The early glacial build-up of ice can no longer be determined, because the associated moraines have been removed and reshaped. It can, however, be understood by reversing the successive Late Ice Age deglaciation process. Just as during the development of ice, the drainage of a small interglacial Kyetrak glacier from a northerly direction is blocked by the formation of inland ice pressing in from the north (Fig. 1, I3; Fig. 3, in the right fifth) and then turned towards the south, so too has the deglaciation in southern Tibet now again led back to a Kyetrak glacier drainage dependent upon local relief, towards the north.

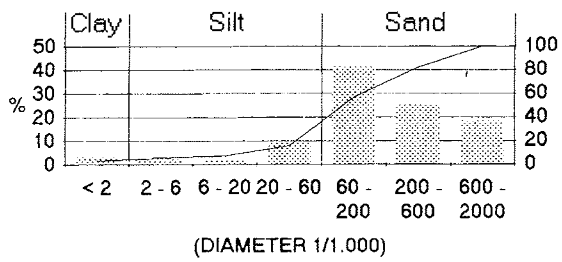
This reverse development from the Ice Age to the interglacial ice drainage is documented by the moraine ledges on both valley flanks (Fig. 2, between No. 32-38: I to IV). During the early-late-glacial Stage I, the ice level was still so high (Fig. 13, cf. position of I with the Nangpa La pass below No. 31) that an outlet glacier with its continuous surface incline towards the south over the Nangpa La rock threshold could possibly have existed. A lateral moraine remnant of this stage has been preserved on the west valley flank (Fig. 2, I to the right of No. 35). The change in direction of the drainage of this ice occurred at the latest during the late-glacial stage II (Fig. 12 ■ II; 13 II) (for the ages of the stages I, II. III. IV to XII, see Kuhle 1997, Tab. 1). From this time onwards, the ice level had melted so far down that only a local Kyetrak-Himalayan glacier still existed. The tongue ends of its late-glacial stages II, III and IV flowed down to the plain of Ting-Jih at 4500 to 4300 m. This is proved by the hilly end moraine landscape (down to 28°25'N, 86°37'E; Fig. 2, below No. 38).

The diametrically opposed direction of ice drainage in the LGM towards the south and from the late-glacial to the present time towards the north is reflected in the significant difference in lime content of the moraines: whereas the oldest ground moraine of the LGM or the early late-glacial period contained 17.32 % (Fig. 9), the younger moraines only show 0.15-6.99 % (Fig. 7 and 8).

The most prominent late-glacial end moraines of the stages III or IV (Fig.2, between No. 32 and 38; Fig. 8) contain at least 45.5 % glacially crushed material (Tab. 1; Fig. 5, 23.08.96/2). Since the samples were taken from the surface of a decametres-thick moraine sediment, kilometres away from the outcropping rocks, confusion with freshly weathered material can be completely excluded. A further 37.8 % of the material is also roughened. It cannot, however, be morphoscopically excluded that this could have happened by aeolian corrasion. That would, after all, have been possible in the cold-arid milieu concerned. Late-glacial up to Holocene ground moraine matrix, taken from the drainage track of the Kyetrak glacier (Fig. 7), contains 52.1 % material from the group "glacially crushed" (Fig. 5, 23.08.96/1), i.e. as would be expected, more ground material than the lateral and end moraine matrix. The fraction of $SiO_2$-grains which could have been roughened in an aeolian process (38 %) is of similar size. The history of the glacier described for the region includes such frequent glacigenic displacement of the matrix in the course of the Pleistocene that its granulometry and morphometry are generally very uniform. All the more meaningful evidence for its origin from the edges of the glacier or from the underground is gained from the very clear statistical differences with respect to the formation of quartz grains.

These late-glacial ground and end moraines were deposited on the ground moraine plain of Ting-Jih which emerged in the LGM (= stage 0) (Fig. 2, No. 38). The typical bimodal grain size composition with a small clay peak proves an intensive postgenetic washing-out of this plain (Fig. 10) typical of these kind of fore-fields of the late-glacial ends of the glaciers.

CUMULATIVE FREQUENCY GRAIN-SIZE CURVE 26.08.1996/2




HUMUS CONTENT: 0,72 %

LIME CONTENT: 1,26 %

**Fig. 10:** 4265 m a.s.l., matrix taken from a depth of 0.1 m from the ground moraine plain of Tingri (Fig. 2 No. 38). It belongs to the LGM (= stage 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 carbonate content evidences that the material has been transported from the north, where the limestone bedrock is located.

**Abb. 10:** In 4265 m ü.M. aus 0,1 m Tiefe entnommene Grundmoränenmatrix von der Ebene von Tingri (Fig. 2 No. 38), die ins LGM (= Stadium 0) eingeordnet wird. Die Korngrößensummenkurve hat den für Moränen charakteristischen bimodalen Verlauf, wobei der Feinkornpeak im Ton nur schwach (mit 4 %) ausgeprägt ist. Der Peak im Feinsand (41 %) ist dagegen sehr deutlich. Der Kalkgehalt belegt die Transportrichtung des Materials von Norden her, wo der Kalk ansteht.

