Editors' Preface

The co-operation begun by Chinese and German scientists in 1981 has since then led to four joint expeditions to High Asia and Tibet. The investigations of the 1981 and 1984 expeditions dealing with glacial geology, climatology, geoecology, and especially with Pleistocene studies and glaciology, have already been published in a first volume (GeoJournal vol. 17, no. 4, December 1988, edited by Matthias Kuhle and Wang Wenjing). The present, second, volume contains the research results of the 1986 and 1989 expeditions, in both of which the Chinese and German editors have taken part.

In 1986 the expedition went to the area of the Karakorum north slope (K2 or Chogori Feng) and of the Aghil and Kuen Lun mountains on the western edge of Tibet, in 1989 to the Tanggula Shan (central Tibet), to the Namjagbarwa Feng and into the Arun valley (southern Tibet) with the adjoining eastern side of Mt. Everest. The Chinese and German leaders of the expedition and editors of this volume both wish to thank the Deutsche Forschungsgemeinschaft, the Max-Planck-Gesellschaft and the Academia Sinica for their financial support of the two expeditions.

The first contribution (M. Kuhle) presents findings and evidence for an Ice Age glaciation of the interior of High Tibet from the centre of the plateau to its southern edge, on the basis of original investigations in areas of the High Himalayas carried out in 1989. An investigation of the geomorphology and Quaternary glaciation of the Karakorum north slope, evaluating the 1986 expedition, is presented by Xu Daoming. The study by Y. J. Ding also stems from this work in the field. It is a comparison of precipitation data of the nearest weather stations with snowfall in recent glacier feeding areas that aims at extracting an altitudinal gradient.

Shen Yongping analyses the morphodynamics of avalanches in the NE- and NW-facing walls of K2 in the source area of the K2 glacier (Karakorum). The investigations by Feng Qinghua address the problem of glacier reservoirs on the Karakorum north slope in the Shaksgam and Yarkand areas in respect of their sudden overspills, which tend to have catastrophic consequences for the areas of settlement. This is a case of linking fundamental research with its applications. The results of plant research carried out in the Karakorum north side during the 1986 expedition are presented by W. B. Dickoré. They concentrate on the vegetation zonation of the mountains. The final contribution of this volume is by S. Meiners; she analyses the upper limit of alpine land use in central and southern Tibet under the special conditions of different supplies of precipitation and of varying topographical conditions.

The editors wish to thank both Dr. Wolf Tietze, the Editor-in-Chief, for the generous publication of this second volume, and the different authors for their contributions. Thanks are also due to Mr. C. A. Halstead, Mrs. I. F. Hellen, Dr. J. A. Hellen and Dr. Mikhail Sokolov for the translations into English.

Göttingen and Lanzhou, May 1991 — Matthias Kuhle and Xu Daoming

Observations Supporting the Pleistocene Inland Glaciation of High Asia

Kuhle, M., Prof. Dr., University of Göttingen, Department of Geography, Goldschmidtstr. 5, 3400 Göttingen, Germany

1. Introduction and Aspects of Method

Research in the field was carried out in the period between August and November 1989 by a gemorphological expedition financed by the Deutsche Forschungsgemeinschaft, the Max Planck-Gesellschaft, and the Academia Sinica. They concern sections of Tibet which had hitherto *not* been *accessible* to investigations of that kind, with the exception of the area of SW Nyainqentanglha (central Transhimalaya), extending to and beyond the Latzu massif (Lhagoi Kangri) and the Panga La (Pazhug, Tibetan Himalaya) as far as the Dzakar Chu where we had been able to work in 1984 (Kuhle & Wang Wenjing 1988) (Fig 1, No. 9).

The *special method of glacier reconstruction* must account for the fact, that it is a matter of reconstructing chaotic systems, which continually form different, that is new, indicator constellations. Statistical methods cannot be applied at all in this case. What is needed is evidence through *indices* which provide an all-in argument by presenting continual constellations, referring to a great number of homologous indicators where the differences of the regional findings can be attributed to the differences of topography.

The *central* reference and proof of evidence is consequently not provided by a single glacial-geomorphological phenomenon, like striated boulders, a diamictite deposit, or a steeply rising bank of gravel deposits, but by the *locational relationships* of such phenomena to each other (Kuhle 1990 b, pp. 206–211). For example: the more elevated glacial polishing occurs on the valley side, the more *extensive* glaciation of the territory has been, which has thus been proved. Fig 2 (scheme of homologous characteristics) explains these locational relationships with the help of a catalogue of 15 indicators. As a rule, a limited number of these glacier indicators have to suffice as it is rare for *all* phenomena to occur, and even rarer for them to be preserved since the high-continental, periglacial milieu has an extraordinarily effective and rapid influence on the fine traces of glacial polishings in the Tibetan sedimentary rocks.

The principle adopted here is best shown by the following statement:

"There are never any two situations in the field which present identical glacial-geomorphological phenomena, that is have experienced identical *glacial developments*". Although prehistoric *glacial developments* is a non-biological and non-intelligent - ie *non-adaptive* - system, its conditions are nonetheless too individual and too varied to permit far-reaching generalisation. Even minor topographic-climatic differences may result in a *dichotomous* character. Small differences in the gradient of a valley or in the altitude of catchment areas may, for instance, determine *which* part of a glacier stream forms an

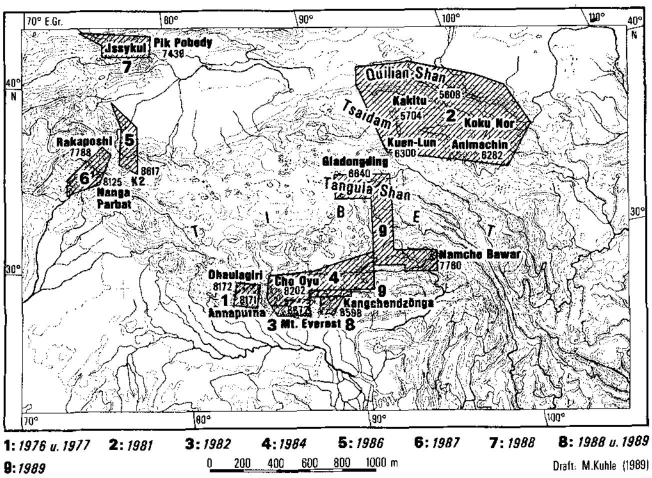


Fig 1 The areas in High Asia under investigation by the author science 1976

ice marginal site at the valley exit or in a mountain foreland. This may, in turn, decide the indicative value of finding erratica at a certain point in the field, as for example on an intermediate watershed etc.

For instance, one has to recognize that the interaction of a complicated mountain relief with the high plateau of Tibet has created a particularly significant type of mountain foreland, which in this special configuration plays an essential role in the formation of glaciers. This fundamental fact of glacio-geomorphological method points to the *only possible way of marshalling evidence* for both process and way of presentation. Statistical statements are almost entirely omitted. In their place *topographically* orientated description of the field takes on an essential role. It is the *basis* of all evidence of glaciation.

The presentation of findings in the field in ten chapters does not pay regard to the chronology of obtaining them in the course of expeditions. It begins with the description of the *central Tibetan* Tanggula Shan as a massif from which glacier ice has always flowed out throughout the Pleistocene Ice Ages. This implies that this particular group of mountains has never been reached by a forward-thrusting complex of inland ice flowing towards it. On the contrary, the accumulation of inland ice has taken place on the spot and moved out from there. Following the growth structure and run-off dynamics of the inland ice, the description moves from the centre to the marginal areas of central High Tibet visited by the author. This was orientated to the Nyainqentanglha mountain system in the S, which borders on the valley of the Tsangpo (Yarlung Zangbo Jiang) (Fig 43). The Tsangpo furrow is the lowest area of S Tibet and drops from c. 3900 m at Xigaze (Shigatze) to 2800 m asl at the Namjagbarwa Feng. The topographical consequence of this is the formation of a deeply dissected valley region in contrary to the central high plateau. A glacial cover resembling a network of ice streams must have taken the place of the inland ice (cf Kuhle 1987 a, p. 413, Fig 27). Conditions of the remnants of the high plateau of the Tibetan Himalaya S of the Tsangpo (Yarlung Zangbo Jiang) up to the Arun valley (Pum Qu) and the valleys of its origin on the N edge of the High Himalaya must have been similar. In the Arun valley (Pum Qu) the Ice Age outlet glacier has left the Himalaya towards the south. This is the subject of the last two chapters of this study (chapters 10 and 11).

The concept thus emerges clearly as being dependent upon topography and altitude above sea-level in relation to the prehistoric ELA (snow line) and the resulting glaciation. The author therefore begins with the *most central* area, which experienced the *longest-lasting period* of inland glaciation and will again be first affected during any future *long-term uplift above the snow line.*

2. The Central Tibetan Area of the Tanggula Shan (33°-33°45'N/90°30'-92°30'E) (Fig 1, No. 9; Fig 43)

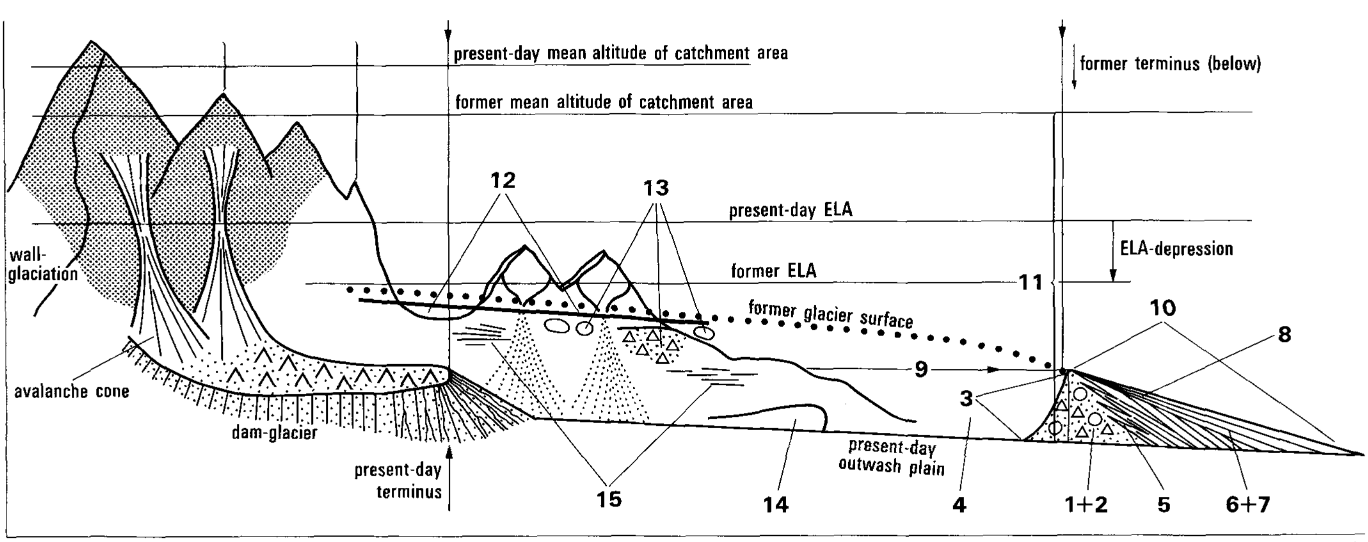
In the region of the Tanggula Shan the altitude of the Tibetan plateau is about 5000-5300 m. The Geladaindong massif rises from this level to a height of 6525 (or 6621) m (Photos 1 and 2, No. 1). Consisting of *corrie and hanging glaciers* with flanking ice and firn-ice shields, but also of valley glaciers of more than 10 km (Photos 3 and 4) *recent glaciation* is adapted to the *level* of the *mountain foreland* (Photos 5, 6, 2). Situated at c. 5300-5400 m asl, the extremities of the glaciers are almost all in the process of retreating. A convincing example is the Geladaindong glacier (Photo 5), the end of its tongue having lost its compact edge as it became torn into individual *strands of ice pyramids and complexes.* It is not only the altitude of the mountain foreland at exactly that altitudinal range which glaciers attained during a recent glacial snow line at about 5600-5700 m, which makes the ice flow stop precisely at that point, but another important factor - namely, the *petering-out of the container-valleys* towards the forelands so that the ice of the glacier margin is able to *disperse radially,* thus putting an end to outflows reaching further into the foreland. The ice masses required for this are no longer there, ie there is a *topographically-conditioned run-off threshold* towards the foreland of the mountain ranges. It is founded in the altitude above sea-level, *as well as* in the sudden change from a *valley landscape* to a *highland terrain without a rim.* The Geladaindong massif is the model for the ten massifs of the Tanggula Shan, which are now glaciated. Measuring almost 1000 km^2, it is by far the largest glacier area.

Further uplift above the ELA, which is likely not only for tectonic but also for *glacio-isostatic* reasons (cf Mörner 1978; Kuhle 1988 a, pp. 483-485; 1989 a, pp. 282-284; Chen

1988) will produce more and more favourable conditions for the *enlargement of glaciers.* A raising of the relief by 100 m above the snow line causes the lower edge of the glacier concerned to reach down another 150 m to approximately 200 m. The future interaction between *relief* and snow line can be imagined by observing *late* to *neo-glacial deglaciation* of the area in *reverse chronology,* evidence of which exists in moraine ranges. After the raising of the ELA above the *mean altitude of the plateau* of central Tibet during the Late Glacial (cf. Kuhle 1987 a, pp. 418–420, Fig 31; 1988 b, p. 593; 1989 a, pp. 282–284), the total cover of the inland ice street of the Glacial Maximum also disintegrated into individual ice caps attached to a mountain group of that kind. Forming around these particular mountain groups, glaciation created concentric *piedmont glacier edges.* This took place at a time when the ELA was set about 100 to 200 m *deeper into the relief* than is now the case. The *glacier feeding grounds* at the valley heads were more extensive at that time (Photos 1, 3, 4), and the ice-filling of the relief attained this *extensiveness of area* by extending the cross-sections of the original glacier arms. Their terminal and abandoned lateral or medial moraines are situated 1 to 10 km away in the forelands of the mountain groups concerned (Photo 2▼, 3▼, 5▼, 6▼; Fig 43, No. 1). It is *not possible to be sure* of the *climatic conditions* prevailing in central Tibet at the time of the late Late Glacial or early Neo-Glacial period. The subject under consideration here is solely the *interaction of relief and ELA.* Above all else the ELA must have risen so far above the central plateau that the thickness of the inland ice is

Fig 2 Scheme of homologous features of glacial indicators and marginal *sandurs* (design: M. Kuhle). Points 1–15 are homologous features of the glacial landscape; thanks to their spatial coordination they present mutually supportive evidence of pre-historic formation through an ice stream and thus permit statements to be made at a high level of probability.

1. Grains vary greatly in size and type of rock, their forms varying from angular to rounded.
2. The material (1) is not stratified, ie it is totally mixed.
3. The material occurs in the form of walls with an extremely steep slope on the side facing towards the mountain.
4. A tongue-basin-shaped area of excavation occupies the up-valley area of the wall.
5. Stratified, and sorted according to grain sizes, material on the outer slope dove-tails jaggedly with the unsorted material of the wall, thus providing evidence of their synergetic formation.
6. The wall's down-valley material has been sorted according to grain sizes, and stratified by water during fluvial processes.
7. The material is dominated by rounded to very well rounded components, with their longitudinal axes adjusted at right angles to the direction of transportation.
8. The inclination of strata decreases from the core of the wall to the surface.
9. The wall's outer slope is formed by these fluvial gravel strata, and is considerably steeper than the recent gravel floor; this cannot be explained by the present topography.
10. Small valleys, which have been let into the surface of the cone, start as a notch at the top of the wall without expanding into a catchment area, and do not correspond with recent climatic conditions.
11. The pre-historic snowline (ELA, GWL) with a depression that contrasts with the recent, ie present, snowline. This depression has a definite relationship to the altitude of the mountain catchment area and the altitudinal situation of that wall (1–10); ie in very high mountains such a wall will occur very far down and far out in the mountain foreland. In lower catchment areas, on the other hand, it occurs at a higher level, ie also nearer to the mountain or even – in any case up-valley – closer to the catchment area.
12. Polish lines and transfluence passes.
13. On transfluence passes and rock shoulders there are chaotically mixed deposits as well as erratic blocks, which can only be explained by glacier transport considering their size and considerable distance.
14. There are glaciated knobs and polished rock areas within the tongue basins.
15. Glaciated knobs and valley floors show glacier striae, the pattern of which follows the valley gradient.



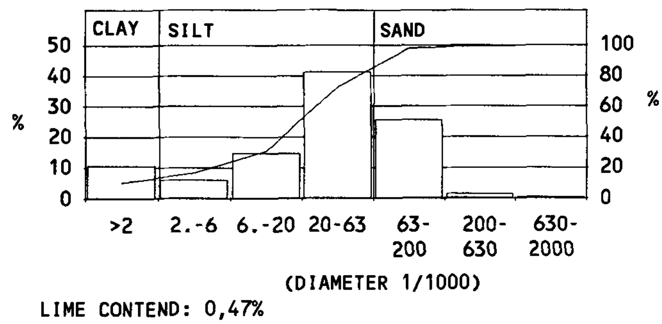


Fig 3 3.8.89/3. Ground moraine material, pedestal moraine, 4000 m asl, S of Lhasa: Fig 43, No. 48; sand 27.7%, silt 61.7%, clay 10.6%.

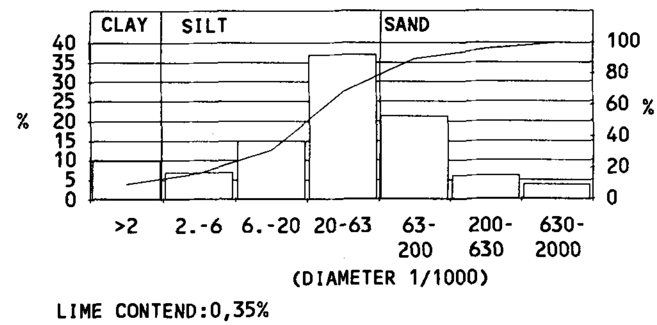


Fig 4 5.8.89/1. 30 km ENE of Lhasa, ground moraine on transfluence pass, 4560 m asl; Fig 43, No. 49; taken from a depth of 50 cm; sand 31.3%, silt 58.8%, clay 9.9%.

calculated by the author to be several kilometres at a maximum (Kuhle 1988b, p. 591; 1989a, p. 267, Fig 3 and 4 inter alia) - melting down so far that a glacio-isostatic depression resulting from the glacier load must have been followed by a *glacio-isostatic uplift* (Kuhle 1988a, pp. 483-485). This uplift intensified only after the burden of inland ice had largely *melted away*. In conjunction with the process of uplift more mountain terrain will sooner or later have to rise again above the ELA and become a glacier-feeding area. If this is not yet the case at present, and there are indications of that in the most recent *glacier regression* (Photo 5●; 3●); the process is *superimposed* by an even faster *rise of the snow line*. According to worldwide historical oscillations of climate, it is only a short-term process of super-imposition. In general, however, the glacier-feeding areas will clearly rise above the ELA by one cm or more per year over the course of the coming centuries. In a few thousand years the glacier edges will accordingly extend over several kilometres into the mountain foreland in order to bring about *depressions of ice margin sites* of 100 to 200 m.