## DISCUSSION OF THE LITERATURE

ZHENG BENXING (1988: 535, Tab. 3) also considered lateral and end moraines from the plain of Ting-Jih which the author included in the late-glacial stages III and IV to be glacigenic deposits, but classified them as belonging to his "Qomolangma glacial". He, therefore, puts them in the pre-last- and in the Last Ice Age ('penultimate and last glaciation'). His interpretation was also applied to the Chinese Quaternary Glacial Distribution Map (SHI YAFENG et al. 1991). The discrepancy occurring yet again in the age classification of end moraines, for which the author assumes a late-glacial age of c 14000-15000 yr, whereas ZHENG BENXING determined a middle Pleistocene age, has been extensively discussed for the neighbouring Tibetan Shisha Pangma foreland (cf. Fig. 1; see KUHLE 1988: 479-483).

The ground moraines in the plain of Ting-Jih and in the highest positions which are more important for our question, as well as even higher erratics and glacial traces in the Kyetrak valley, which the author classifies as belonging to the Last Ice Age (see above) have only been incompletely or not at all mapped by ZHENG BENXING. He did not even consider an ice transfluence into the Himalayan southern slopes (cf. ZHENG BENXING & SHI YAFENG ZHENG 1976, SHI YAFENG et al. 1982).

In contrast, three quarters of a century before the author, ODELL (1925: 331) reported his result of a complete glacier cover of the Ting-Jih basin. He found erratics containing ammonites on Phusi La (5411 m a.s.l.), 300 m above the present-day Kyetrak glacier and concluded that the flow of ice must have been in the opposite direction from north to south over the water divide. These boulders of Jurassic rock lie on top of pre-Jurassic metamorphic crystalline rocks. ODELL (1925) suggests that the transport distance between the original position of the rock in the north to Phusi La was at least 30 km (see KUHLE 1988: 464/465).

### *A kame on the ground moraine plain of Ting-Jih and further data on the lower Kyetrak Chu*

Six kilometres north of the late-glacial end moraines (Fig. 2, III to the right of No. 38), there is a kame on top of the ground moraine surface of Ting-Jih (No. 39: 38°31'N, 86°34'E; basic altitude 4220 m a.s.l.), which stretches from north to south for about 1 km and has a rhombic outline. It is 40 m high and consists of horizontally layered components the size of sand up to gravel. Situated several kilometres away from the east and west valley flanks of the Kyetrak Chu (cf. Fig. 2, No. 39), it lies geomorphologically isolated from these by the ground moraine plain. Thus, it cannot be interpreted as a glacial border kame terrace. The kame must, therefore, be interpreted as a sediment body which was filled into a hole in the ice caused by supraglacial meltwater in the middle of the outlet glacier. This happened in the late-glacial period (stages I and II) when the south Tibetan ice stream network I3 (Fig. 1, Fig. 3, in the right-hand fifth) melted. It was held in place by the walls of ice acting like a baking tin.

The eastern slopes of the Kyetrak Chu are mountain ridges 4400 to 5675 m high which have been polished round by the covering of glacier ice. In some places, there is still moraine on the slopes (Fig. 2, No. 41). Its soft, light-coloured loose rock can easily be recognized from a distance by the fresh erosion rills.

The former glaciation of Rongbuk, Dzarka and Arun Chu adjoining this mountain region to the east, north of Mt. Everest, was already investigated during two three-months expeditions in 1984 and 1989 (KUHLE 1988, 1991).

East of the settlement of Ting-Jih, which itself lies in an ice age (last high glacial maximum = Würmian) ground moraine region, is the Pum Chu (Fig. 2). Along its course (east of the section in Fig. 2), the author found no clear indications of a past glaciation. Therefore an ice-free valley region stretching for a few decakilometres towards the east is assumed. This contained an ice-free lake. On this subject and concerning the former glaciation of the more easterly regions, field data and their analyses have also been presented.

## CONCLUSION

Both the Bo Chu and the Kyetrak Chu were, as concluded from absolute and relative datings from neighbouring regions (KUHLE 1998), filled by glaciers during the Last Ice Age. These were 75 and 100 km long and flowed down to about 900-700 m and 1500 m a.s.l. respectively, reaching the south Himalayan foothills. The two ice streams originated 30 and 60 km respectively north of the Himalayas in Tibet. There they emerged from a more than 1000 m thick covering of inland ice at an altitude of 4200 to 5200 m a.s.l. (Fig. 1, I3 between Shisha Pangma and Mt. Everest). Its edge had in the north-south course of the two valleys flowed over both a 5060 m (Yagru Xiong La: Fig. 2, No. 25) and an approximately 5300 m (Nangpa rock threshold below the present-day Nangpa La: Fig. 2, No. 31) high pass. These were, therefore, south Tibetan outlet glaciers which followed the Bo Chu and the Kyetrak Chu transverse valleys and were joined in their middle sections by local Himalayan glaciers. These new findings confirm earlier results from the western, northern and eastern adjacent regions.

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