Here at the *centre* of the Tibetan inland ice associated with the *Main Ice Age*, the question of *maximum glacial thickness* remains. It would be important if relatively "hard" indicators could be made available. The most important ones are *smoothly polished mountain ridges* (Photos 4▲ and 6▲). In the E foreland of the Geladaindong glacier they tower up to 5800-6000 m asl (Fig 43 No. 2), where they are covered by recent perennial snow patches or firn and small hanging glaciers (Photo 6▲). These current morphodynamics point to the *destruction* of the smoothly polished forms, since it produces *sharp-edged frost cliffs* and *rocky ledges* in the wake of linear snow drifts or inblown snow ledges. The resulting meltwaters support *selective* outcrop-orientated weathering. Higher *forms of glaciated knobs*, which rise above the 6000 m mark, are even today subjected to a *glacier transgression*, tens of metres thick, within the Geladaindong massif (Photo 4▲). Although these knobs are still glaciated, they must have received their shape when the *entire relief* was being polished by inland ice. It is striking that there are mountain peaks of the same height in the immediate neighbourhood, with *steep* rocky ridges and pointed summits (Photos 4↓ and 1, No. 1). The highest of the rounded mountain forms reach altitudes of 6178 m. All the higher summits of the massif are *peaks* between 6180 and 6621m asl (Photos 2, No. 1 and 1, No. 1). Neither among the rounded mountain tops nor among the peaks can a prevailing strike be discerned. Evidently the wealth of forms is the result of the radial pattern of valleys from mountain massifs of that type. This pre-Pleistocene and probably Tertiary hydrological basal structure of the present valley systems of the Tibetan plateau has subsequently been developed further during the main and interglacial periods. In the *interglacial* period it took place in a way we are able to reconstruct: ie by the action of valley and corrie glaciers in the vicinity of the valley head, as well as by melting waters which followed on, *further moulding* the valley bottoms far out into the foreland (Photos 3 and 1). Transferring the valley flanks back in this way, they became *facetted* up to their very peaks. The basic linear plan of their superstructures ran parallel to the valleys (Photo 4♦). However, in its run-off pattern, the Main Ice Age formation must also have followed the underlying relief with its relief-filling glaciation, ie with an *inland* ice, or have been subjected to *canalization* by the valley receptacles. The reason for this is the fact that the Tanggula Shan is situated at approximately the *centre* of the highland, and in one of the *highest* altitudes of all Tibet, as it always has been, even in the Main Ice Age. *Not only* the absolute altitude, but also the amount of precipitation are significant in this context. The inland ice flow is at its greatest in places where a maximum of snow precipitation causes the greatest pile-up of *ice-domes*, since altitudinal locations above the ELA - which are occupied by a central relief section of Tibet - with accordingly low prevailing mean temperature, can generally *exceed* their effect on *in situ ice formation* by increased precipitation in place of the normally merely semi-arid precipitation. It is therefore likely that a *more significant* inland ice run-off from the more humid E part of the Tibetan Plateau in the surrounding area of the Tanggula Shan (as well as Jurhen Ul Shan; 32°-34°N/90°-94°E; Fig 43) took place than from the higher Mayer Kangri massif (32°-34°N/84°-88°E) in the west. Extending approximately 180 km in a W-E direction and 70-110 km from N to S, the Mayer Kangri area maintains an almost uninterrupted height of 6000 m, occasionally reaching maxima of up to 7000 m. Judging by estimates of vegetation, however, it receives markedly less precipitation, ie scarcely more than 400 mm/year. Snow- profiles dug by Ding Yongjian et al. in the course of the 1989 expedition showed that the feeding areas of the Geladaindong glacier (Tanggula Shan) at 5800 m asl (Photo 1×) receive about 700 mm/year. On the basis of these conditions, the Tanggula Shan massifs in question cannot be assumed to have an inflow of "foreign" ice from higher areas further to the W. One ought rather to think of an *inland ice cover* tied to the very spot of the mountain relief, which has built up here to a *dome* of more than 1000 m. The rounded forms of the mountains, all of which are showing characteristics of true glaciated knobs, are evidence of rock *polishing* up to 6180 m asl. It is important in this case to distinguish between the upper limit of rounded mountain forms and the maximal pre-historic glacier level. The rounded mountain forms are evidence of a *minimum level,* but show at the same time that the ice cover must have been higher than the present level of the mountain ridges, since a certain *load weight* is necessary to enable effective polishing by hanging glacier ice to take place. Individual peaks *piercing* the inland ice surface may be observed in many places of the recent inland ice surface in the Antarctic as well as in E Greenland (eg/ Mt. Forel, 3383 m, 67°N/ 35°W) to name but one example. All these mountain structures come to a nunatak-like point and pierce the ice surface like a shark's fin. Polished and rounded peaks, on the other hand, are rarely found in such positions. These observations lead to the conclusion that *both these mountain summit forms* are evidence of a pre-historic inland ice level: the rounded ones (Photo 4▲) remained several decametres to several hundreds of metres below the ice surface, whilst bevelled peaks *define* the *level of the immediate* glacier surface *more closely,* since they find themselves partly below and partly above the ice surface. On the one hand, the process of *bevelling peaks* is tied to the line of rock-snow contact of the ice surface, which assists weathering through frost, on the other hand undercutting, ie basal polishing, is required for the carving out of steep walls. At the same time the *higher* part of summit walls remain unaffected by glacier flank polishing. They tend to break down subsequently, depending on fissures. In this way the peak remains steep. Rounded and pointed summits thus become incicators of a median ice

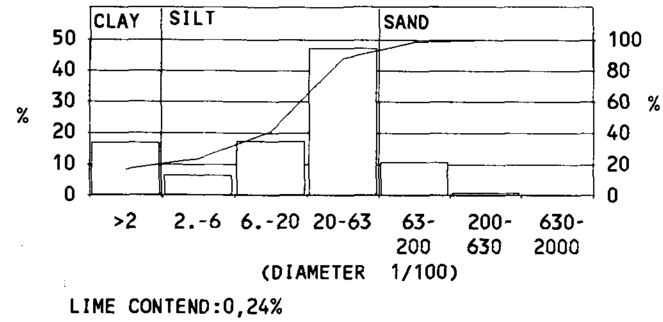


Fig 5 5.8.89/2, 30 km ENE of Lhasa, ground moraine on transfluence pass, 4560 m asl; Fig 43, No. 49; taken from a depth of 25 cm; sand 11.8%, silt 71.2%, clay 17%.

thickness of c. 300-500 m *above* the higher rounded mountain ridges which reach about 6000 m above sea-level. This implies that the strikingly pointed main peak of the Geladaindong (6621m; Photos 1 and 2, No. 1) towered 120-320 m above the inland ice sheet.

Such *formative processes by polishing* can reflect the chronology of historical ice levels only as an integral feature. In this case it is implied that during a brief period of maximum thickness several hundred metres of inland ice may well been superimposed upon even the highest peaks of the mountain massif for a few thousand years. However, the longest *duration of formation* which finds its echo in the shapes of mountains carried forward to us tends to concern a growing, early glacial and a late glacial, melting inland glaciation of the same level reconstructed on this basis. The *mean* ie Early and Late Glacial *thicknesses of inland ice* in the capital Tibet Tanggula Shan were accordingly 1000-1400 m. In this context it needs to be taken into account that the thickness of inland ice in the mountain massif must have been less than in the lower highland area around the Tanggula Shan. The research for this is the more steeply rising curve of the valley gradient towards the valley heads in the mountains. The surface vaulting of the inland ice was shaped like a very shallow dome - the *vertical distance* from the highland surface to the inland ice surface must therefore have been greatest in the flat and depression areas of the highland. This *geometrical* analysis bases the argument on the existence of a dome-shaped, balanced and very flat ice surface. Equally valid, however, would be an argument deriving from *gravitational flow dynamics:* the ice could not fail to flow into and collect in the depressions of the highland between mountain massifs and as a liquid medium, it had to form the *greatest thickness* there.

Following the area of the Geladaindong massif out into the eastern mountain foreland one finds further *tongue basins* as continuations of present glacier tongues (Photos

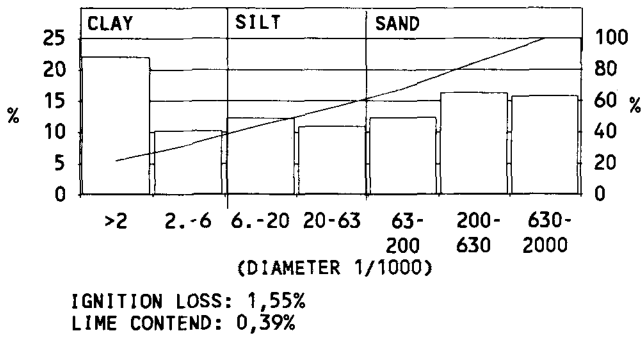


Fig 6 1.9.89/1, valley on the left bank of the Geladaindong glacier, 5540 m asl, ground moraine; Fig 43, No. 1; Photo 4 (◉); sand 44.4%, silt 33.5%, clay 22.1%.

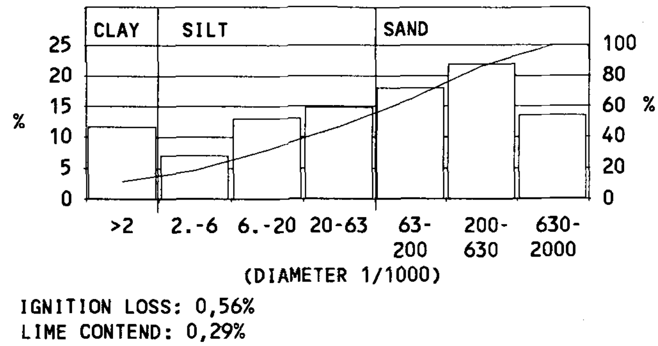
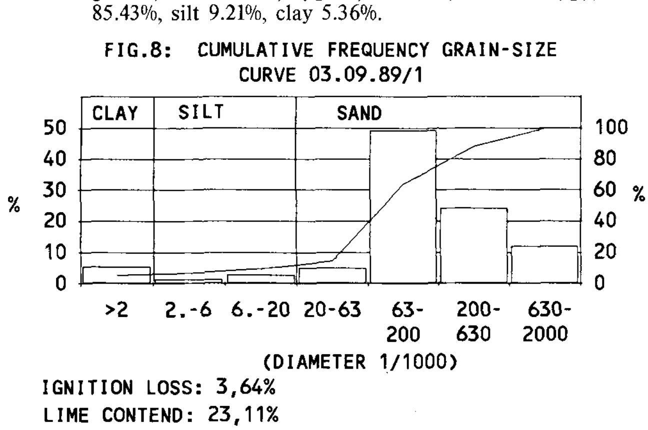


Fig 7 1.9.89/2, ground moraine in the foreland of the Geladaindong glacier, 5280 m asl; Fig 43, No. 1/2; Photo 5 (◉); sand 53.4%, silt 35.0%, clay 11.6%.

4 and 6) and sub-recent tongue basins as far down as 5141m (Photos 5×, 3× and 2▼). They increasingly combine larger catchment areas with more and more numerous glacier arms. Three *seismic cross-section profiles* constructed here between the present glacier tongue at 5350 m asl and the adjoining tongue basin, measured ground *moraine thicknesses* of 9–20 m on quartzite bedrock which had been eroded by ground *polishing*. The hammer blow seismology of the expedition was in the hands of Dr. D. Ortlam and Mr. Wang. *Measurements* were carried out with a signal amplification seismograph (a single channel "Bison" 1570C instrument). The three profiles were plotted over distances of 80 to 100 m by way of shot and countershot (Fig 43, No 1). It was also possible to use the measurements to establish the *permafrost table*. On the profile mentioned above it ran between *0.4 and 2.7 m* in the boulder clay *under the surface* during the days between August 20th and 30th 1989. These are *thicknesses* of *mollisols* such as occur regularly in central-W Spitzbergen (0.2–0.5 m at 250–500 m asl at 78–79°N) or in W Greenland (1.5–2.5 m at 50–350 m asl at 70°N) in mid-summer Kuhle 1983b; 1983c). The *striking forms of tongue basins* extend for 20–27 km from

Fig 8 3.9.89/1, ground moraine 15 km E of the Geladaindong glacier, 5080 m asl; Fig 43, No. 1/3; Photo 7 (◉); sand 85.43%, silt 9.21%, clay 5.36%.



the foot of the mountains into the E foreland, and down to 4842 m asl. The tongue basin which extends furthest is lined by 200 m high abandoned lateral and end moraines (Fig 43, No 1). The *ground moraines* found in the tongue basin consist of clay (5.36 to 22.1%) and a *preponderance of sand* (85.43 to 44.4%) (Fig 6, 7, 8). The sand fraction increases with distance from the present glacier whilst the *clay fraction* decreases. This 4842 m high ice margin in question is more a long and narrow, than broad lobe-shaped tongue basin. The lower 7 km call to mind the forms of tongue basins which have been described for the Animachin massif in NE Tibet (Kuhle 1987b, p. 216, Fig 23), as well as the long strips of tongue basin outlines in the S foreland of the Kakitu massif in N Tibet (Hövermann & Kuhle 1985, pp 43, 44, Fig 4, 5). The next recent and somewhat higher tongue basin, on the other hand, is *very wide* and has a triangular outline. At its start at the foot of the mountain its breadth measures 20 km - and this at a length of 15–20 km - the calculation being extended into the mountain foreland. The two deepest generations of moraine-flanked tongue basins are evidence of an *ELA - depression* of only 230 m (the height of recent glacier tongues ends in 5300 m asl, lowest prehistoric ice-marginal location in the immediate mountain foreland 4842 m asl, altitudinal difference 458 m : 2 = 229 m). This implies that it is the last Late Glacial or Neo-Glacial stable location of an ice margin the development span of which was too short to allow relatively *thick* and *significant* abandoned lateral and terminal moraines to be built up. This history of glaciation which took place before this time, ie *stillfurther outside the mountains,* already touches upon the basal height of the Tibetan plateau, thus indicating a complete inland ice cover. Accordingly there is no evidence of other geomorphologically unambiguous terminal moraines for many decametres around. This is the place to emphasize that even a *very small step in the depression of the snow line* of only a little more than 230 m below the present ELA was sufficient to achieve a larger ice cap and inland glaciation which covered the entire terrain and built itself up further.

The method of integral consideration followed here, which endeavours simultaneously to reflect the diversity of *evidence by indices* required for *chaotic systems* is significantly assisted by the following additional information: wherever it was possible to derive evidence of a Main Ice Age depression of the ELA, ie in the *mountains on the fringe of Tibet,* values of 1200 and more metres of depression were found (Rost 1991, unpublished manuscript; Schröder-Lanz 1986; Heuberger 1986; Kuhle 1980; 1982a; 1987d; 1986a; 1987c, pp. 307–313; 1988c, pp. 416/417 et al.). Presented in this place, it implies that here too in *central Tibet,* corresponding snow line depressions are probable. Such a conclusion by analogy would *not contradict* a dome-shaped rise of the snow line above central Tibet either which is induced by the *effect of mass uplift* (v. Wissmann 1959, map 1:5 000 000). This applies even though unfavourable climatic conditions are widely assumed for currently observable values of updoming and uplift for a complete cover of inland ice. *An inland ice cover* could of course not enable the atmosphere above the highland to be *heated up* as is now the case, since it is a matter of a cooling surface which reflects 70 to 90% of the sun's energy (Kuhle 1985a, pp. 45–46; pp. 48–50; 1987a; 1989a, pp. 276–277). It is for this reason that an ELA depression in central Tibet must be assumed to be *more severe* than on the edge of the plateau. In the context of the observations made in Tanggula Shan it implies that an inland ice cover must still have been in existence in central Tibet during the *middle Late Ice Age,* when the ELA ran about 500–700 m lower than today. Traces to give positive evidence of this, are extensive *assemblies of glaciated knobs and polished basins* with *extents of polishings on their flanks,* which have been observed at least as far as 100 km E of the Geladaindong massif (Fig 43, No 3 and Photo 7).

Everyone of these forms is overlaid by a *solifluction cover of only slight thickness.* Under present climatic conditions of frost-thaw cycles above the permafrost line, a build-up of this kind could take place between 4700 m and 5400 m asl within a few centuries or millenia (Photos 6 and 7).

The *inland ice* left behind a landscape which is to be regarded as a *melt down landscape* with *little glacial drift material.* Little of the latter because this almost static, cold ice cannot have carried *much internal or surface moraine.* In many places small dells, shallow polished basins are characterized by *ponded water.* This points to underlying *clayey boulder clays.* They are topped by decimeter-thick layers of peat in the form of hummocks (Photo 7×). It is significant that *very shallow* valley bottom formations with terrace steps of just a few meters in height were observed, as for instance, in the eastward-leading, 23 km long valley 55 km E of the Geladaindong massif (NE of the 5570 m high summit, 33°31'–33°35'N/91°49'–91°57'E; Fig 43, No 3). In the vicinity of the valley exit, at 4800 m asl, *ground moraine thicknesses* of 2–7 m were measured on two 50 and 80 m long hammerblow, seismology cross-section profiles, respectively which ran parallel and across the bedrock strata of Jurassic rocks (50°N/30°E). These *ground moraines* are immediately superincumbant upon the tilting clay rock series. In the centre of the valley floor they have been deeply dissected by a clear water stream (ie a stream without glacier connection), which had to cut through 1–3 m of *ground moraine.* Around August 20th 1989 the *permafrost soil* had *thawed to a depth* of 1.5 to 1.7 m. Quite apart from the *easily provable ground moraine character* of the loose rock, its slight thickness of merely 2–7 m already astonishes in a valley which is after all tens of kilometers long and spans a vertical distance of 800 m. In the present - ice-free state, on the other hand, the extensive slopes of this valley with a *catchment area* of 230 km^2 receive intensive deliveries of debris which solifluction sends to a valley floor that is only a few metres wide. There is a permanent mountain stream which *produces* c. 7–11 m^3/sec in summer, ie the equivalent of a mean annual precipitation of about 500 mm for the catchment area mentioned above.

Unbroken in its path by any forest vegetation (there is short alpine grass between 4800 and 5100 m asl, and decreasingly sporadic dwarf shrub vegetation further up), such a retarded morphodynamic leads to a *considerable rate of rock wasting* within a rather *short* time period. The *small amount of debris* observed in this representative valley of central Tibet consequently presents a *contradiction to what is presently occurring.* The small amount of debris proves that the current regime has only been operating for a very short while indeed. The question therefore arises as to what the possibilities are that such a *filling of valley floor with debris* could not have taken place in prehistoric times or why it came to a standstill or was interrupted. The *only possibility* for this is an interval of Main or Late Glacial *infilling and covering of this relief by glaciers.* This important aspect of the "clean" and largely debris-free valley relief will be taken up again in the context of the treatment of the E Transhimalaya (Nyainqentanglha) from the Lhasa valley to the Namche Bawar massif (Namjagbarwa Feng) (see below).

3. Traces of Glaciation in the South-Eastern Tanggula Shan (32°30'–33°07'N/91°45'–92°30'E)

The connecting link with the area of the W Tanggula Shan (see above) is the large valley that runs from the altitude of the Tanggula pass (c. 5300 m) to the N, and accommodates the N–S route through central Tibet. It is formed by Jurassic sedimentary rocks and shows a number of *glaciation indicators,* such as *bands of polishing on outcrops* (▲) orographic left-hand side of the valley flank, which continue up to the mountain ridges of the intermediate interfluve (Photo 8▼▼). This side of the valley is now free of glacier ice. The small perennial *nivation ledges* only *form mantles* for the glacial polishing on the highest ridges (Photo 8↓). By contrast with the horizontally placed polishings of flanks, this supra-forming takes place parallel to the fall-lines of the slopes. On the orographically right-hand side of the valley flank triangular

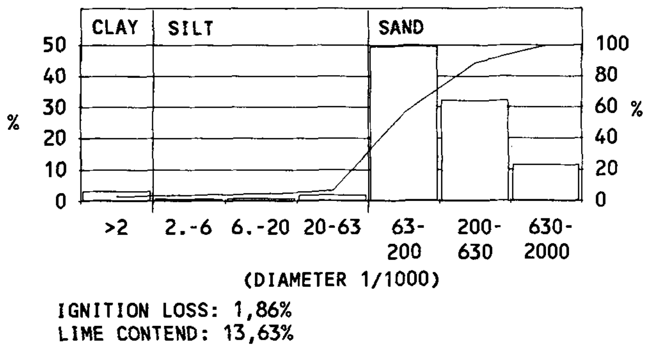


Fig 9 3.9.89/2, 4970 m asl, ground moraines N of the S Tanggula pass; Fig 43, No. 5; Photo 10 (● below); sand 93.2%, silt 3.5%, clay 3.2%.

glacial slope areas (after the Davisian sense 1912, p. 416, Fig 148, p. 417, Fig 149) present unambigious indicators as typical, polished-back slope facets between the parallel openings of side valleys. Some of these forms are now covered by shallow *hanging glaciers, firn snow shields* and larger *snow patches* (Photo 9▲▲). In the valley heads of the orographically right-hand side valleys, valley glaciers of a maximum of 8 km reach down to 5300-5500 m asl (Photo 9●). Other box-like valley chambers with anastomosing channel tracks and up to 5 km wide, pile up extensive *debris areas,* alternate with threshold-like straightenings of the valley floor. This valley floor also has a string of shallow lakes, which are some (at most 5) kilometres long (Fig 43, No. 4; Photo 9, middle distance) - a visible expression of the changing pattern of shallow troughs and trough thresholds. This glacigenic landscape character finds a very similar expression on the N edge of the Alaska Range (63°25 N/150°W), again based on sedimentary rocks. In a mutation brought about by crystalline massive rocks in situ a landscape of this kind may be observed at 900 and 2000 m asl in the Sarek and Kebnekaise massif in the N Skanden (68°N/19°E).

There is a 35-km-wide and some 60-km-long shallow depression between the N Tanggula Shan pass (at 5300 m the main pass) and the S Tanggula pass (c. 5200 m asl), which runs from W to E and descends to an altitude of 4946 m (32°43'N/91°52'E; Fig 43, No. 5). The floor of this large intramontane basin is overlaid by largely contour-less cover of *ground moraine blocks* (Photo 10, Fig 9). Due to a large proportion of granitic sand, the ground mass is very sandy (93.2%). Clay and silt make up another 3.2 or 3.5%. Up to 1.7 km long and predominantly *round lakes* (Photo 13▽) occur among the interspersed and flat *ground moraine ridges,* which run from W to E (Photo 11). At this altitude of about 4950-5300 m asl the grassland vegetation is so sporadic and intermittent that the suspended blocks and finer matter is totally exposed over hundreds of square kilometres. *Surface gradients* are so small that solifluction transport of the block cover must not be assumed. Neither the *quantity of water* available here nor its combination in one stream or the gradient of the soil surface are in the least sufficient for *transporting* or distributing these large-scale collections of blocks. The only *remaining possibility* to explain them, as well as the *mixing* of rough blocks with material, is the *drifting of the material* by the action of an *inland* ice-cover. The edge of the intramontane basin is lined with a framework of raised sedimentary rock, which has undergone polishing in the manner of glaciated knobs (Photo 13↓↓; Fig 43, No. 5). Still covered with glacier ice, the massifs of the E Tanggula Shan (5981m asl) follow on in the NE. With their hanging valleys, they are adjusted to the floor of this depression. Even an ELA-depression of only 400 m to an altitude of 5200 m would lead to a *total glaciation* of this central highland area.

4. The Central Tibetan Plateau between the Southern Tanggula Pass and the Northern Nyainqentanglha Massif (30°45'-32°30'N/91°30'-92°15'E)

The *glacial* relief in the landscape of *polished anticlines* and *basins* S of the Tanggula pass varies in height between 4500 and 5600 m asl. 36 km S of the settlement of Pagnag (Ando) at 31°51'N/91°43'E there is a particularly representative section of this landscape with *glaciated knobs* somewhat in excess of 5000 m. They act as a framework to basin floors at about 4800 m, which are infilled with ground moraine (Photo 14; Fig 43, No. 6). Here, too, sandy-silty in composition, the *boulder clays* contain *polymict blocks* of granite, gneiss and more or less metamorphosed crystalline slates up to 2 m in length. The metamorphic blocks of slate are *erratica,* ie they have been *transported from afar.* But even the large proportion of granite blocks has been transported across several hundred metres to at least a distance of some kilometres. *Isolated from one another,* the large blocks "swim" in the fine ground mass (Photo 14 ●). Besides the definition of the sediment itself, the verification method showing that these are indeed *glacial diamictites* also includes a *contra-inductive elimination process* which has to investigate the possibility of other *transport mechanisms.* In principle there are always three other transport agents which deserve consideration: 1) wild water transportation, 2) mud or mudflow-like transport, and 3) solifluidal shifting of material. Agent 1 has always been excluded on the basis of the description of the type of sediment, since the homogeneous composition of material, as well as the characteristic sorting and layering of fluvial deposits are missing. Moreover, there is no wild water capable of transport, and a sufficiently high and large catchment area is lacking, too. There is merely a small, and just decimeter deep runlet carrying a negligible amount of water of at most 1 m^3/sec (Photo 14▼▼). Because of the *absence of a substantial catchment area* and the non-existence of a vertical distance required for the *kinetic energy* of mudflows, agent 2 must also be excluded. *Lakes in higher locations,* which could overspill and built up mudflows in the process, are not available either. There is no sign of any major high *perennial patches of hanging snow*, the melting waters of which could trigger mudflows during summer periods of *depressed permafrost tables*. The condition for solifluidal shifting of material (3) is a gradient, ie a slope to allow changes in frost to induce shifting in moving moraine covers. Such a gradient is totally lacking on the floor of these polished basins (Photos 14 and 15, foreground to middle distance). It would therefore prove impossible to explain the delivery of the large blocks to the level *surfaces of loose rocks* by way of alternations in frost leverage and depression resulting from thawing, since this could only take place on the spot. There is in consequence *no other transport mechanism* than that provided by an *overflowing inland ice* which is capable of forming a *homogeneous boulder clay cover.*

Another *classic area of ground moraines* occurs 5–20 km further S (Photo 15; Fig 43, No. 7), again in a *region of polished anticlines and depressions* at an altitude of 4700–5373 m asl (31°45'N/91°42'E). The *ground moraines* are especially significantly *marked* by the bedrock *granites* and a large proportion of local moraine from this block-forming rock. They include very large boulders of more than 1 m and even of 2 m in length. Here they are embedded in a fine unsorted ground mass (Fig 15●●). In the case of granite the *rounding* of the actual *blocks* does not constitute a significant indication of transportation by ice. Thanks to clefts due to removal of load and to spheroidal (spherolithic) weathering by hydration ("onion-peel" weathering), even in-situ blocks weathering within the mass of bedrock already show rounded edges. In this place, too, (Fig 43, No. 7) transport mechanisms other than glacial ones can be excluded on the basis of indices listed for location 6.

A kame terrace, the formation of which requires an all-round covering and surrounding ice overlay of the terrain has been preserved 27 km S of 31°35'N/91°40'E at an altitude of 4550 m asl (Fig 43, No. 8.). It is a fully 1 km long, graded and stratified deposit of *pebbles and sand.* Its highest surface, which is more or less on one and the same level and thus in the *form of a terrace,* has added slight hill cupolas. The hilly surface is a secondary formation and the result of a dell-shaped retreat of a slope. This uppermost *kame terrace level* attains a height of about 45 m. This highest and *south*-facing *terrace spandrel* is joined by two lower terrace levels, c. 35 and 21m above the large-scale plateau level. This shows a step-by-step process of deposition up against an ice margin that is melting down and retreating at the same time. As the lee side of this kame complex has been deposited up against a *glaciated knob,* lying in front of it to the N, the setting may be taken as an *indication of the direction of flow of the inland ice* in this region from N to S. The kame formation took place in the flow shadow of this glaciated knob, as it has done on many an occasion. This glacio-fluvial sedimentation process of comparatively very slight thickness must be assigned to the *Late Glacial period.* Here, in a central Tibetan location at an altitude of 4550 m, to the E of ridges rising to more than 5800 m, an earlier main glacial period encountered an inland ice-cover with a probably thickness far in excess of 1000 m (see above). It is for this reason that this *kame terrace* must be regarded as one of the rare indications of the central Tibetan disintegration of ice during the late Late Glacial period.

A cold, high-continental, arid inland-ice tends to leave behind very few traces of its melting-down process. In remote analogy, evidence of an equivalent has already been furnished by the corresponding paucity of forms and indicators in Scandinavia, although that had been at least twice as wet and rather *oceanic* an *inland ice.* The Scandinavian ice had a more substantial turn-over of mass, and thus much greater flow dynamics even during the retreat of the ice.

Another essential indicator of a *complete inland ice cover,* with significant *ground polishing activity* was found c. 35 km further S and 10 km further E (31°11'N/91°50'E; Fig. 43, No. 9). It is a *perfectly polished glaciated knob,* the particularly classic proportions of which stand out in the large-scale landscape of polished basins and anticlines of the surrounding area (Photo 16). Formed from metamorphic rocks, it bears the typical surface structure of the *band polishing of glaciated knobs* in correspondence with the layered structure of the rock. On this glaciated knob, ground polishing has brought out *exaration and detersion grooves* along the glaciated knobs of the rock strata, so that the knobs are covered by a pattern of stripes which run parallel to its longitudinal axis (Photo 16▼▼). This meso- to miniature formation is now under a thin and transparent *veil of debris,* which has arisen since *deglaciation.* It is overgrown by an almost complete cover of alpine grassland vegetation. Outcrop heads *producing much scree through congelifraction,* as well as the continental highland climate, with its great frequency of frost-thaw cycles, cause such a thin scree cover to develop within a short time. This is an indication of a deglaciation which occurred only a *few thousand years* ago. The significant *interference* of still visible *forms of polishing,* together with a very *slight* thickness of superimposed scree, as it occurs on this glaciated knob, is typical for the whole of central Tibet. It has been found in sedimentary rock and phyllites, as well as in sandstone, limestone, anhydrite rocks and metamorphosed silt and clay rocks (Photos 6, 8, 9, 14 and 15▲). This embraces an observation which points to the "clean landscape" key word and argument already mentioned above. Argued *contra-inductively,* it implies that the scree cover would be thicker had it not been for a recent, ie up until Late Glacial times an active – that is polishing and removing – *inland ice* in central Tibet (I_2 after Kuhle 1985a, p. 41, Fig 2). This thought continues consequently along the following line: if, however, there had been no such active ice during the last (Würmian) Ice Age, it *cannot* have occurred during the *preceding cold periods either.* The reason for this consequence is the fact that during the earlier cold periods High Tibet must have been *distinctly lower* – at a lower altitude above sea-level than during the last Ice Age. But *without any Pleistocene* *glaciation* whatsoever *no* removal of scree worth mentioning could have taken place on the relatively arid high plateau. In a vast hilly landscape like this the necessary relief energy is missing (Photos 7, 10, 11, 12, 14 and 15). The result would be a very *substantial scree cover* of central Tibet, which could already have been laid down during the Tertiary period without ever having been thoroughly removed - but such a scree cover does not exist.

This glaciated knob strikes NE to SW (40°/220°). Its NE-facing and *steeply rising head* (Photo 16 ↓), or its SW-facing, more smoothly truncated leeward slope are evidence of a general N/S direction of the ice flow. The exact longitudinal alignment of the glaciated knob *does not necessarily* agree with the direction of flow, since the position of a glaciated knob also always depends on the *pre-glacial alignment* to the ridge of rock as the past form shaped as a result of fluvial action and rock structure. *The interference of pre-glacial relief and direction of glacial erosion* consequently decide the longitudinal alignment of the glaciated knob. This conformity with the law of nature is also the reason for the varying quality in the shaping of glaciated knob forms. The greater the *agreement* between past form and direction of ice flow, and thus the direction of glacial erosion, the more perfectly shaped is the individual form of a glaciated knob. This conclusion is essential for the correct evaluation of the *evidence of indices* available for the reconstruction of glaciers, as they explain why truly classic *glaciated knobs* are rather *rare* and *need to be so* in relation to the very considerable areal extent of $2 \times 10^6 km^2$. By far the largest number of pre-glacial rock crests, ridges and walls had by necessity been placed *diagonally* and *some times also obliquely* to the large-scale, radial ice outflow from the central highland. They were therefore transformed into polished thresholds. Added to this is the fact that directions of *ice outflow* must have *varied* with the thickness of the inland ice or the ice-stream network during the glacier build up of an Early Ice Age as during a *thawing, regressive glaciation* of a Late Ice Age against those main glacial regimes and direction of outflow. This thus makes every form of rock polishing an *integral phenomenon* of pre-glacial form and direction of glacial rounding. This "compromise form" is achieved by the pressure of the burden as a function of the thickness or the ice and velocity of ice-flow in relation to the *duration of their effect* and the *intensity of the process*. A *further factor* is the ice temperature at the bottom of the glacier. This is the temperature of the ground ice where it is in contact with the rock. Since it was subtropical highland ice of arid character (Kuhle, Herterich & Calov 1989, pp. 204, 205), it can only have been a *cold inland ice* with temperatures of –10 °C at the ELA level. In the case of an equally cold ground ice it would imply that *large blocks of rock* were torn out of the bedrock context by ice that was frozen to the *underground* in places, but periodically forcefully torn away in the course of the general pattern of outflow. Should the *great thickness of the ice* in central Tibet, however, have led to the pressure melting-point having been exceeded, the rock parts thus affected would in contrast to the rough shapes mentioned above have been more likely to produce smoothly polished surfaces on the glaciated knobs thanks to the influence of a *film of water* forming between ground-ice and rock surface. They are less open to post-glacial *frost weathering,* thereby *reducing* the *processing of scree.* Glaciated knobs of this kind, which tend to have *finer reliefs* formed by *less viscose* and warmer ice, have indeed been observed in W Tibet (Kuhle 1989a, p. 270, Fig 7). 150 m long, this glaciated knob towers 22 m high above an area of ground moraine; to the E of it, further classic bands of glaciated knob polishings have been preserved on the much higher rockface of a *polished threshold* (Photo 16▲).

Proceeding c. 30 km further SSW along the N/S profile towards the NE end of the Nyainqentanglha massif (Fig 43, No. 10), *large-scale sheets of ground moraine appear* (31°03'N/91°42', 4770 m, Photo 17), even before the locally increasing relief energy has been reached. Again, block components of granite material are the reason for the *special significance* of the *ground moraine-boulder clay* character. Big, isolated blocks inserted into a finer ground-mass of glacial composition dominate the picture on the surface of this ground moraine landscape. It is surrounded by rounded heights, totally determined by glaciation (▲). They reach altitudes of maxima of 5763 m. Streams some 35–40 km long mark this otherwise *featureless landscape with post-glacial incisions* of 10–12 m at most (Photo 17▼▼). The minimum thickness of the ground moraine sediments described above can be established from exposures along terrace edges.

With regard to the *history of glaciation,* the N/S profile of central Tibet as the largest, continuous, very elevated area of High Asia described in the foregoing chapter must be considered in relation to other altitudinal *lines,* the *tree-line* and the *permafrost line.* The entire area is at least 500 m *above the tree-line.* The reference level for this information is provided by the floors of the *lowest* polished basins at about 4600 m asl, together with an assumed very high potential tree-line at approximately 4100 m asl. This is the altitude of the highest stand of trees in irrigated monastic settlements in the Lhasa valley 150–300 km S of the area under investigation. For planetarian reasons, the tree-line may well drop below 4100 m further N up to the Kuenlun and Animachin (between 35° and 36°N) on the N edge of the central plateau, reaching 3700–3800 m asl. In accordance with the *integral method of comparison* these altitudinal relationships need to be compared with those of, for instance, the *Scandinavian Ice Age area of inland ice.* This area is now predominantly covered by *forest.* Even places where the centre of the North American inland ice was once located are now well within the altitudinal level of the *boreal coniferous forest belt,* ie at about 500–700 altitudinal metres *below the upper tree-line,* indicating at the same a surface location of at least 1300–1500 m below the snow-line. The high plateau of central Tibet, with its mean altitude of at least 4800–5200 m (5400 m if the higher mountain groups are included), is, however, not only far above the tree-line in the cross-section under investigation (with plateau heights like the aforementioned ones even far above the 500 m, ie 700–1300 m), but even *above the permafrost line.* In S Tibet and in the high valleys of the Himalayan N slope it runs at about 5000 m asl, dips to at least 4800 m asl below central Tibet, or at any rate does not rise above the altitude of 5000 m (cf. Luo Xiang-Rui 1982; Wang Shaoling, 1982; Zho Youwu & Guo Dongyin 1982; Kuhle 1985b, p. 189 Fig 2, amongst others). Peathummocks, as well as large-scale *back-ponding water* and numerous *shallow lake formations* at an altitude of about 4600 m in this N/S profile of Tibet point to *sporadic or discontinuous permafrost complexes* up to just below 4600 m asl. *Evidence of permafrost* between 4750 or 4800 m and 5300 m asl (cf. above) was given in the seismic profiles mentioned above. One has so far been unable to exclude the possibility that this is a matter of late Late Glacial *fossil permafrost.* A precautionary assumption of a permafrost line at 5000 m asl, together with an indication of an altitude still below the average height of the central Tibetan plateau (cf. above) *makes the point* that Tibet is very much closer to the climatic snow-line than any other large inland ice or ice-stream network area of the past Ice Age. At the same time it implies that, among the worldwide and approximately *comparable ELA depression,* the *falling snow line* must have undercut the Tibetan plateau as the *first* very large area on earth. This must have happened *long before* the large – now forest-clad – areas of those other inland ice areas could have been touched, let alone undercut by the falling snow line.

In the *European Alps,* which were glaciated by filling ice-stream networks (c. 270,000 km^2 in area) during previous glaciations, the recent *permafrost* line runs just a few hundred metres below the present ELA. In the W Alps the *climatic snowline* runs at about 3200 m asl, and the *permafrost line* at an altitude of about 2800–3000 m. Due to more intensive *sub-tropical* solar radiation in *central Tibet* the *vertical distance* between the two altitudinal lines is about 200–400 m greater at 29–34°N than in the Alps at 47°N. The average *altitude of the Tibetan Plateau,* which is the highest level of the lower permafrost line (5000 m asl) is logically brought very *close to the present snow line* (5600 m asl), thanks to the *concurrence* of the situation of this *"snowline-adjacent" climatic line.* This implies a much *greater approach* to the *total glaciation* of its relief during an ice age than existed in the exemplary Alps, where the large-scale *main* (and as it happens also *longitudinal) valley floors* are situated 2000–2700 m below the present snow line. The *mean level of all the Alpine valley floors* is around 1500–1700 m below the present snow line level. In the Alps the snow line must consequently have been depressed by *three times this value* for an Ice Age ice stream network glaciation to occur than was required in central Tibet for the formation of an inland ice.

5. The Large Outflow Valley South East of the Nyainqentanglha Massif and the Central Tibetan Ice Run-off Canalized there (31°02'–29°40'N/89°57'–91°50'E)

After this excursion into regional geography, which was devoted to the comprehensive comparison with present conditions in other prehistoric inland areas, the discussion will return to the method of *topographically orientated description of indicators;* continuing with the central Tibetan N/S profile in a southerly direction from where the central Tibetan plateau meets the large mountain system of the Transhimalaya, running from W to E (Fig 1, No. 9; Fig 43 Nyainqentanglha). The N/S cross-section of the high plateau continues here along the floor of the 15–20 km wide cross profile of a large valley SE of the 7162 m high Nyainqentanglha Feng mountain range. Four times the size of Lake Constance, the 80 km long Nam Co (Tengri Nor) extends NNW of the ridges of this mountain range at an altitude of c. 4750 m asl (cf. Fig 43). At 30°46'N/91°35'E (Fig 43, No. 11), exactly at an approximately 4800 m high and very flat threshold at the N end of the valley, smoothly shaped *hilly ground moraine ridges* are close to the orographic (SE) valley flank (Photo 18). This moraine cover consists of polymictic, medium-sized and largely facetted blocks (♦), with quartzite and a substantial amount of granite. Here, as everywhere in High Tibet, it is the relatively rare crystalline parts, above all the *block-forming granites,* which make the moraine deposits look *significant* at first sight.

The orographic left flank of the valley has been subjected to total *glacial polishing* up to their culminating points at 5542 m (Photo 18▲).

Part of this ground moraine has undergone further transformation by two tongue basins from two 10 km long, orographic left side valleys with catchment areas up to 5542 m high; the transformation extends as far as the central section of the main valley (Photo 18▲▲).

The next location to yield evidence is situated 20 km further S down the main valley, ie about 150 m lower down. Here, too, the 8 km wide valley flor is covered by several metres-thick *ground moraine* at 30°08'N/91°32'E (Fig 43, No. 12) (Photo 19). In this *polymictic ground moraine* striated boulder were found among the facetted blocks (Photo 20). At about 4650 m asl this is an area of *composite glaciary catchment areas.* The ice flowed from central Tibet in the N, as well as from the here already 6532 m (6590 m) high massif of Nyainqentanglha in the NW (Photo 19, background). This NW ice-flow was not so much from the peaks there, but moved through the mountains across *passes* in the more than 5000 m *high gaps* (▽). It originated in the large prehistoric 7500 km^2 ice collection area of the Nam Co (Tengri Nor) and its banks. In order to enable the ice to move through these narrow gaps *in the way of overflow glaciers,* it had to gain a mere 500 m more above the floor of that basin (lake-level) at 4718 m asl, coming directly from the central plateau. However, the bulk of the ice pushed down valley from the N without any hindrance. The major proportion of ground moraine material was consequently supplied from there (Photo 21, seen from the background). It was only during the later part of the Late Glacial period, when the Tibetan central ice (I_2), and thus the main valley ice, had *melted,* that separate mountain valley glaciers, which had been *isolated from one another* by now, sent their tongues out and across into the main valley floor (Photo 19). These glaciers, which have left these gaps with classic trough profiles, cut out transverse series of tongue basins in the piedmont plain-like wide main valley floor (Photo 19, middle ground) which have at times been occluded by pronounced frontal moraines (Photo 21×); (Location: Photo 19; Fig 43, No. 12).

5.1 Some Notes on the Melting-down Process of Inland Ice Masses and the Difference between those of Highland and Lowland Areas

This is the place to go into an *aspect of principle,* which contributes to the understanding of the "substantial glaciogeomorphological gap" that exists between the peak of the Maximum Glacial inland ice cover and the later part of the Late Glacial to Neo-Glacial positions of the ice margin and end moraines. It should be remembered that in the immediate foreland of the present Geladaindong glacier (as well as the other Tanggula Shan eastern glaciers) the deepest end moraines one can find in central Tibet are just a few decakilometres away and only a few hundred metres below. It only required an *ELA depression* of a mere 200-300 m to reach these through the ice (cf. above). A slightly greater *depression of the snow line* already resulted in an ice cover tending inland ice, which was only able to deposit its end moraines in the *substantially deeper valleys* of the Tibetan *fringing mountain ranges.* The "glaciogeomorphological gap" is to be discussed here in respect of terminal moraines, ie the very substantial *distance* between end moraines from the Last Glacial Maximum and the nearest other ones many hundreds of kilometres further away on the high plateau in the immediate vicinity of the glacier. It is important in this context that between very recent terminal moraines and those from the Maximum Glaciation early and middle terminal moraines of the Late Glacial are lacking. This is a fact that is also known to occur in the area of the prehistoric Scandinavian inland ice. It is a matter of a discrepancy of, for example, terminal moraines which were deposited during the Maximum Glaciation at a period of an ELA level that was at least *1200 m lower* than the present one, to those which came into existence at the time of the Late Glacial with an ELA depression of only *800-600 m.* Throughout the world the *interval* between these two stages of ELA depressions, ie the *temporal distance* from the Maximum Glaciation to the Late Glacial amounts to approximately 6000 years (18 Ka to 12 Ka; see, inter alia, Schwarzbach 1974, p. 80, Fig 61 and p. 248, Fig 167).

In the central plateau area of high altitude Tibet, where the largest inland ice complex I_2 (Kuhle 1985a, p. 41, Fig 2; 1987a, p. 413, Fig 27; 1988a, pp. 508-9, Fig 75) was situated, only 6 Ka were available for the *process of melting down or melting back* from a *Main Glacial compensation of the mass balance to a Late Glacial one.* This was evidently too short a span for the melting down of the enormous body of inland ice. In other words: the *remaining inland ice, which had not melted so rapidly,* continued to cover the relief of the high plateaux at a time when an ice margin that corresponded to the meanwhile rising ELA level should already have *retreated much further.* The *rise in the ELA* accordingly took place *faster* than the process of melting down the inland ice. This generally applies the more the bigger a continuous ice mass is. On the other hand, a small valley or corrie glacier follows the climatic events after some delay, ie a time lag of only a few years or decades. *Absent from the centre,* although presented in perfect detail in the peripheral mountain ranges of Tibet (for the case of the Himalaya cf. Kuhle 1982a, pp. 153-160 and map Fig 184; 1983a, pp. 225-333, as well as Jacobsen 1990, pp. 28-67 and map 1 : 250,000) the early Late Glacial and the Late Glacial (12 Ka) moraines are therefore evidence of the necessarily *very substantial ice mass covering* central Tibet. At the same time it must be remembered that only an *ELA rise of more than 400-600 m* would have enabled the Tibet plateau to react by reducing its mass. Such *mass losses as a result of initial melting processes* will, of course, at first have been restricted to the *peripheral areas* of the inland ice and its *outflow glaciers down the peripheral mountain ranges.* This observation illustrates the fact that *high plateau inland ice areas* differ on principle from those of the *lowlands,* like the North European or North American inland ice. Lowland ice margins retreat approximately horizontally during the melting process, whilst highland ones melt back upwards at an oblique angle. With increasing altitude this process becomes *slower and slower* as temperatures diminish. An *upland ice* is consequently more stable against a rise in the ELA than *lowland* ice masses. The *glacier catchment area* too, remains larger at its maximal extent than is the case with the lowland ices, since the same reason – the lower temperatures – allow the depletion area of, for instance, the Tibetan ice to be tied to the periphery of the high plateau for a much longer time. The onset of the melting process did not allow it to expand at once into all directions towards the ice centre. That was only possible once the ELA had reached the *height of the plateau,* or had passed beyond the upper convex knick- point of the plateau edge. With a lowland ice, on the one hand, the rise in the ELA is accompanied by a *decrease in base and catchment area* from the very start of the Ice Age regression, for the lowland ice is an *ice dome undisturbed* by the horizontal relief. It is an *ice dome,* the *vaulting* and *height* of which are directly related to the *base,* ie are in a purely climatically induced relationship. In the case of the highland ice, on the other hand, which flows down to and over the plateau edge, such a *base-related* cupola-vaulting extends *only as far as* the edge of the high plateau. However, this highland ice dome has reached its relief- dictated outer fringe there in the form of individual outflow glaciers in the steep ice run-off at the plateau edge. This implies that the dome would have

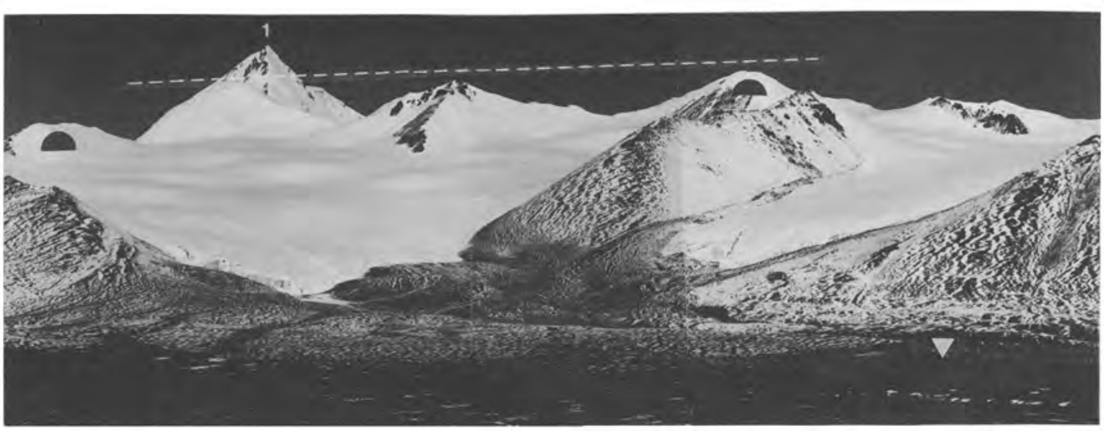
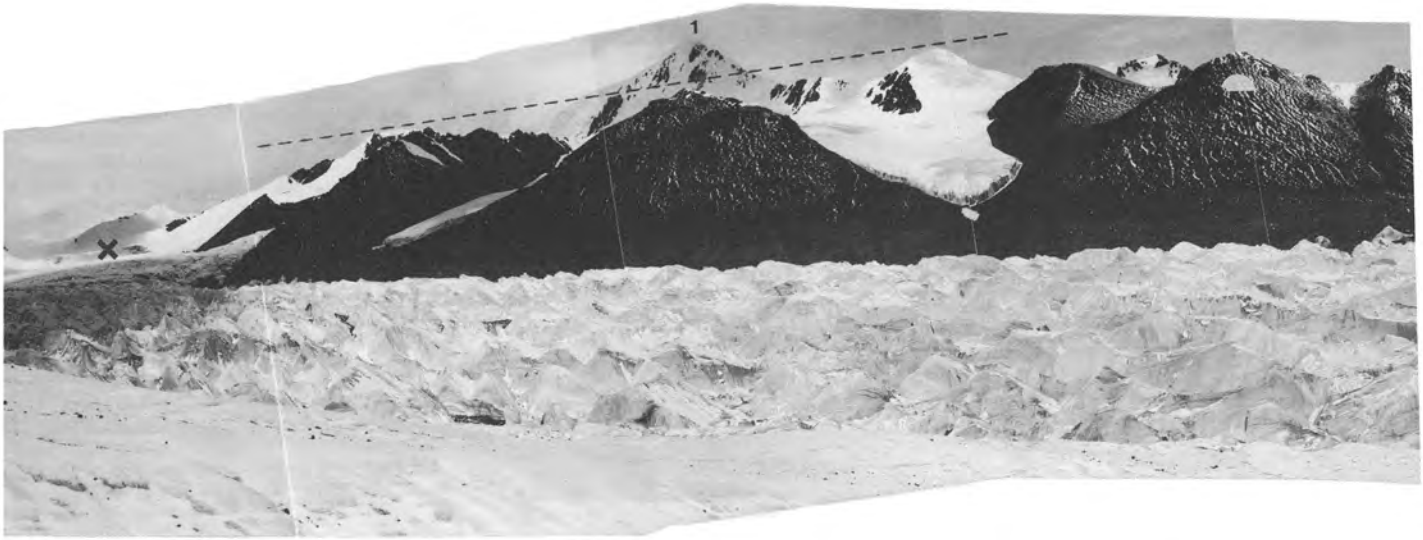


Photo 2
The Geladaindong massif in tl
(6525 or 6621 m) (Fig 43, No.
5100 m asl (Fig 43, No. 2). The
the flat high plateau of Centr
(No. 1), which must have towe
mountain relief has been roun
The Ice Age glacier level here v
- - -). Photo: M. Kuhle, 21.8.



ıe Tanggula Shan with its highest peak
), seen from the east at an altitude of
recent hanging glaciers reach down to
al Tibet. Apart from the highest peak
red above the prehistoric ice-level, the
ded by the polishing of inland ice (▲).
vas at least 1000 m above the plateau (-
39.

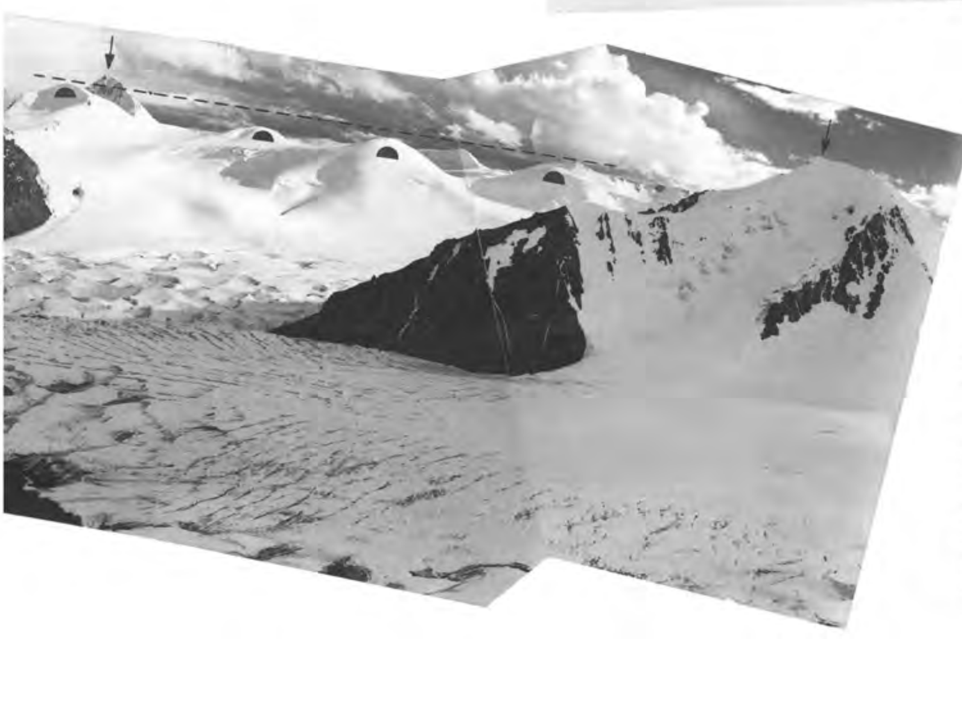


Photo 4
View taken at 6050 m asl facing S across the Ge
and the S part of the Tanggula Shan (Fig 43, Nos. 1
and some 6000 m high glaciated mountain ridge:
glaciated knobs, which have been polished by the
terior, and extended over the entire mountain ar
surface was consequently somewhat above - - - -
peaks (↓↓) towered over the inland ice cover for a
angularisation of the relief generally occurs as a
glacier filling in inter-glacial periods when even
crêtes became more pointed by glacial lateral er
Kuhle, 29.8.89.

Photo 1
The Geladaindong glacier (Fig 43, No. 1) and the side glaciers of its catchment area taken at an altitude of 5600 m asl, facing N. The highest peak (No. 1) is 6525 m (or 6621 m) high. The valley flanks show complete glacigenic rounding (⌓). The minimum level of the inland ice sheet at the time of the Last Glacial Maximum is marked - - - -. The glacier tongue has disintegrated into subtropical ice pyramids and is receding. Photo: M. Kuhle, 22.8.89.

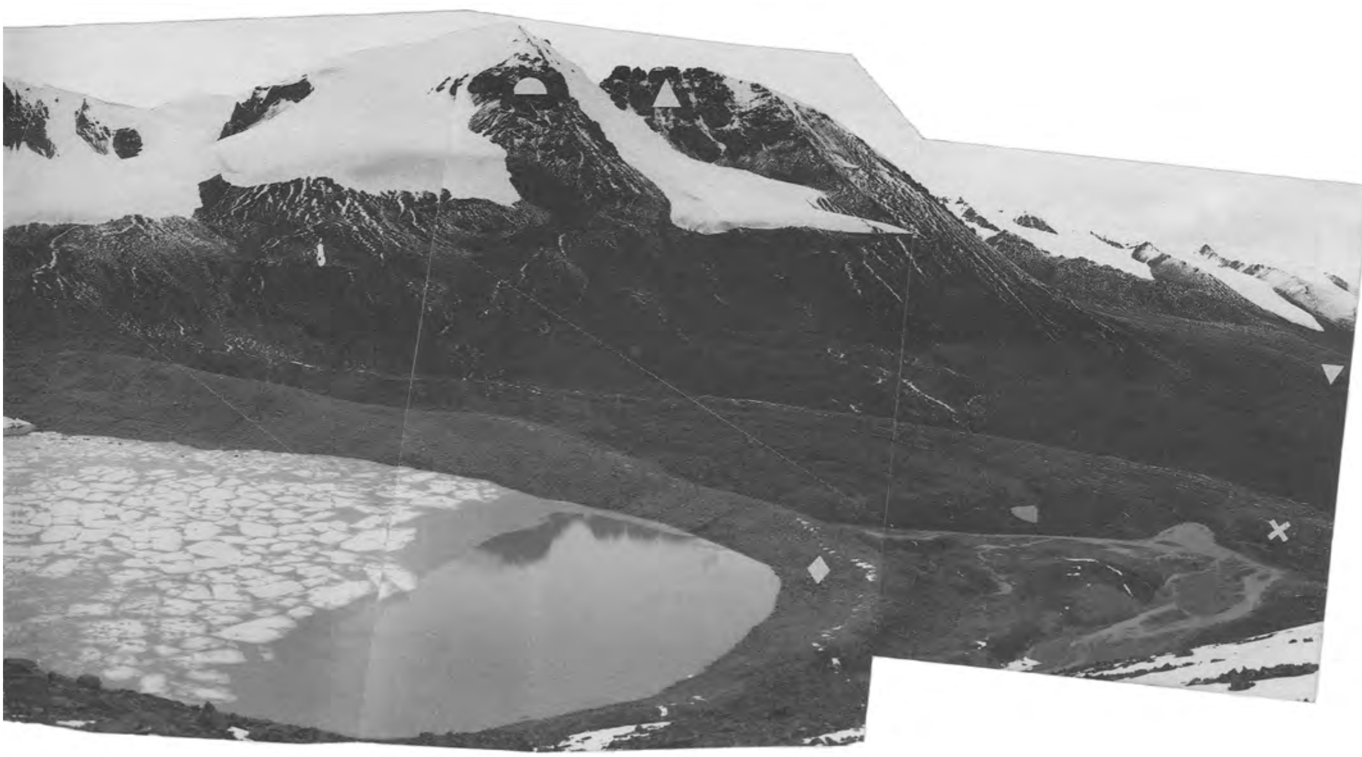


Photo 3
Southern mountain group in the Geladaindong massif, which rises to 6361 m asl (Fig 43, No. 1), taken at 5600 m, facing W. The recent hanging and smaller valley glaciers are retreating. The valley glacier calves into a moraine lake (●), which has been taken over by a more recent historic ice margin (1850?) (♦). The somewhat older historic end moraines (×) are evidence of considerable enlargement of the area and even of the volume of glaciers, as does the ice margin which had reached the central high plateau area of Tibet. Here, too, the mountain relief has been rounded during the main Ice Age (⌓) and been made more angular during inter-glacial periods, as at present (▲). Photo: M. Kuhle, 23.8.89.

ıdaindong glacier
ξ 2). The rounded
(⌓) are Ice Age
ce cover of the in-
:a. The inland ice
Only the pointed
vhile. Progressive
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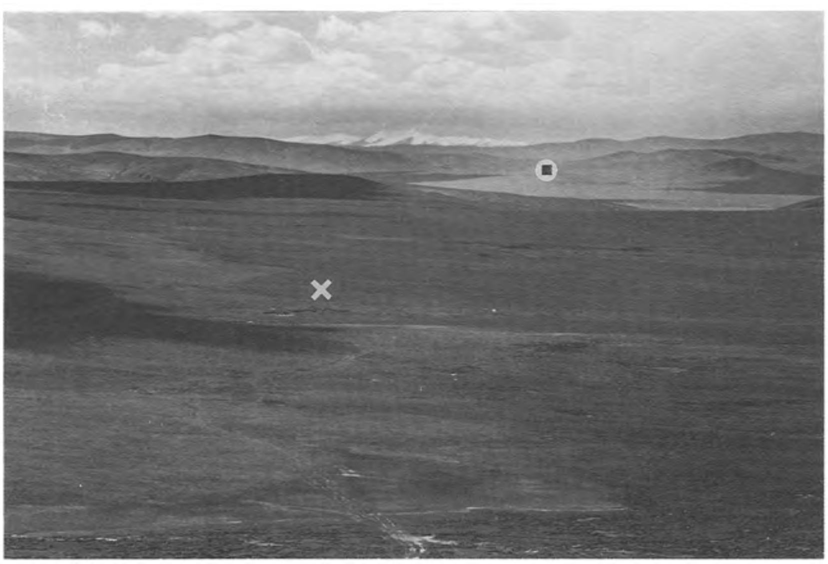

Photo 7
Still glacier-covered, the Geladaindong massif (central Tanggula Shan; background) has been photographed from a distance of 60 km from the E and from an altitude of 5100 m asl (Fig 43, No. 3). It is a landscape marked by polish undulations and depressions, with an extensive covering of ground moraine boulder clays and Holocene drift floors (sandurs). The terrain lies above the permafrost line. Photo: M. Kuhle, 20.8.89

Photo 5
Taken at 5450 m a
glacier ends at 53
Tibetan plateau (I
would consequen
plateau glacier and
(●), the tongue is
dead ice which m

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Photo 8
Banded outcrop polishing (▲) between 4950 m and 5300 m asl on the orographic left-hand flank of the large main valley which leads down N from the Tanggula Shan pass (Fig 43, No. 4), taken from the valley floor at 4900 m asl, facing W. Glacial flank polishing has etched out the outcrops fror sedimentary rocks. Photo: M. Kuhle, 18.8.89.

Photo 9
A mountain group of the E Tanggula Shan of up to 6104 m in height, taken from an altitude of 5050 m asl, facing E (Fig 43, No. 4). It is a mountain region which, having received its characteristic formation through a complete Ice Age covering of ice, continues to be covered by glaciers at this time (●). The characteristic features include triangular slopes (▲) and polished flanks on the spurs of the intermediate valley sides. The mountains have been glacially rounded. The foreground is taken up by ground moraines. Photo: M. Kuhle, 3.9.89.

ıl, facing SE, the tongue end of the Geladaindong
ı0 m asl and is adjusted to the level of the central
'ig 43, Nos. 1 & 2). Even a minor ELA depression
ly first lead to the build-up of an ice cap and a
then to an inland ice. Broken up into ice pyramids
now retreating and disintegrating into blocks of
ay persist for years. Photo: M. Kuhle, 22.8.89.

ɔto 6
ished round during the Ice Age, glaciated knobs (▲), some of
ch bear small flat shields of firn snow and recent glaciers, as well
ıermanent snow patches, were taken at 5800 m asl facing E (Fig 43,
s. 1 & 2). In the foreland of the Geladaindong glacier tongue
'eground) historic neo-Glacial terminal moraines have been
ıosited (▼). Photo: M. Kuhle, 26.8.89

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ı the

Photo 10
Substantial ground moraine sheets which have built up from scattered polymict blocks, and now line and completely cover the basin between the N and S Tanggula Shan pass (Fig 43, No. 5) at 5010 m asl. Photo: M. Kuhle, 3.9.89.

Photo 11
Ground moraine ridge running from W to E, taken from the S and facing N (Fig 43, No. 5) at an altitude of 5050 m to 5250 m asl. The polymict blocks, as well as the sandy basal mass of the moraine sheet, includes a large proportion of crystalline rock mass (granite, gneiss). Due to a lack of surface gradients, next to no solifluxion movement of material took place. Even erosion processes are minimal. Photo: M. Kuhle, 3.9.89.

Photo 12
Central Tibetan ground moraine landscape with shallow lakes (↓), taken from the S Tanggula Shan pass at 5200 m asl, facing N (Fig 43, No. 5). In the background the foot-and foreland area of the 5830 m high massif to the E of the Tanggula Shan main pass. The terrain of this intra-montane basin area is so lacking in relief that solifluction super-imposition and erosion compensate one another, leaving and preserving the moraine surfaces almost unchanged for thousands of years. Photo: M. Kuhle, 3.9.89

Photo 13
View from a ridge near the S Tar
layers of ground moraine (Fig 4
The mountain edge of the mas:
knobs (↓) of the Ice Age inlan

Photo 16
Well preserved glaciated knob in the central Tibetan plateau taken at 4500-4600 m asl (Fig 43. No. 9), facing S. Ice has flowed over this form from right to left. The rock ridges in the background show the same outcrop polishing as the glaciated knob (▼▼). They, too, have been totally rounded by glacier ice (◓). Photo: M. Kuhle, 4.9.89.

Photo 17
Ground moraine landscape, taken at 4770 n
the post-glacial period a river from a side va
most of the Scandinavian *fjell* landscapes

ggula Shan Pass at 5220 m asl to the N across the intra-montane basin S of the 5822 m massif, which is covered with ·, No. 5). Water collecting above the ground moraine indicates the level of thawing above the permafrost sheet (▼). ıf, which is still glaciated, shows rounded forms of flank polishing (☗) with triangular slopes and isolated glacial l glaciation. Photo: M. Kuhle, 17.8.89.

Photo 14
Landscape featuring polish u
classic forms of glaciated kno
at times of very large polym

asl facing E (Fig 43, No. 10). The large blocks of granite lie isolated from one another on the almost absolutely flat ground moraine sheet. During ley cut a terrace form into the ground moraine (▼). The peaks, some of them in excess of 5700 m asl, were polished round even more perfectly than (☗). Photo: M. Kuhle, 4.9.89.

ıdulations and depressions in central Tibet, S of the Pagnag between 4800 m and 5100 m asl (Fig 43, No. 6). These thresholds sometimes present ɔs (☗), where outcrops of banking structures had "heads" etched out by polishing (↓). The depression floor is filled with ground moraine made up ıct blocks (●). Photo: M. Kuhle, 4.9.89.

Photo 15
Central Tibetan ground moraine landscape, which is divided up by polished and thus rounded rock ridges (☗). Consisting of very rough blocks (●), the moraine here occurs at 4700 m asl, about 60 km S of the Pagnag (or Ado/Ando) settlement (Fig 43, No. 7). The rock ridges present strikingly smooth polish facets, which are evidence of the continuation of glacier polishing up to recent times (↓). Photo: M. Kuhle, 16.8.89.

Photo 18
Ground moraine area in central Tibet, 4800 m asl (Fig 43, No. 11) with an orographic left-hand side-valley tongue basin from the Late Glacial leading on to it. It is framed by fresh and relatively steeply-dropping lateral moraines (▲). The ground moraine includes facetted, polymict blocks (◆). The mountain ridges are up 5542 m high. They were totally covered, and then perfectly rounded by the flow of inland ice (☗). Photo: M. Kuhle, 4.9.89.

Photo 19
Ground moraine exposure in central Tibet on the NE edge of the Nyainqentanglha massif taken at 4650 m asl and facing west (Fig 43, No. 12). The glaciated mountains rising up in the background reach maximally to 6532 m asl and are separated by classic U-shaped valleys. The U-shaped valley visible here ends in a transfluence pass, in excess of 5000 m in height (▼), from the Ice Age when ice from the interior came flowing across from the Nam Co basin. Photo: M. Kuhle, 4.9.89.

Photo 20
Glaciated clast of the ground moraine shown in Photo 19 (Fig 43, No. 12). It is facetted quartzite drift, the surface of which has been preserved in a very good condition in glacial striae which cut across one another at acute angles. Photo: M. Kuhle, 4.9.89.

Photo 21
Late Glacial local moraines from the valleys of the Nyainqenta which form a small-scale hill relief (×■), have been superim upon older, less clearly contoured areas of ground moraine be 4650 m and 4800 m asl (Fig 43, No. 12). During the Glacial Max both valley floor and valley flank relief had been totally infil covered by glacier ice. Evidence of this may be seen in the ro forms of the valley flanks (▲). Photo: M. Kuhle, 4.9.89.

Photo 23
Glacigenic flank polishing (▲) on the right-hand flank of the SE of the Nyainqentanglha massif, which has formed the be large outlet glacier in central Tibet (Fig 43, No. 13). Flank polish particular well preserved between 4400 m and 5400 m asl. Pho Kuhle, 4.9.89.

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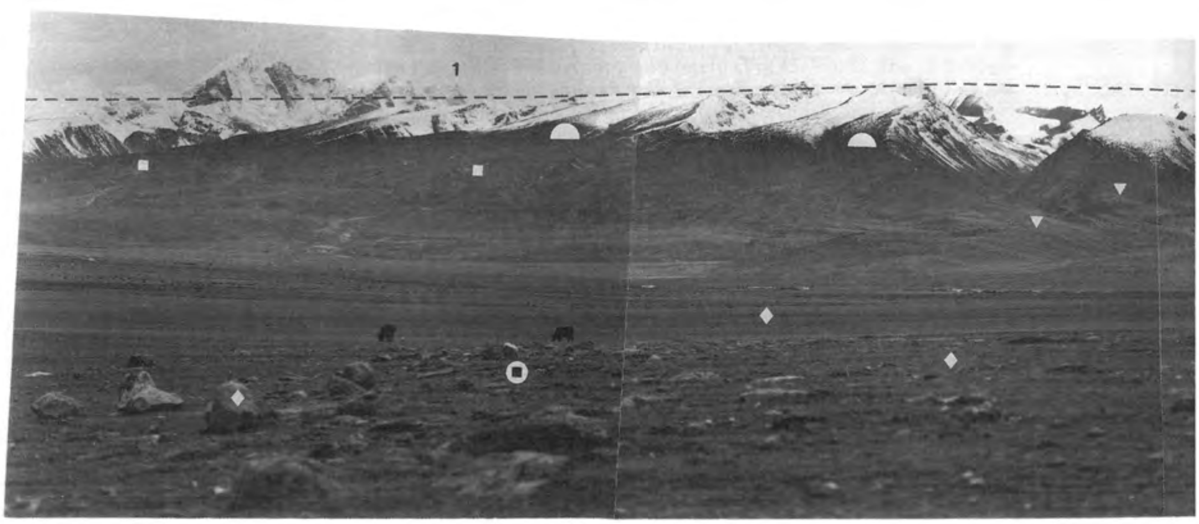

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Photo 25
One of the U-shaped valleys which conduct the Ice Age glacier ice from the Nam Co basin (Tengri Nor basin) over a transfluence pass (5300 m high in this case (→) through the Nyainqentanglha Shan into the large longitudinal valley SE of this massif (Fig 43, No. 17). The view has been taken at 5500 m asl in a SE direction down the U-shaped valley. In the background the large longitudinal valley SE of the Nyainqentanglha is visible. All the mountains up to 5700 m have been rounded (▲) thus providing a relief-fillingglaciation during the Last Glacial Maximum which covered at least a large part, if not all, of these mountains. Photo: M. Kuhle, 3.11.89.

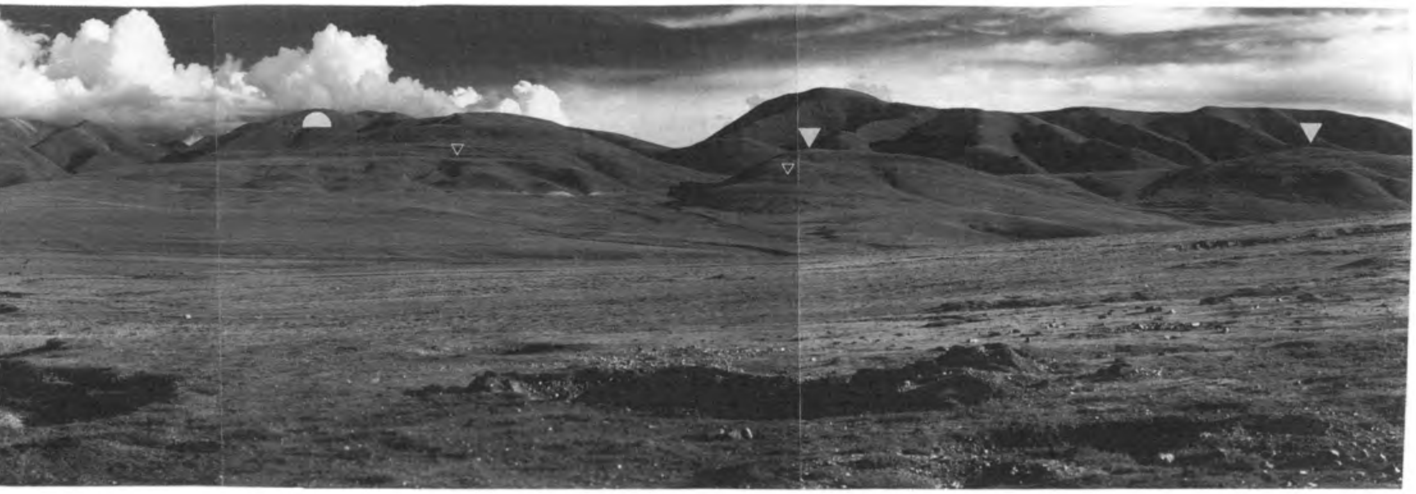

Photo 22
Glacigenic flank polishing (◠) on the orographic left-hand flank of the large valley SE of the Nyainqentanglha between 4500 m and 5500 m asl (Fig 43, No. 14). Besides the polishing forms which are manifest in the "sanded-down" forms of the slope facets (↓), exaration grooves running parallel to the slope have been preserved along with corresponding erosion forms (▽), which form a pattern of approximately horizontal stripes on the slopes. Photo: M. Kuhle, 4.9.89.

Photo 24
The crest of the main peak (1) of the Nyainqentanglha attains 7162 m; it has been photographed here from the main valley in the SE at a height of 4200 m asl, facing W. (Fig 43, No. 16). Up to about 5800 m or even higher, the valley flank has been polished by glacigenic flank polishing (◠). The reconstructed prehistoric minimum surface of the inland ice sheet is marked by - - - -. Triangular areas have formed (▲). Local moraines (valley exit moraines) were deposited from the U-shaped side valleys (▼▼). At the foot a Late Glacial lateral moraine terrace runs along the main valley slope (■■). In the foreground and middle ground, large-scale ground moraines have formed (⧫). Photo: M. Kuhle, 3.11.89.

Photo 26
The panorama was taken at 5500 m asl from a round polished mountain (Fig 43, No. 17) in a NW direction across the Nam Co (Tengri Nor) landscape o which had built up in this lake basin completely covered the relief, so that a minimum ice level of around 5800–6000 m asl must be assumed in any rec Glacial level of the Nyainqentanglha SE slope towards which the ice overflow was directed. Photo: M. Kuhle, 3.11.89.

Photo 29
The orographic right-hand flank of the large valley SE of the Nyainqentanglha massif (Fig 43, No. 19) with its Ice Age flank polishing forms (▲). This triangular slope extends upwards to 6000 m asl, and is thus evidence of the ice level during the Last Glacial Maximum (- - - -). In inter-glacial periods corrie glaciers (●) as they exist even now will destroy ie break up, the glacial flank. Photo: M. Kuhle, 16.8.89.

Photo 31
The orographic right-hand flank of the large valley SE of the Nyainqentanglha massif down valley towards the south, taken at 5300 m asl. A Late Glacial lateral moraine (●) with a moraine lake (dead ice lake) was deposited at this flank (left of ●). The remnant of a lateral moraine rises (●) to 650 m above the valley floor, and is thus evidence of a corresponding thickness of the outlet glacier in the main valley. This moraine deposit has been preserved in very good condition, and is even still separated from the valley slope proper by the counter gradient of a preserved basin on the banks (▼). Photo: M. Kuhle, 10.8.89.

Photo 30
Erratic granite blocks (↓) at 5270 m asl on a ridge on orographic right-hand flank of the valley SE of Nyainqentanglha massif (Fig 43, No. 20). In the backgr is the 700 m lower valley floor with flank polishing follo beyond (▲). The photograph is facing E. Photo: M. K 10.8.89.

'basins and glaciated knobs (▲). The water-level of this, the largest lake in central Tibet, lies at an altitude of 4750 m. The main Ice Age complex of inland
ınstruction. At the transfluence pass (⌒) the Maximum or Late Glacial glacier level had been depressed to c. 5600 m asl (- - - -). Here it had to adjust to

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Photo 33
The 16 km long side valley to the SW below the 7162 m high Nyainqentanglha main peak, taken at 5500 m asl in a SW direction from its orographic left-hand valley flank (Fig 43, No. 21). It is a U-shaped valley, which was increasingly filled with Late to neo-Glacial recent moraines, talus cones and talus slopes (●). Glacigenically-polished triangular slopes (▲) are evidence of total glaciation of the valley up to the peaks (- - - -) (cf. the exit of this valley in Photos 30, 32, 34 & 35). Photo: M. Kuhle, 14.8.89.

ice (cf. Section I_2)
the probably Late

Photo 27
Extensive ground moraine areas at 4200 m asl on the very wide floor of the main valley SE of the Nyainqentanglha massif (Fig 43, No. 19). Large to very large granite blocks "swim" in the loamy fine-grained matrix (●). In the background, ie towards the NW, Ice Age evidence in the form of triangular slopes and glacial polish flanks (▲) extend to 5800 m asl. U-shaped valleys polished into them have provide Late to neo-Glacial local moraines (▼). Photo: M. Kuhle, 3.11.89.

Photo 28
Another characteristic section of ground moraines, with large, and in this case, erratic blocks of granite (●) on the floor of the valley SE of the Nyainqentanglha (4200 m asl; Fig 43, No. 19) which was the likely route for a more than 1500 m thick outlet glacier of the inland ice of central Tibet to take. Such thicknesses are suggested by flank polishings and triangular slopes which have been preserved at altitudes exceeding 5800 m (▲). No. 1 marks the 7162 m high peak of the Nyainqentanglha. Photo: M. Kuhle, 3.11.89.

Photo 32
Erratic granite block (●) at 5150 m asl, ie 350 m above the *talweg* of the side valley (in the centre, below) (Fig 43, No. 20), and 650 m above the main valley floor (background, right-hand top). Older (■), as well as more recent (↓), local and moraine material poured out from the side valleys of the Nyainquentanglha which led down in a SE direction. The most recent dumped end moraines (↓) are even of merely historic age. The base of the end moraines occur around 4800–4700 m asl. Photo: M. Kuhle, 10.8.89.

Photo 34
Orographic left-hand flank of the valley (see Photo 33; Fig 43, No. 21), SW of and below the 7162 m high peak of the Nyainqentanglha massif, taken from 5400 m asl, facing N. Between the mouths of the two hanging valleys with hanging glacier tongues late Late Glacial glacial flank polishing in the form of a perfectly-shaped triangular area has been preserved (▲). On the valley bottom there is a recent outwash plain (◆) with historic kames (right-hand side above ◆). Photo: M. Kuhle, 13.8.89.

Photo 37
Section from Photo 36 (Fig 43, No. 22); glaciated knob in granite (▲). On the left the shallow stoss-side of this form of polishing (←), from where the overflowing ice came. Photo: M. Kuhle, 9.8.89.

Photo 39
Panoramic view of the orographic right-hand (SE) flank
1600 m further up and parallel to the valley axis (ie a

Photo 38
Down-valley view facing N from the point where Photo 37 was taken; on the orographic left-hand, 15 km W of Lhasa (Fig 43, No. 23) these glaciated knobs or glacigenic forms of flank polishing occur between 3800m and 4100 m asl (▲). Photo: M. Kuhle, 9.8.89.

Photo 35
Taken from the same spot as Photo 33, but facing SSW down the U-shaped valley (Fig 43, No. 21). The location of the erratica shown in Photos 30 and 32 between 5150 m and 5270 m asl is marked (↓). This side valley has been completely filled with glacier ice. The production of local waste occurred solely during the Holocene. Photo: M. Kuhle, 14.8.89.

Photo 36
The orographic right-hand original arm of the Lhasa valley and its side valleys ar
photographed from 4120 m asl (Fig 43, No. 22). Glacially polished flanks with triar
moraines up to 300 m high (▼). Photo: M. Kuhle, 9.8.89.

of the large valley SE of the Nyainqentanglha massif facing SE, taken at 4300 m asl (Fig 43, No. 24). The 17 km wide valley floor consists of lightly undulatin
lmost horizontal) (▲). This permits the reconstruction of a prehistoric ice stream network surface at about 6000 m asl (- - - -). Photo: M. Kuhle,

Photo 40
The large valley SE of the Nyainqentanglha massif 30 km E of the 7048 m high Qungmoganze peak, taken down-valley and facing S\
of micaceous granite (●) which covers the lower layers entirely. Glacial ground polishing has transformed the bedrock sedimenta
centrally situated kame terrace triangle (▽). Polishing on the mountain flanks up to 5800–5900 m asl is evidence of a Maxin

: formed in granite and have been finished by glacial action (▲). Facing W across this confluence area, a U-shaped valley joining-up on the right is gular slopes and glaciated knobs (▲) shape the valley flanks up to the mountain peaks. Comparatively small Late Glacial accumulations form lateral

; ground moraine with numerous rough blocks (●, granite erratica). The glaciated knobs and the valley flanks behind show glacial polish approximately 3.10.89.

V (Fig 43, No. 24). Almost 20 km wide here at 4300 m asl, the valley bottom has a lightly undulating layer of ground moraine with facetted erratic blocks ry rock ridges towering over it in the centre of the picture into glaciated knobs (▲). On the right there is a kame terrace (▼) and in the background a ıum Glaciation ice level (- - - -) at an altitude of 6000 m (cf. Photo 41). Photo: M. Kuhle, 3.10.89.

grown further of the high plateau, ie the base, had been more extensive at that same level. Thus it is the *plateau base* in relation to its location above sea-level that controls the height of the ice dome and the inland ice mass. Only when the *snow line rises above* the height of the plateau does the *symmetrical reduction* of the *ice dom* set in, including its specific - and also *temperature-controlled* - proportion of base to altitudinal elevation.

With regard to the substantial distance between the Maximum Glacation and *much more recent* moraines under consideration it implies that the earliest post-Maximum, the early Late Glacial and even the subsequent main Late Glacial sequences of terminal moraines in the valleys on the edge of Tibet crowd together over a *short horizontal distance.* At the same time it is the reason for the very substantial distance between these moraines and the Tanggula Shan moraines, which amounts to 300 km from the N (from the edge of the Kuenlun), and 600 km from the S (from the Himalaya).

The local moraines from the contiguous mountain massifs described in the following are consequently *much more recent* than those *large-scale* ground moraines in Tibet of the Last Glacial Maximum they *mix* with, *superimpose* upon or in places *supra-mould.* Findings of small-scale and recent tongue basins, which are bordered by the terminal moraine ranges, are in a *very good and particularly striking state of preservation* (Photo 21). Some of the earlier researchers were thus led to regard this local glaciation as the maximal glacier cover (v. Wissmann 1959, pp. 1316–1365; Table 1914 II, p. 8 et seq.; p. 44 and Tables 10, 11; p. 49, Table 13; Hörner 1938, p. 206 inter alia).

Fourteen km down-valley (30°33'N/91°25'E) where the two flanks of the valley are about 10 km apart, very well preserved *glacial polishings* have been found to extend over many kilometres on both sides (Fig 43, No. 13, No. 14; Photos 22 and 23). They are orographic left-hand *glaciated knobs* (Photo 22▼), which are separated from the valley flanks by more or less marked *polished basins.* Above them *flank polishings* continue (Photo 22●). Both glaciated knobs and polished areas on the flanks show *glacial erosion grooves* which, intersecting with the bedrock glaciated knobs, form typical glaciated-knob groove polishings (Photo 22▽). On the orographic right-hand main valley flank polishing is particularly fresh, and unambigiously preserved up to about 1000 m above the valley floor. Its *glacial* origin is indirectly confirmed by the *contrast* with the *formation* of *dells* and *gullies,* as well as the *incising of small hanging valleys* (Photo 23↓↓). These incisions increasingly *dissect* these main valley polishings, thus proving that the *present* geomorphological regime does *not* continue where the prehistoric one left off. On the contrary, it is destroying its objectivation and presents a *contrast* to the prehistoric formation regime. This is the fundamental differences between large-scale glacier polish workings set across, and linear incision by *water running-off* in *glacier-free* areas.

At the exits of *large* side valleys, the cutting-away of the edges to the main valley flanks are much less pronounced (ie considerably rounded) than on those gullies and small hanging valleys. Between these openings of the larger side valleys classic *triangular areas* have been polished (Davis 1912, p. 416, Fig. 148; p. 417, Fig. 149; p. 453, Fig. 175; p. 454, Fig. 176.) (Photo 23▲). Such *triangular areas* cannot be brought about by any process other than flank polishing. At best they can be subsequently tolerably well-preserved during post- or inter-glacial periglacial periods, because solifluidal movements of drifting scree covers are also processes with area-covering effects. They naturally proceed down-slope, ie at *right-angles* to the flank polishings. Both the orographic right-hand *flank polishings* and at topographically conditioned intervals also the left-hand flank polishings (series of suitably high protruding valley flanks were absent here) - continue almost without interruption 200 km further to the S (Photo 27●, Photo 28●, Photo 29●).

25 km down-valley an approximately 10 km- long *kame terrace* begins on the orographic right hand. It is 100 to 150 m high, reaching 200 m or more of relative height in places (30°31'-34°N/91°04'-08'E; 4600 m asl Fig 43, No. 15). These glacio-fluvial accumulations were brought out from the valleys of the Nyainqentanglha's SE ramp and poured out against the *remaining,* possibly *dead and no longer replenished* ice masses of the main valley. This *must* have been at a time when the ELA had already *risen* so far as to prevent the local and steeply descending glacier tongue end from reaching 4600 m asl any more. At this flank of the 5802 m and 5854 m high massif the recent side valley glacier tongue flows down to 5600 m asl. This implies a *rise in the snow line* to a smaller depression than the 500 m depression in contrast to the present level of the snow line. Assuming for the Last Glacial Maximum an ELA depression of approximately 1200 m for Tibet (cf. Kuhle 1988a, p. 509 and 1988b, pp. 586–591) it corresponds to a rise of the snow line of already more than 700 m within the course of the Late Glacial. This kame terrace consequently confirms that *dead ice remained for a very long time* - indeed doing so up to a time with a very noticeably *warmer* climate than that had necessarily prevailed during the *build-up of the ice in the main valley,* which in its function as an outlet glacier had profited from its connection with the central Tibetan inland ice (I_2) (cf. Oerlemans 1987, p. 353). Another c. 15 km long kame terrace is situated 22–37 km further SW on the same side of the valley (30°20'-26'N/90°45'-52'E, 4600 m asl) (Fig 43, No. 16). This form contains integrated Late-Glacial *local moraines* which have been transported from a 6214 m high massif of the Nyainqentanglha (from four SE sloping parallel valleys (Photos 24 and 27▼▼). The *present* glacier tongues in this exposition end between 5300 m and 5500 m asl. The problematic issue of local moraines in their relationships to the Maximum Glaciation ice fillings of the main valley will be further examined below on the basis of detailed data from the localities.

An important feature is the *Maximum Glacial ice spill-over from the* Nam Co (Tengri Nor) highland basin into the main valley SE of the Nyainqentanglha, which is being discussed here. A transitional gap in the mountains, which begins with a 5300 m high pass 15 km SE of the Nam Co (30°40'N/91°07'E) may serve as an *example* (Fig 43, No. 17). Taken at 5500 m asl, the panorama photographs show the *topographic connection* between this valley and the surrounding mountains with the pass and lake basin acting as an *outflow for ice* from the W (Photos 25 → and 26). It is a typically rounded *corridor* opening into a classic *trough* further down towards the SE. Formed from the metamorphosed sedimentary rock and sandstones, the mountains are shaped in the form of *rounded hills or ridges* and covered on all sides by light layers of scree, or made steeper on the N face by *corries* which carried ice as late as the Neo-Glacial. Smaller rockwalls have been formed here (Photos 25 and 26▼▼), as is characteristic for a "late-maturing to old corrie landscape" in terms of the Davisian definition (1912, p. 421 Figs 154 and 155). Both valley and mountain forms, which rise up to 5700 m, are evidence of a *relief-reducing ice cover from the Maximum Glaciation*. Since the lowest known point of the Nam Co basin (lake level) is at 4718 m asl, the relief forms indicate a *minimum in the ice thickness* of fully 1000 m for the Last Glacial Maximum.

Well preserved and several hundred metre-high *glaciated knobs* occupy central positions at middle of the main valley at 4200 to 4400 m asl. They consist of migmatitic rock (at 30°27'N/91°00'E) (Fig 43, No. 18). In the same valley section characteristic forms of *subglacial meltwater activities* may be observed, too. In this case it is a *box-shaped* erosion cross-section, 100–200 m wide, which has been carved out of the rock base of the km-wide *trough-shaped* valley to a depth of about 15–20 m (Fig 43, No. 18). *Torrents* have deposited rough bands of debris against the almost *vertical rock walls* of the box profile, and even on the rock terraces above, with the sediments ranging from pebbles the size of a fist to several blocks several metres in size. The material conveys the phenomenon of merely rough-sorted *subglacial meltwater deposits*. The very large blocks have been washed out of the *ground moraines*, some of which can in fact be seen in places nearby. They have merely undergone a *critical shift* in the process. Such cubatures can, however, *not* be transported *over greater distances* by subglacial meltwaters. Only *hanging glacier ice* has been capable of doing that. *Subglacial meltwater erosion* at about 4250 m is evidence of the *glacier surface* above this level as having been located *below the snow line*. The subglacial activity of the melting waters *must* therefore have taken place in *Late Glacial* times as the Glacial Maximum-ELA has remained *below* 4500 m here (cf. Kuhle 1988a, p. 458, Fig 2: concerning the area N of the 4500 m ELA line). At this main Ice Age level of the snow line the thickness of the ice should have been noticeably less than 250 m in order to produce any *subglacial meltwater* at all. However, during the main Ice Age, the thickness of the glacier must have exceeded 1000 m (cf. above and below), and the ice surface have been at least 5300 m high. *Rises in the ELA* and the resulting *lowerings of the glacier surface* can therefore have met at this place only during the Late Glacial, so that the surface and ELA exchange positions, placing the glacier surface *below* the ELA for *subglacial meltwater* to form. To enable this to happen, the ELA may well have been raised to at least 5200 m asl; this would have allowed the ice surface to melt down to below the 5000 m line and produce meltwater.

An adjacent locality further south furnishes *further evidence* for enormous prehistoric glacial infilling of the relief in the form of extensive *areas of ground moraine* at about 4200 m asl (30°25'N/90°56'E; Fig 43 No. 19). In the middle of the 15 km-wide valley floor there are boulder clay areas which extend over tens of kilometres (Photos 27 and 28). Isolated from one another, large blocks of granite, several m^3 in size, are embedded in the clayey, silty, sandy ground-mass. Gravel and pebbles are almost entirely *lacking*. The block fraction also includes rock other than granites, although they are of subordinate importance. Most blocks have *rounded edges*, some being round and a few have retained their sharp edges.

In this some 30 km long valley chamber the orographic right-hand valley flank extends to 7162 m, that is to the main peak of the Nyainqentanglha (Photo 24, No. 1). Glacially polished *triangular areas* and classic *flank polishings* have been preserved on it up to heights of 5600–5800 m: they run in a SW direction at approximately *one* level of the upper limit. This is evidence of a corresponding main Ice Age *minimum glacier level* (Photo: 24 - - - -; Photo 29 - - - -; Fig 43, No. 13–19). These marks of *polished flanks and polishing boundaries* which endow the landscape with a character reminiscent of *Central Scandinavia* – the Dovrefjell, for instance – and which are known to be a glacigenic characteristic (cf. Photo 29) are evidence that *during the Last Glacial Maximum the thickness of ice* in this cross-section must have been at least 930–1600 m (the valley floor nearby = 4200–4670 m asl).

Findings of erratica at altitudes of up to 5270 m asl have made it possible to substantiate *this determination of ice thickness* through glacial *traces of erosion* (Fig 43, No. 20): at 30°18'N/90°36'E there are *rounded blocks of granite* (Photo 30 ↓ on – in this valley cross-section – a *small erosion surface* (c. 40 m^2) within the course of a ridge of an intermediate divide at least 700 m above the highest section of the valley floor in the W flank of the main valley concerned. Though there is granite bedrock here as well, it must nonetheless be a matter of *erratic blocks*. These big *rounded* and *round* blocks, which are up to 90 cm long, are embedded in more broken-down and sherd-like and sharp-edged granite frost debris eroded in situ. Deposited on the arête of a ridge, there is no slope above these blocks that could have acted as a *catchment area* (there is a complete absence of such), so that they appear to have "dropped from heaven" and can only be explained by *ice transport*.

The topographical analysis shows that it was *not* solely a matter of ice from the two adjoining side valleys coming from the NW from the Nyainqentanglha massif, and thus not only of local erratic blocks. The hypothesis of local glaciation consequently does not apply because of the location of erratica on the spur of an intermediate valley in the position of a side valley exit within range of the main valley flank. At this very *high location* the ice surface in the side valley exit was *only sustainable* by the *damming-up* of the particular contributary glaciers against the main glacier, which filled the main valley, at least to the level of the erratica findings. This *compilation* was the reason for these side valleys being fully (ie up to their upper edge) glaciated during the Main Glacial period (Photos 33 and 35). Judging by the boundaries of polishings in the side valley under investigation, the ice level was at least 500–700 m higher than the position of erratica at 5270 m asl. Evidence of the corresponding main valley ice level is again provided by flank polishings at 5800 m (cf. above) to maximally even 6000 m asl (Photo 29 - - - -). The rock domes in the vicinity of the erratica deposits under consideration have been rounded and polished by glacier ice (Photo 30▼).

In this locality (Fig 43, No. 20) the *combination* of *main Ice Age traces of glaciation of the main valley and Late to Neo-Glacial local moraines* is of representative conspicuousness. The main Ice Age traces consist above all of *forms of polishing* and some preserved *erratica* at high altitudes, as well as featureless *ground moraine areas* in the lowlands. In the course of the Late Ice Age lateral moraines in the main valley became more and more noticeable (Photo 31●). On the triangular slope of the main valley they reach altitudes of 5154 m. The recently initiated formation of banks has a strikingly *fresh form* and preserves a *morainic lake,* which continues to contain water despite its exposed altitudinal location. At the same time the moraine formed a lateral moraine and a median moraine which was deposited between the main and the contributory glacier. In addition there are well preserved remnants of a syncline on the bank, together with its reverse gradient from the main valley flank to the outer slope of the moraine (Photo 31▼). Rich in *erratic granite blocks,* this bank formation is evidence of an *ice thickness* of at least 650 m asl of the main valley floor; it is *bound* to belong to a period in which the ELA had already *risen noticeably above* 5150 m asl (the altitude of the lateral moraine surface). Failing this (ie above the snow line) no moraine could have been formed or deposited – further down more generations and levels of more recent, lowered glacier levels follow on (Photos 29■, 31■, 30■ and 32■). These lower and more recent moraines are predominantly built-up from *local material* which has been forwarded from the 16 km-long valley south of the 7162 m peak (the Nyainqentanglha main peak), which runs down from the NW. As is to be expected from a very steep, short-cut catchment area (Photos 33, 34 and 35), the moraine material consists of proportionately strikingly large *accumulations or rough blocks* of bedrock granite from the valley. After their short distance transportation the *size* of the blocks reaches that of a hut.

These moraines are significant because they are indicators of a qualitative *leap* of the formation of prehistoric glaciation. If there had so far been talk of continuing *glaciation of the main valley,* the level of which had been lowered in accordance with the increasingly rising ELA, the main valley ice is now largely, or even entirely, *absent.* Evidence of this exists in the arrangement of these side valley moraines, which have been deposited up to 2.4 km out into the main valley in the characteristic *form of terminal moraine walls* (Photos 30⧫ and 31↓). The fact that the main valley ice had already melted away together with the *short horizontal and vertical distance* to recent glaciation show that it must be a matter of comparatively recent, Recent Late-Glacial to Neo-Glacial ice margin locations. A present side valley glacier ends at 5320 m asl (Photo 33■, far right), and the lowest side valley moraines to be deposited in the main valley, extend down to 4700 m asl (Photo 30⧫). On the main valley floor some of the glacier tongues from the side valleys have coalesced into a common, piedmont glacier-like ice margin. The local 18 km long side valley glacier, for instance, joined the tongue of the parallel, SE glacier of the 7046 m peak in the N. Its glacier tongue now extends down to 5200 m. Even in historic times (probably during the "Little Ice Age" of the last century) this SE glacier tongue from the 7046 m peak flowed down to the main valley floor at 4800 m. This advance must have continued for several decades, since a *dumped terminal moraine,* tens of metres in thickness, was left behind by the glacier (Photo 32↓). The *pioneer vegetation* on this glacier tongue-shaped dump moraine has not yet reached the stage of dense an matted growth which it tends to form at the peak of its development at this height; this is proof of the *recent age* of this moraine.

In the area of the *floor of the tongue basin,* just before the exit of the 16 km long side valley under consideration (Fig 43, No. 20; Photo 30 ○), seismic measurements on an 80 m profile taken at 4800 asl showed moraine thicknesses in excess of 35 m. At the time of the measurements on August 14th, 1989, the *mollisol* above the permafrost table was 2.1m thick (the measurements were carried out by Dr. D. Ortlam and Mr. Wang). Outside these "side valley exit moraines" 3–6 km wide *cone-shaped outwash plain lobes* set in. Their recent glacio-fluvial covers of stratified drift material raise the floor of the main valley by several metres or even tens of metres. These drift covers provide large-scale mantles for *ground moraines from the* main Ice Age (Photos 30 × and 31 ×).

This 16 km-long side valley has the character of exemplification and is evidence of the *communication* between its prehistoric glaciation with the main valley ice. Its present catchment area includes a total of 22 separate *small glaciers* and *glacier tongues* (Photo 33■), only one of which – the 7 km long ice stream at the valley head – reaches the valley floor at 5320 m asl (30°21'30"N/ 90°32'30"E; Fig. 43, No. 21; Photo 33■, far right). The other glacier tongue, several of which spring from the *same* feeding ground, hang more or less steeply from short floors of hanging valleys or *cirque-terrace-like* erosion surfaces in the valley flanks. Their moraines and steep alluvial cones *pile up* on the valley floor and obscure the *U-profile* of this valley (Photo 33●). The polished flanks are best preserved between these hanging glacier ends (Photos 33 and 34▲). Thanks to the *historic ice margin location* of the largest glacier in the valley which flows down from the 5830 m high pass at the head of the valley, the longitudinal valley profile is "chambered" (Photo 33▼▼). Within these ice margin locations, which are situated 0.5 to 2 km apart from one another and are climatically separated by only small ELA steps of a few tens of metres, glacier tongue basins have *dammed up trains of drift material from the glacier cave* with the help of their end moraines (Photos 33 and 34⧫).

As previously proved by the erratica at the valley exit at 5270 asl (Photo 35↓), the valley had been completely filled with ice during the Ice Age. In the meantime the then polished flanks have been cut up again by waters (Photo 35▼▼). As shown by the uppermost *boundary of polishings in the main valley* (cf. above), the ice extended at a maximum another 500–700 m *upwards beyond the location of the erratica.* This also implies the probability of an *overspill of ice* (Fig 43, No. 21) coming from the NW across the 5830 m pass at the head of the valley, ie from the large glacier basin of the Nam Co (Tengri Nor) (see above with regard to the NE parallel glacier overspill coming from the Nam Co across the Nyainqentanglha crest). The orographic right hand slope of the valley under consideration SSE of the four peaks (7162 m, 7111m, 7117 m and 7046 m), of the highest Nyainqentanglha mountain has been shaped in the heads of the bedrock granite (Photo 35▼▼). It is much, although *not especially deeply,* cut up – or, rather, grooved – by gullies. These cuts of a maximum 8 to 10 m into the slope took approximately 6,000–10,000 years to develop, whereas the *talus* cones that have consequently piled up at their *base* had a mere 4,000–10,000 years since a Neo-Glacial glaciation of relatively small thickness continued to cover this side valley (see above). These *traces of secondary formation* serve once again to demonstrate the rapid dissolution of glacial trough flanks in High Asia.

The orographic right-hand arm of what was to become the *Lhasa valley,* which joins the Lhasa valley 10 km to the W of Lhasa, begins in the main valley SE of the Nyainqentanglha at 4300 m asl at 30°05'N/90°33'E. This valley saw a very substantial ice flow-off to the SE. There are rough banks of bedrock granite here, which have been rounded up to the more than 5200 m-high mountain ridges. The key locality for the Ice Age glaciation of this valley lies, however, in the first widening of the valley in the region of the confluence of a right-hand with a left-hand valley at 4120 m asl at 30°02'N/90°37'30"E (Fig 43, No. 22). Three powerful arms of the *ice stream network* joined forces in this valley chamber; *forms of glacial polishing* are evidence of it (Photos 36 and 37). The cross-sections of the more than 10 km long side valleys are those of *classic troughs* (Photo 36). Mountain spurs descending towards the area of the confluence have undergone perfect rounding (Photo 36▲). More recent (post-glacial) fluvial *gullies* and *gashes* (Photo 36↓) are clearly distinct from *older forms of flank polishing.* The unambiguously glacigenic elements of forms include an obviously *glaciated knob* (Photo 37▲), the *flat head* (luff side ←) of which points up the main valley. This shows that while the main ice stream came from the *big* and regionally by far the *highest* glacier catchment area (in excess of 7000 m) of the Nyainqentanglha, another one approached from the *inland ice area* of *central Tibet.* 38 km down-valley and 15 km W of Lhasa (at 3800 m asl and 29°41'N/90°54'E) rock polishings similar to those of the glaciers have been preserved on the granites of the Lhasa plutons on the orographic left-hand (Photo 38▲; Fig. 43, No. 23). These findings call for a *consideration in principle* on the *suitability of granites* as rock for the *preservation of glacial polishings.* The problem consists in the fact that a crystalline rock mass like granite, which inclines to large-scale *desquamation* and *disaggregation* may also develop forms converging on glacial polishings under different conditions, such as tropical or arid climates. In the valley system of Lhasa, however, there are neither tropical nor arid conditions in spite of its subtropical latitude. On the valley floor present annual precipitation is 440 mm, quickly increasing to c. 500–600 mm/annum on the valley flanks, glacial formation of these rock polishings is therefore the most likely cause in this locality. Glacial striae, however, which are without convergence phenomena, ie they cannot come about in any other way, are almost entirely *absent* from prehistorically polished granites. They are missing here, too. Disaggregation, which eliminates the possibility of longer term preservation of striae, does also take place in humid, semi-arid and periglacial climatic conditions. The *coarse crystalline grain* of granite, moreover, already impedes the *primary application* of such delicate structures as glacier striae. Dragging across the granite, drift material contained in ice *splinters* and *crumbles* the long granite crystals into broader, less well defined grooves on the bedrock than would appear in finely grained metamorphites. These are subsequently much faster attacked by post-deglaciation frost weathering than narrow, serried and well-defined striae would be, and are *more prone to frost shattering.*

Interpreted as glacial flank polishing by the author, this rock polishing constitutes the lowest hitherto observed indicator of the main Ice Age ice stream network in the main valley system of Lhasa. There has so far *not* been *any evidence* of associated terminal moraines. On the other hand, there are numerous well-known present-day marginal locations of valley glaciers without *end moraines* (ie the 42 km long Skamri glacier on the N slope of the Karakoram; the 70 or more km long Fedtschenko glacier in the Pamirs etc.). However, at the same time there is no evidence that this valley glacier tongue of the main Ice Age ice stream network has ever *ended at all.* It is possible that the main Ice Age ice completely infilled even the Tsangpo valley, the deepest valley of S Tibet (after Kuhle 1985–89, amongst other publications, I_2 and I_3 in the E part of S Tibet were separated by the Tsangpo valley, which is thought to have then still been freed from ice there (eg Kuhle 1987a, p. 413, Fig 27).

After this excursion into a side valley branching off in the direction of Lhasa in order to consider the ice flow-off towards the SE, observations return to the vast clearance area SE of the Nyainqentanglha, following it further up to the SW, towards the Tsangpo valley (cf. Fig. 43).

Orographically on the right-hand - the second highest massif of the mountain range, with the 7048 m high Qungmogangze rises up. In this valley chamber of the large clearance area even the orographic left-hand area peaks of maximally 6190 m reach the recent altitudinal level of glaciers. In this valley section the significant *polished flanks* with their triangular areas described above for the middle section of the valley (Photo 29▲) continue on both sides (Photos 39 and 40). Extending to 17 km here (Fig 43, No. 24; 30°02'N/90°26'E), the valley floor presents a contourless *ground moraine relief* with numerous large to very large granite blocks. Isolated from one another, they tend to be embedded in a sandy, silty, loamy ground mass, but do occur free-lying on the surface (Photos 39 and 40). Forced by circumstance to appear always as the minimum thickness, the greatest ice thickness, as evidenced by well preserved polishings on the higher mountains, reached up to 1600 m. The associated highest glacier level approached a height of 6000 m in this case (----). Belonging to the more recent, Late Glacial period, according to it topographic connection, a kame terrace (cf above: corresponding observation) extends over about 10 km along the orographic right-hand edge of the clearance area (Photo 40▼▼). At the terrace edge it is about 60 m high, and contains *glacio-fluvial pebbles* as well as *glacilimnic sands*. Up against the actual mountain structure, where it was laid down against the *remnant of dead ice deposit*, the rising *kame terrace area* reaches a relative height of 100 m above the valley floor. The *recent Late Glacial to neo-Glacial local moraines* deposited at the exit of every side and hanging valley (Photo 40↓↓) (cf. above) need not be gone into again in detail.

Another large *kame terrace* is situated in the centre of the valley chamber E of the Qungmogangze (7048 m), its basis being at 4300 m asl (29°57'N/90°20'E; Fig 43, No. 25). Sections of these 50–70 m high accumulations can also be interpreted as *subglacial esker or oser formations* (Photo 40▽). They are likely to be a *mixed form*, which has been deposited into a recent Late Glacial *central thaw depression in the ice*, the slopes and walls having acted as a *container and frame* for the *glacio-fluvial drift* not unlike a *cake-tin*. The ice having thawed, the body of drift material - triangular in outline - remained standing as a striking three-dimensional shape. The phenomenon has been described before (Kuhle 1988a, p. 459 and p. 458, Fig 2, No. 3) and somewhat wrongly located at 29°41'N/90°15'E, due to the imprecise ONC - 1:1,000,000 map available at the time. Photo 41▲ shows the almost perfect orographic right-hand *flank polishing* (Fig 43, No. 26, at 29°55'N/90°17'E; 4300–5800 m or even up to 5900 m).

A glacial *trough valley* with classic triangular areas on the *polished flanks* (Photo 43▲▲) leads from this locality to the Tschü Tschü La in the W, a 5300 m high *transfluence pass*. This pass with its *granite erratica* has already been described under the name Shüke La or Chalamba La (Kuhle 1988a pp. 458–460, Fig 2 No. 2, Figs 4 and 5). Its locality had then been given somewhat imprecisely as 29°41'N/ 90°15'E; it is, however, at 29°54'/90°08'E (Fig 43, No. 27). The in part large and light-coloured erratic biotite granite blocks with k-feldspar lying here over dark chlorite-containing bedrock of rhyolite rock (Heydemann, A. and Kuhle 1988, p. 617, Figs 3 and 4) had their positions on thir pass rechecked during the 1989 expedition, and have been mapped from further, new perspectives (Photos 42↓↓ and 43↓↓). Both these *erratica* on the *peaks* of extensive, perfectly *rounded polished ridges* or *glaciated knobs* (▲) and the contrast to the typically *pointed forms of summits and crests* (▲▲), which start at heights of more than c. 6000–6100 m asl, are evidence of a *large-scale ice cover* and *ice transfluence* of an approximate thickness of at least 700 m (Photo 43 ----). (For altitudinal orientation: on Photo 43 the present ELA runs at about 5800 m asl).

In 1984 the author was of the opinion that the erratica on the Tschü Tschü La provided an indication of a main Ice Age ice flow over distances of 80–100 km from the area of the Lhasa pluton in the E (Kuhle 1988a, p. 459). As a result of extended investigations in the field in 1989, this interpretation, which had been arrived at with the help of the geological map of Gansser (1964, Plate 1), needs to be corrected or at least modified. The main ice-flow - the one from the *inland ice in Central Tibet* (I_2) came from the NE by way of the large clearance area SE of the Nyainqentanglha. The *inflow* through this main valley had been proved in this chapter on the basis of indicators of prehistoric glaciation, which had been presented in detail. Its level at an altitude of at least 5800–6000 m *communicates* with this *level of the ice overflow* via the Tschü Tschü La. The *granite erratica* deposited in this place have consequently not been brought along from the Lhasa pluton, but had been taken up from the SE slope of the Nyainqentanglha. This implies transport distances of a few hundreds of metres to 200 kilometres. This required a *central Tibetan inland glaciation* as a precondition for the necessary high ice level of 5800–6000 m to be built up. It is not impossible that some of these *granite erratica* have been brought along from much further afield, ie the *granitic areas of central Tibet* and passed by that large outflow glacier the Nyainqentanglha massif.

The last area to overlap with the one under investigation during the expedition of 1984 (Kuhle 1988a), and to be re-examined over a distance of 20 km, is the valley that leads from the Tschü Tschü La to the SW. To start with, *erratica* are found over a distance of 12 km, and downwards are increasingly embedded in ground moraine covers (Photo 43♦). These *ground moraine covers* attain thicknesses of several decametres (Fig 43, No. 27). South of the 7048 m high summit of the Qungmogangze, which continued bringing glacier ends from steep hanging valleys to the valley floor even during the neo-Glacial period, they are associated with *recent terminal and contributary moraines*(29°50'N/90°02'E). Another 8 km down-valley *large-scale flank polishings* and *forms of glaciated knobs* (Photo 44▲), minimum glacier level ----) are preserved on the orographic left-hand (Fig 43, No. 28; 29°45'N/ 90°00'E, 4400–4800 m asl).

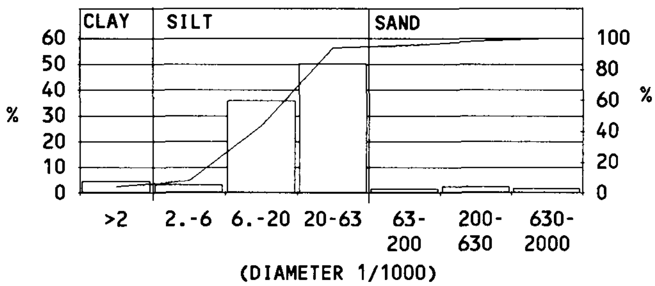
6. The Main Ice Age Glacier Cover of the Nyang Qu (=Chu = Valley) Catchment Area and the Lower Tsangpo Valley, Including the Namche Bawar Massif (Namjagbarwa Feng, 7651 or 7782 m) (29°00'-30°20'N/91°30'-95°25'E)

50 km from Lhasa to the E, up the Lhasa valley, there are *no* clear traces of a main Ice Age glacier filling. (Whilst there is glaciated knob-like flank polishing at the same altitude above sea-level in the valley W of Lhasa, cf. Photo 38). After that, however, rock polishings resembling flank polishing begin on both sides of the up to 3 km wide valley drift floor, which has been laid down as a Late Glacial sandur (fluvio-glacial drift floor). They are associated with a *change in the rock material* from soft metamorphites to reddish-brown granites. Granite evidently preserves glacier polishings *better* than the sedimentary rocks outside the valley. Remnants of terminal or lateral moraines are lacking, so that that *polish* constitutes the only evidence of prehistoric valley glacier ice down to c. 3770 m (Fig 43, No. 29a) (29°49'N/91°40'E). It is *highly likely* that the *outlet glacier* of an ice stream network catchment area, which covers a large section of the Transhimalaya of more than 5500 m throughout and still displays a thickness of at least several hundreds of metres here, once stretched many decakilometres further down valley and into the Tsangpo valley. Final proof of this, however, is still outstanding (cf. below, this chapter, as well as chapter 7).

The large side valley, which culminates in the 5300 m high Min La, a pass leading over into the Nyang Qu (Chu) was followed up as one to constitute an example. This 75 km long valley presents all the essential *glacial forms of erosion,* which characterize a *valley-filling* glaciation. There are classic *trough profiles.* The flanks are identified through substantially down-polished *triangular areas* and other forms of *convex polishing.* In parts the adjoining side-valleys are formed into *hanging troughs.* But even without a steep gradient some of them lead into the valley of the next higher category (Fig 43, No. 29; 29°48'N/92°02'E; 4200 m in altitude on the valley floor). Almost all the valley heads under observation present corrie-like formations and *U-shaped cross-sections.* The glacial formation of the relief on both sides of the Min La is exemplary (Photo 45). The valley floors below c. 4600 m asl consist of recent Late Glacial *drift* floors (sandurs) which partially cover, ie encase some *glaciated knobs* in barrier mountain positions with sediments at the base. Above this altitude recent Late Glacial *lateral, terminal and dumped end moraines* frequently occur on the valley floor and on the slopes in the *form of ledges and hills* (Photo 45■▼). During the last main Ice Age the entire valley relief, which is surrounded by peaks of up to 5800 m, was filled with a *network of ice streams.* It was only in the more recent Late Glacial period that these valleys were freed from ice to such an extent as to permit renewed advances of smaller glaciers to be marked by these *moraine formations.*

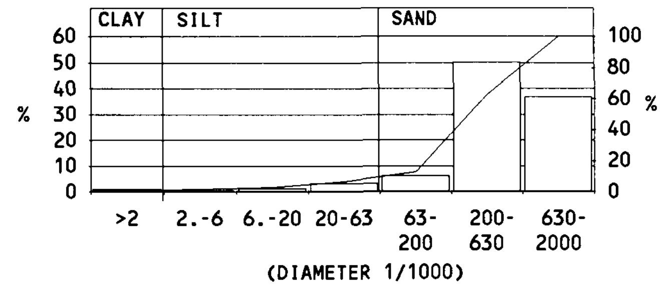
In the longitudinal sections of these valleys on both sides down from the Min La geomorphological leap, or change in outward shape of the surface forms appears in an exemplary way, which is, in principle, characteristic for the whole of Tibet and the adjoining mountain systems. It is the mark of very active *periglacial morphodynamics* above the *permafrost line,* ie here above the altitude of about 4800–5000 m, which has transformed even recent, Late Glacial moraine surfaces and rounded accumulation ledges and edges (Photo 45). Below the *permafrost line,* fluvial processes like *gully erosion* and *linear erosion* even of small streams, appear increasingly on the scene. Although solifluction continues to take place here, it is less efficient in relation to increasingly fluvial morphodynamics down valley. Though this break in formation only concerns the *style of formation* near the surface of the soil, and not the actual elements of valley forms and larger dimensions, superficial observation *without the benefit of comparisons* could well give rise to the impression that the lower limit of most intensive solifluction is also the lower limit of historic glaciation. Such deception is supported by the kind of solifluidal transformation which proceeds in perfect *concordance* with the glacial surfaces of valleys and mountains. After all it preserves the glacial shape of the landscape in the area of erosion down to its details and does not alter it. Fundamentally different, however, is the transformation through fluvial processes, as this *dissects* and thus *destroys* the prehistoric glacial forms. Added to this is the fact that the lower valley regions have been *free from ice* and thus exposed to fluvial remodelling for a much *longer* time than the upper valley reaches. *Decreasing altitude above sea-level* within the altitudinal level of fluvial transformation consequently results in an *increasing distortion* of the former glacigenic wealth of forms. This geomorphological break is further *intensified* by the fact that from a certain altitude of the catchment area of the mountains recent Late Ice Age moraines looking very fresh and therefore striking, have been deposited precisely within that band of altitudinal limits. This aspect is given significance by the formerly very widespread and still extant *erroneous estimate* of the maximal extent of glaciers in High Asia (v. Wissmann 1959, pp. 1327–1365; Shi Yafeng et al. 1982; Zhang Shuyuan 1982; Zhang Zhenhuan 1984; Zheng Benxing 1988 pp. 525, 527-532, amongst others). In many places (as for instance v. Wissmann 1959, pp. 1343 and 1316–1327) those above-mentioned recent Late Glacial to Late Glacial moraines with the *upper,* well-preserved glacial forms of erosion by contrast with the forms *below* were used as evidence for a glaciation which was estimated as being *much smaller,* but held to be the maximal extent.

In the subsequent pursuit of the Nyang Qu in an initially northern, and then more or less strictly easterly direction down to the Bayizhen (Baji) settlement at 3200 m asl, the gathering of indicators will be restricted to the cursory mentioning of *particularly significant* exemplary phenomena without describing every one of the important localities. The repetition of these phenomena is too frequent. Attention will rather be directed towards the hitherto rarely or – in its topographical variant – not at all observed glacio-geomorphological phenomena. The



IGNITION LOSS: 1,64%
LIME CONTEND: 0,28%

Fig 10 7.9.89/1, orographic left-hand lateral moraine terrace near Bayizhen, 3200 m asl, boulder clay; Fig 43, No. 35; Photo 48 (■); sand 6%, silt 89.6%, clay 4.4%.



IGNITION LOSS: 0,35%
LIME CONTEND: 0,25%

Fig 11 7.9.89/2, orographic left-hand lateral moraine terrace near Bayizhen, 3200 m asl; Fig 43, No. 35; Photo 48 (■ below); sand 93.5%, silt 5.3%, clay 1.2%.

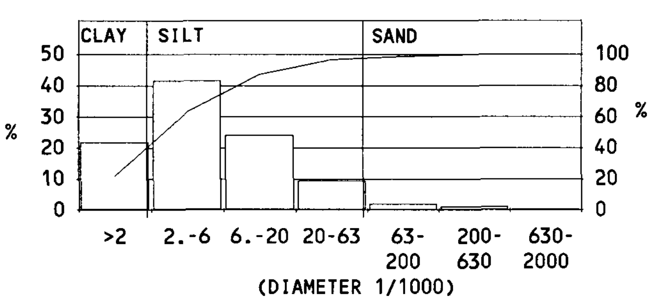
uppermost 15 km of the valley are characterized by all the elements of *prehistoric trough valley geomorphology* (Fig 43, No. 30). Below 4400 m, after a confluence with another orographically left-hand branch of the valley, it is followed by an approximately 12 km long, narrow, gorge-like stretch with the features of a "trough-shaped gorge" or a "gorge-shaped trough" (Kuhle 1982a, p. 59 et seq; 1983a, pp. 155–159) (29°54'N/92°55'E, Fig 43, No. 31). The upper parts of the transverse profile of the valley are characterized by *corrie terraces* and *hanging, short troughs*. Further down valley there is an area of granite with barrier mountains on the mouths of the hanging side valleys with subglacial *gashes* which have been polished into *glaciated knobs*. Very high and well preserved *flank polishings* are evidence of an approximately *total infilling* with *glacier inserts* from the main Ice Age.

To give just one example, this applies at 29°47'N/93°50'E, Fig 43, No. 32, where bedrock metamorphites have received *glacial polishing* to heights well above 4500 m (Photo 46▲). Covered by more recent drift floor, the valley bottom line here is at an altitude of c. 3350 so that ice thicknesses of more than 1300 m are likely to have existed.

13 km up-valley an orographic right-hand side valley joins on, opening up a view of the highest region of this section of the Transhimalaya (Photo 47; Fig 43, No. 33). Here the mountains attain maximum altitudes of 6296 m (5822 m on the left side of the photo and 5692 m on the right-hand) and are iced over with maximally 2–3 km long hanging glaciers (●). The *historic* to *Recent Late Glacial* range of glacial forms is accordingly perfectly represented (Photo 47), and there are many *lakes in troughs and corries* of the numerous higher valley chambers and near valley heads between 4000 and 5500 m asl (↓↓) which are mostly clearly dammed back by *moraines*. The present ELA runs at approximately 5500 m asl here; due to increasing precipitation towards E Tibet, it is situated at a lower altitude than in the central Tibetan areas considered so far. With a minimum depression of 1200 m, ie down to 4300 m, the *Ice Age area above the snow line* must have been much more extensive than the valley floor areas *below* the snow line. This course of considerations permits a realisation at this later stage of how fast and inevitable the *infilling* of the containers of all the main valleys in this area must have been at a time of ELA depression.

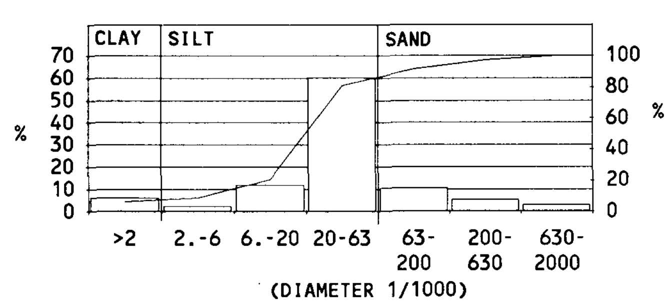
At 29°45'/94°17'–19'E on the orographic left-hand in the Nyang Qu there is a large *glaciated knob formation*, and on the slope of the glacier escarpment concave flank polishings have been preserved below, with convex ones

Fig 12 7.9.89/4, orographic left-hand lateral moraine near Bayizhen, 3280 m asl, varve clay on the inner slope of the moraine; Fig 43, No. 35; Photo 48 (■ above); sand 3.3%, silt 74.9%, clay 21.9%.



IGNITION LOSS: 2,41%
LIME CONTEND: 0,48%

Fig 13 8.9.89/2, orographic left-hand lateral moraine near Bayizhen, 3300 m asl, boulder silt; Fig 43, No. 35; Photo 48 (■ above); sand 19%, silt 74.7%, clay 6.3%.



IGNITION LOSS:1,45%
LIME CONTEND: 0,48%

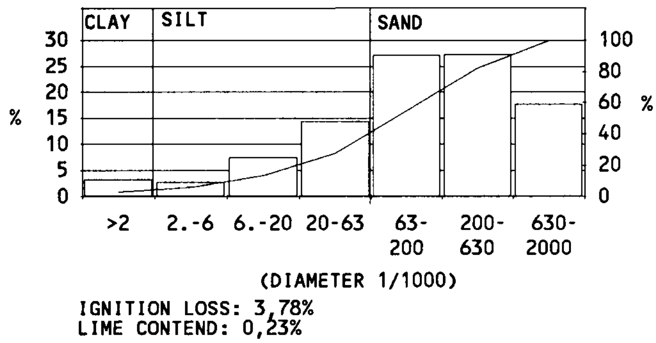


Fig 14 10.9.89/2, orographic right-hand lateral or pedestal moraine terrace in the Tsangpo (Yarlung Zangbo Jiang) valley (Stadium III), 3300 m asl; Fig 43, No. 45; Photo 71 (● below); sand 72.2%, silt 24.5%, clay 3.2%.

above, as are typical for trough slope profiles (Fig 43, No. 34). Bedrock granite has formed rough banks here. *Subsequently weathered* bank seams and clefts have *roughened up* the polishings. In part this happened syngenetically, so that *subsequent rock-falls* took place already during the time of glacial influence. These are characteristic for *glacially undercut,* ie oversteep valley slopes in massif rocks. (An Alpine example: subsequent rock-falls in the Zemgrund in the E Zillertal Alps, especially on the orogographic right-hand; in Scandinavia the flanks of the granite bell mountains of the Fjell region of Gjerdalen, 50 km N of the town of Fauske present a striking example).

The most important observation concerns the overall impression of the Nyang Qu and belongs to the term "clean landscape" introduced above. The Nyang Qu is indeed a very strikingly clean valley, ie with little drift and almost free of *talus cones and talus slopes.* Being bedrock slope, the steep valley flanks drop *abruptly* below the drift floor of the valley bottom. There is next to *no* - or only very small amounts - of detritus weathered in situ on these slopes to form a transition from the steep curve of the slope gradient and the flat valley bottom surface. It follows that this is a matter of a valley clearance area, which must have undergone a thorough *cleaning out* only a *short time* ago. Everything else would fail to explain the absence of drift because no valley, and certainly not a valley with such steep flanks and such extensive vertical slopes since Tertiary times, or the one but last or the last Inter-Glacial, could have been preserved in a *state so free of detritus.* Even the *drift floors* in the main valley and in the adjoining tributary valleys are of small thickness. All the *drift terraces* are very *fresh,* and the sharp-cornered terrace edges testify to their recent formation. Based on estimates on valley terrace bodies, drift *thicknesses* in the Nyang Qu hardly ever exceed 10-20 m. In view of the extensive catchment areas of the 270 km long main valley, with its numerous and several tens of kilometres long side valleys, and a *relief energy* of 3000 m in vertical distance, it is a *remarkably small* drift thickness. Valley bottom fillings of such *minor thickness* are to be regarded as deposits of recent millenia. Even if they were mere river deposits of the past 10,000 years, they would have to show multiples of these *drift masses.* An Inter-Glacial fluvial clearance through *tectonic uplifts* of this mountain range section must be *excluded* on the grounds that, even during the current and very intensive uplift, no incision but rather build-up is taking place.

The only viable interpretation of this "clean landscape" is the one of *total glaciation* of the Transhimalaya, which filled and cleansed the relief during the last Ice Age. In terms of typology it must have been an *ice stream network glaciation* on the S fringe of I_2 (Kuhle 1985a, p. 41, Fig 2; 1987a, p. 413, Fig 27) of the type known to have also existed in the European Alps during the Ice Age, to quote just one example (A. Penck & Brückner 1901-1909). These recent *drift fillings* took place after far-reaching deglaciation; they are the Late Glacial, Neo-Glacial and historical *sandurs,* or glacial drift floor build-up of the most recent millenia. Photo 48♦ depicts the large orographic left-hand side *lateral moraine* at the settlement of Bayizhen (Baji, Baghi) (Fig 43, No. 35). Seen from a viewpoint looking down-valley, it is the first, ie the highest-lying, large-scale accumulation of moraines in the Nyang Qu (29°40'N/ 94°22'-25'E). This *moraine terrace* is about 450 m high and is situated between 3200 and 3650 m asl. Its longitudinal extent is 8 km. It is situated in the confluence area of a 27 km long N side valley on the escarpment of a protracted S bend of the main valley. It was possible to investigate this moraine at several vertical *outcrop profiles* (Photos 49 and 50). Selected analyses of grain sizes (Fig 10-13) give a representative overview of their characteristic materials in the *fine grain spectrum.* Sample 7.9.89/1 (Fig 10), which establishes the prevalence in the *silt range* (89.6%), which is typical for *lateral and terminal moraines,* was taken at the base. It also proves the other features of *boulder clays,* like approximately *equally small* proportions of sand and clay. Interspersed nests of gravel and sand which, showing a 93.5% *sand preponderance,* confirm the contribution of meltwaters in the construction that is normal in the terminal moraine environment, occur adjacent to it at the same level (Fig 11). Sample 7.9.89/4 (Fig 12) was taken from *glacilimnic rhythmites* (varved clays) of the *inner moraine slope* 80 m above. The glacier having receded, an *impounded glacier lake* between ice margin and glacial diamictites must have bordered it; it had a maximum depth of 80-100 m. 74.9% silt and 3.3% sand characterize the *summer strata,* and 21.9% clay the *winter* or *autumn and spring strata.* Taken at 3300 m asl from 1.5 m below the surface and from beneath very *large blocks* that had been deposited there (Photo 49), sample 8.9.89/2 (Fig 13) provides evidence of *unmodified lateral to terminal moraine.* It is the *boulder clay type* one encounters in *mountain moraines,* containing 74.7% silt and 6.3% clay. *Mountain* *boulder clays* tend to be *cleaner* ie sandier (here 19%) and more lacking in clay than those from *lowland ices.* Viewed macroscopically, the exposure of *boulder clay block packings* show the *absence of alternatives in sedimentation* by glacier (Photo 49). *Isolated* from one another, the blocks lie embedded in *fine intermediate masses;* they consist of crystalline as well as metamorphic rocks, like quarzites. At the same time boulder clays are very tightly packed, which is not the case with mud-flow sediments. Some blocks are marked by striae (Photo 50↓↓).

17 km down-valley from this moraine formation - though on the orographic right-hand side of the valley (Fig 43, No. 36; 29°32'N/94°26'E, 2980 m) this time *ground moraine coverings* extending 200-300 m up the valley flanks have been preserved, including even the primary glacial exaration grooves (Photo 51▼). These are now protected from erosion by a cover of meadows and dwarf shrub. Accordingly these *boulder clay slopes* have only been transformed by small gullies. Further down valley they are immediately followed by shore formations, which assume the character of kame terraces in some parts. These surfaces are at the same level as, and thus probably as old as the ground moraine covers. On their valleyward slopes large *rounded blocks* have been preserved over a distance of 2-3 km (29°29'N/94°25'E). Due to its flow-off the *Late Glacial valley glacier,* which had been associated with these accumulations, had been pressed against the opposite valley side - the *outer slope* of the valley formation - so that an increasingly enlarged *intermediate fringing area* on the slip-off slope (orographic right-hand) between ice margin and valley slope was infilled with local deposits from the small side valleys and slope gullies, and the *kame terrace* formation developed.

The next locality to deserve attention in this context is the orographic right-hand valley exit outwash area of the Nyang Qu, ie the spur between the mouths of the Nyang Qu and the Tsangpo valley (Fig 43, No. 37; 29°25'N/94°26'E; 2950 m asl) where glacial *diamictites* lie on top of bedrock granite which has been polished in the way of glaciated knobs. Their composition is authenticated by sample 27.9.89/2, which was taken 160 m above the Tsangpo, ie from the valley floor (Fig 28). The noticeably large proportion of sand (37.2%) goes not so much back to meltwater activities linked with them, but rather to the *local addition of granitic sand.* Contained in this ground mass [the rest of which is silt (47.3%) and clay (15.4%)], but occasionally lying on top, *block masses* as well as some *block nests* were found. The large granite blocks exactly on the *flat profile line* of the *intermediate valley* are particularly noteworthy (Photo 52●). Although they are not actually *erratic blocks,* they can *only* have been deposited here *through glacier transport.* With nothing but local, downhill, fall-line parallel shifting by solifluction or autonomic mass movements from the upper slope downwards, the blocks *could not* have followed that spur profile line in *any other way,* but would have *swerved above* and, describing a curve, got into the extended areas of the slope. These findings lead to the conclusion that the Nyang Qu glacier reached the Tsangpo valley and *dammed back* the Tsangpo river at that time. Evidence of this occurs in the form of glacier-dammed sediments. These were found in an 80 m exposure 17.5 km upstream on the Tsangpo and on the orographic right-hand in the area of a side valley exit near the "Ganga Bridge" (Fig 43, No. 38; 29°18'N/94°21'E; 3000 m asl). Photo 53 shows *still-water sediments* which became finer from bottom to top. Fig 24, 25, 26 and 27 show the composition of the sediment at the base of the exposure (3060 m asl) in the middle section (3082 and 3130 m asl) and somewhat below the top (3140 m; Photo 53 ■) above the 8 m-thick varved clays (Photos 54 and 55; Fig 26). These varved clays are evidence of the *direct presence* of a glacier and its *rhythmic meltwater discharge.* Embedded in the basal sands there are coniferous tree trunks lying at the bottom of the sediments (Photo 53↑↓). It follows that at the beginning *of the damming up of the glacier lake* through the Nyang Qu glacier there was a forest vegetation in the middle Tsangpo valley, the lowest terrain in S Tibet. Coniferous forest continues to grow there even *now* (Photo 53, upper section, and 55, background); it is characteristic for the *altitudinal step of boreal coniferous forest* and, according to Köppen (1936) characterized as a "snow-forest climate". During the *period of the impounded glacier lake,* a climate consequently prevailed which encouraged the formation of this, the *highest altitudinal step of forest vegetation.* Considering the present coniferous forest, *approximately the same climate* must continue to prevail, since even now these coniferous forests are the *tree-line adjacent form of vegetation.* This proves how small the *climatic difference* between that glaciation period and *present conditions* is. In prognostic or deductive terms, it means that a *small temperature drop* is sufficient to allow the Nyang Qu glacier once again to descend into the Tsangpo valley. And again: only a small uplifting of Tibet is required to trigger *another advance of the glacier.*

The results of the C-14 analyses for the determination of the age of those tree trunks are not yet available. In the author's opinion those sediments of the impounded lake under consideration, and the lake itself are *not older than the Late Ice Age.* During the Maximum Glaciation the Tsangpo valley could consequently not only have been reached by some glacier ends, but was *completely filled with ice.* Direct evidence of this, however, still needs to be collated. According to the *sediment thickness in the impounded lake* and the *distance* to the mouth of the Nyang Qu, the thickness of the Nyang Qu glacier tongue in the Tsangpo (Yarlung-Zangbo-Jiang) valley is estimated to exceed 200 m. Above 3140 m asl varved clays and superimposed sand strata cease, and the covering river drift material indicates the *change in milieu* once again to fast-flowing water (cf. "lake breach drift", Kuhle 1982a, Vol. 1, p. 118 and 1983a p. 339 et seq.); ie when the 3140 m level had been passed, still water sedimentation stopped, and the process was *concluded.* The present Tsangpo valley floor is situated in the exit area of the Nyang Qu, which joins the Tsangpo 19 km further downstream - at about 2950 m asl, ie c. 190 m lower than these highest varve clay and sand strata where the glacier tongue was that dammed back the lake. This difference in altitudes is evidence of the *minimum* level to which the lake had been ponded, thus confirming existing full *evidence* of the deposits of the impounded lake. The actual *lake surface* had probably been dammed back several metres to tens of metres higher. The Nyang Qu glacier tongue barring the Tsangpo valley would have to have been *even thicker* in order to rise sufficiently far above this lake surface. The *minimum height* of this overhang can be calculated from the resistance of the ice – with a specific density one tenth less than that of the impounded water, which was required to achieve the damming back. These considerations put *the thickness of the Late Glacial Nyang Qu* at its entrance with the Tsangpo valley at about 300 m. This would imply that the glacier tongue had not only crossed the Tsangpo valley, but had *turned into the main valley.* In view of its still relatively great thickness at the mouth of the Nyang Qu, the glacier tongue would have *followed* the Tsangpo valley *many miles downstream* before possibly terminating.

There are geomorphological indicators in the form of orographic left-hand *bank formations* (Fig 43, No. 39; 29°27'N/94°02'E, 2950–3200 m asl) for the Nyang Qu glacier actually having turned off into the Tsangpo valley. Photo 56 provides evidence that sediments deposited in more or less direct *contact with the ice* and containing *glacilimnic parts* besides *moraine material,* are found several hundred metres up the valley flank. *Edges in the relief* show glacier levels (Photo 56▼). Further down the Tsangpo meanwhile established *slope gullies* reveal loose material even at a distance as being *glacigenic bank material* (cf. Photo 56↓ with 57↓). It is not certain over how many kilometres this tributary side valley glacier tongue has followed the Tsangpo valley downstream, nor whether *confluences* with other contemporary side glaciers occurred. The Nyang Qu glacier flowed at least 10 km further down the main valley, as 200 m high kame terraces, built up from a side valley against the valley glacier tongue, are also there on the orographic left-hand (Fig 43, No. 40; 29°30'N/94°37'E, 2950 m asl). The glacier thickness having here been confirmed once again, it must be assumed that the glacier end reached many more kilometres downstream. Further *glacier bank traces* have been formed up to an orographic left-hand side valley at 29°29'N/ 94°46'E up to a relative height of about 150 m above the present Tsangpo level (Photo 57▼▼). Showing a very well preserved orographic left-hand *lateral moraine,* which is leaving the side valley concerned and stretches out into the Tsangpo valley, as well as remnants of a right-hand moraine (■■) (Fig 43, No. 41), Photo 57 provides evidence of a *simultaneous* or *even more recent* glaciation of adjacent catchment areas. This catchment area is even comparatively *low.* Reaching an altitude of merely 4600–4900 m, it is evidence of an ELA in a S exposition at only 3850 m (mean catchment area altitude: 4750 m; lowest ice margin position, ie glacier tongue end: 2950 m asl = 900 m ELA depression). Since the main Ice Age ELA depression had been at least 1200 m, this *altitude of a snow line* constitutes evidence of *Late Glacial age,* as has been suggested above for the Nyang Qu glacier. Having resulted from a snow line depression of only 900 m, an additional *significant indication* of an Ice Age infilling of the main valley (the Tsangpo valley) with glacier ice has been established. In the *quartz sand dune* shown in Photo 57 (●) characteristic *sand drifts* from *glacilimnic* and *glacifluvial* sediments from the Tsangpo valley and its side valleys accumulate.

Further indicators of a Late Glacial and – even more certain – a main Ice Age Tsangpo valley glaciation were found on both sides of the river at 29°32'N/94°53'E at 2940–3100 m (Fig 43, No. 42). On the orographic left-hand of the bank heads of the bedrock granites have been polished by glacial *polishing.* In spite of the unfavourable rock structure the polish is well preserved. On the orographic right-hand generations of 30 m and 8 m high recent Late Glacial drift floor terraces with very fresh terrace edges have been built up in the main valley. They are situated in the exit of a north-facing larger side valley with catchment areas of more than 6000 m. This side valley of some 18 km length has glacigenic *trough profiles* and its highest origins continue to be glaciated today. Another orographic left-hand side valley with *lateral moraine terraces* at 29°34'N/94°53'E is situated at 2900 m asl (Fig 43, No. 43). It has a median catchment area altitude of 4800 m (the maximum being 5125 m asl). This tributary glacier also reached the main valley floor in more recent, Late Glacial times, a fact that confirms the *ELA depression by 900 m* previously found to apply to the adjacent W valley.

The investigation now moves 23 km down the Tsangpo valley, which is equivalent to describing a 90° turn around the W slope of the 7651m (7782 m) high Namjagbarwa Feng (Namche Bawar) – which will be gone into below. Here gneiss-like ribbons of bedrock metamorphites have been glacially polished and *rounded* from the valley bottom up to the orographic right-hand valley flank (29°40'N/94°55'E; Fig 43, No. 44). These *glaciated knobs* and *flank polishings* occur at altitudes ranging from 2850 to approximately 3250 m, and in closed, continuous formation (Photos 58, 59 and 60). Recent *fluvial erosion* by the Tsangpo *undercuts* and *destroys* the forms of glaciated knobs (Photo 58 ↓). In this valley chamber a steep hanging valley follows on the orographic right-hand by way of a *glacigenic-rounded exit level,* which has already partly cut up by *subglacial* melting waters to form a *gorge* (Photo 60▲); evidence of this can be seen in the traces of *rounding glacier ground polishings* of the side valley glacier which reach into gorge incision (Photo 60⩘). In the same main valley chamber, about 1–5 km upstream accumulations which correspond to glaciary erosion forms, ie *ground moraines* are exposed, some of which show classic compressions. Photo 61 (■■) shows the *boulder clay sheets* on the left side of the valley which, rich in fine materials, are inserted into the river and pebble bed of the present-day Tsangpo (Yarlung Zangbo Jiang). Corresponding moraines are found on the other side of the river at about 2950 m asl at 29°39'N/94°56'E (Fig 43, No. 44) (Photos 62 and 63). The fine material between the *blocks* and *nests of pebbles wedged in between* (samples 24.9.1989/2 and 4) 30 to 40 m above the river is *predominantly sandy* (64.5%, Fig 22) to *silty* (66.7%, Fig 23), and thus evidence of *subglacial meltwater influence.* The *pressure fold* (Photo 63) in the *clayey-silt* is covered by a layer of pebbles that was folded in the same process (↓).

Situated in the lower 300–400 m of the Tsangpo valley cross-section, all these preserved indicators are traces and forms which were shaped during more recent Late Glacial times. This is the conclusion which indicators of a far in excess of 1000 m-thick Main Glacial ice filling found down valley suggest. The numerous *moraine deposits* which cover the valley bottom there as well will not be gone into detail once again. At the Jiala settlement (the lowest settlement above the inaccessible Tsangpo gorge; 29°42'N/94°54'E at 2850–2950 m asl) the rock bottom of the Tsangpo valley consists of up to 100 m high forms of *glaciated knobs* (Photo 64▲). Here, too, the glaciated knobs have formed in sometimes vertically placed gneiss-like *metamorphites.* Towards the N and following the structure of their rocks or stratification, they continue to break down and develop fresher, more acute forms in such places (↓). In this valley cross-section *classic ice-scour boards* have been preserved on the valley flanks up to *extreme* heights, and can be diagnosed as such (Fig 43, No. 44, Photo 64▲). Here, at 2850 m asl, the valley bottom is deep in the forest and grain-belt. The *ice-scour board* rises 400–600 m *above* the *timber line,* which runs at 4000–4200 m asl. This implies that the Main Ice Age *glacier level* occurred between at least 4400 and 4800 m (Photo 64----) - 1550–1950 m above the ground polish-smoothed valley bottom. Here in Tibet's lowest regions, these ice thicknesses of about 1500 to approximately 2000 m reach values like these held to have been likely in the Late Ice Age ice-stream network of the Western Alps (slope of the Valais down to the Rhone valley (cf. A.Penck & Brückner 1901–1909; Furrer 1991, pp. 6–15 and, inter alia, the literature quoted there). On the orographic left-hand main valley flank (Fig 43, No. 44; 29°43'N/94°55'E at 2900–3200 m asl) glaciated knobs with outcrop strip polishings in the gneiss have been preserved (Photo 66▲). Related rock polishings continue almost up to the polishing-line 1000 m higher up (Photo 66----).

On the orographic right-hand glacifluvially marked *lateral moraine sediments* were taken from 60 m above the valley bottom (sample 23.9.89/3). They consist of 63% silt, 32.3% sand and 4.7% clay (Fig 21). The fine grain spectrum difference between them and the *river sediments* of the Tsangpo was examined with the aid of sample 22.9.89/1. It showed a 96% preponderance of sand (Fig 20).

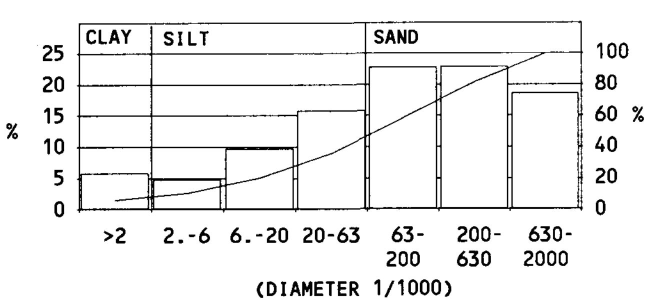
An exact analysis of the panorama Photo 64 (▼▼) shows that the bars above the upper edge of the Tsangpo gorge up to half-way up the valley flanks consist of subsequently gullied (dissection by small water runnels) ground moraines (Photo 64). Photo 65 presents a close-up of an at least 30 m high exposure of the moraine in question above the steep cliff in bedrock granite (▼, on the left) (29°44'N/95°57'E; c. 2900 m asl; Fig 43, No. 44). Another, even more detailed close-up in front of it, ie to the south of it, is to be seen in Photo 65 (▼, on the right). The *main glacial polish line* ran far above this *ground moraine* bar (Photo 64---- on the right; 65----). The appropriate *polish board* below this polish line shows comparatively *shallow Holocene breaches in the rock,* which could not have been eroded before deglaciation (Photo 64↓↓). The adjacent preserved *glaciary rock polishings* do in any case form *noticeably more continuous* rock slopes than those *above* the polish line. Above the polish line (----) there are sharp-edged ribs and ridges as well as smaller-reliefed head wall areas ((Photos 64 and 65↓↓). Also on the other side of the valley, above the almost vertical walls (55°–82°) of the Tsangpo gorge deposits of ground moraines were shown to occur (Photo 65♦).

Considering the average run-off of the *Tsangpo* (Yarlung Zangbo Jiang) *river,* which were estimated to be 500–2000 m^3/sec., the considerable *steepness* of the gorge flanks at the lower storey of the valley cross-section is *easily* explained by deep erosion (Photo 67). In spite of this their *subglacial formation* must be assumed to be due to *meltwater erosion* since stretches of the steep gorge flanks have been smoothed by *glacier polishing.* This applies, for example, to the orographic left-hand gorge wall (Photo 67▼), which starts about 300 m further up-valley than the opposite one. Another part of the gorge walls has undergone large-scale damage by *subsequent* breaks (Photos 65↓and 67↓). These rock falls are *very recent* and have in part occurred in the present age. Evidence of this is seen in the unpeneplained talus cones on the Tsangpo level notwithstanding the fluvial undercutting (Photo 67■■) as well as the freshly denuded light coloured *rock surfaces* (Photo 67▼▼). Even here in the humid Namche Bawar area (Namjagbarwa) the ELA should not have been much below 3400 m asl. This would clearly amount to an ELA depression of 1600 m compared with the current course of the snow line (present altitude of snow line at about 5000 m asl). Evidence of such a comparatively *very high* degree of depression in High Asia has hitherto only been established for the central and E Himalaya (Kuhle 1982a, p. 151; 1990a, p. 420). On the other hand, about 1200 m is normal for the last Ice Age (Schroeder-Lanz 1986, p.41, Fig. 2, p. 47, Fig. 8; v. Ficker 1925, p. 276 et seq.; v. Klebelsberg 1922, inter alia). The ELA at an altitude of 3400 m thus ran c. 600 m above the Tsangpo gorge, so that *subglacial meltwaters,* must necessarily have occurred here. The most important condition for *subglacial gorge erosion through meltwater action* had thus been fulfilled for the main Ice Age as well. During the *Late Ice Age* when the ELA had risen, *subglacially melting waters occurred* in any case, of course, and in increased quantity.

Photo 67 (●) shows the lowest *present-day glacier ends* of the 7151m (or 7284 m) high Jialabaili Feng (or peak) south flank in the background of the Tsangpo gorge (Photo 64, No. 1). They are 8 km away. Their maximal catchment area corresponds with the highest peak, and the glacier tongues (including the ones not visible in the picture) end between 3200 and 3500 m asl. The glaciers of this slope are mainly fed by avalanches (snow and, increasingly, ice avalanches). This is the reason for their tongue ends not *reaching down so far* as the humid climate would permit in cases or less steeply inclined valley glaciers, – which have proportionally much larger catchment areas (Kuhle 1988e, p. 566, Fig. 9 cf. I b and II b with I a and II a). The very *small scale of these glacier feeding areas* is to be attributed to the extreme relief energy, ie *steepness* in conjunction with *maximal vertical distance. The most extreme vertical distance* in the S flank of the Jialabaili Feng (Photo 64, from No. 1 towards the bottom right-hand corner) reaches 4450 m (between 7151m and c. 2700 m asl) over a *horizontal distance* of only about 6 km. Similar vertical distances are not reached anywhere else but in the Dhaulagiri W flank and the Nanga Parbat S flank (both in the Himalayas) (cf. Kuhle 1982a, p. 9).

The 1989 expedition did not get further down the Tsangpo valley; attention is therefore now directed both up-valley into the W slope of the Namjagbarwa Feng (Namche Bawar, 7651 or 7782 m), which will serve to present the geomorphological relationship from *todays glacier end* (Photo 68♦) down to the prehistoric and probably *Late Glacial Tsangpo ice-stream.* The recent Namjagbarwa W glacier consists of numerous components (tributary glacier streams) each of which emerges from one of the big *ice avalanche cones* which are lined up along the foot of the steep walls. The immediate Namjagbarwa W wall is itself just on 3000 m high and builds up avalanches at its foot at 4800 m – clearly *below the snow line.* It is only here that the actual glacier stream, already completely covered by *surface moraine,* starts. The glacier tongue which reach down the furthest, however, does not emerge from the W wall in the fall-line of the highest Namjagbarwa peak now, but from the adjacent *south wall* of the *satellite peak* further west which towers above the 7000 m, too. The *glacier tongue end* is now at 3900 m (aneroid measurement) (Photo 68♦); 29°36'40"N/95°01'30"E, Fig 43, No. 45). A few years ago this glacier tongue still met up with the one from the immediate west wall of the Namjagbarwa, but the latter now ends about 500 m up-valley from their confluence at 4200 m asl. The *third glacier* from this valley head is also composed of *tributary streams fed by avalanche cones.* It runs on the S side approximately parallel to the direct W

Fig 15 13.9.89/1, surface moraine material of the present Namjagbarwa W glacier, 4550 m asl, Fig 43, No. 45; Photo 69 (●○); sand 64.1%, silt 30,2%, clay 5.7%.



IGNITION LOSS: 0,53%
LIME CONTEND: 2,61%

wall glacier. (The author visited this glacier up to 4800 m under misty and rainy conditions from Sept. 11th to 16th, 1989; there is no map of this area. Topographical views hitherto given are approximations only). The glacier no longer achieves a confluence with these others either. However, there is evidence that all three of them came together forty years ago and formed a *common glacier tongue* in 1950. At that time the glacier tongue end *reached down almost exactly 1000 m further* than the presently lowest glacier, ie to 2900 m, the bottom of the Tsangpo valley!

Before going into this *astonishing finding,* the orographic right-hand side valley flank above the present Namjagbarwa W glacier must be introduced with the help of Photo 69. Its well preserved *flank polishings* and *smoothings* are evidence of a Neo-Glacial or possibly Late Ice Age *ice level* between 5000 m (- - - - far right) and 4500 m (- - - - far left). Above the polishings the metamorphic sedimentary rock is dissected by acute *wall gorges.*

Sample 13.9.1989/1 (Fig 15) from the *upper moraine of the recent Namjagbarwa W glacier* was taken at 4550 m asl for the *purpose* of local comparisons. This permitted *identification, ie calibration* of the approximately identical grain size histograms of prehistoric moraine deposits of adjacent catchment areas down in the Tsangpo valley (Fig 16, 17 and 19) as being *typically glacial.*

To return now to the enormous glacier advance in 1950. It must have taken place at around this time according to reports by the people living in the valley. Following up rumours, pointed oral questioning carried out by the mayor, or the highest administrative officer of this valley chamber of the Tsangpo valley resulted in the following report: 39 years ago in 1950, the Namjagbarwa W glacier *advanced substantially* and, reaching the valley bottom of the Tsangpo valley within a short time, it even crossed it and completely *blocked* the river, which had abundant water connected with this event. The *destruction* of the village settlement next to this side valley exit – so the story goes – occurred within a single night. About 100 persons are said to have lost their lives on this occasion. All the inhabitants of the settlement were killed save one elderly woman who had been in an elevated location at the time. So far the presentation, on which there was general agreement, was clear and *unequivocal.* But the additional statement that "the *glacier* had destroyed the settlement" is bound to cause confusion since the constructed settlement opposite the immediate mouth of the glacier valley is situated 3 km further down the main valley (Photos 70↓ and 71↓). The settlement has been rebuilt in the same main valley cross- section, though now in a safer, higher terrace location on the orographic right-hand main valley slope (Photo 70↓). But the demolished settlement had been situated far inside the *dead angle* of the side valley exit, and had been *isolated* from the side valley exit by *lateral moraines* of 150 m in height and more than 500 m in width. In addition there is a shallow contour line emerging from a smaller parallel side valley exit to the north, which again

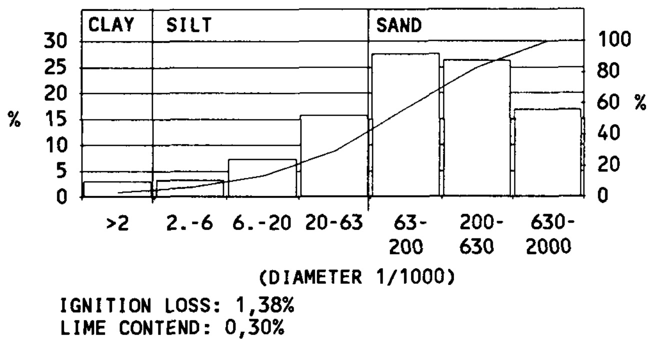


Fig 16 15.9.89/3, orographic left-hand lateral moraine of the Namjagbarwa W glacier (pedestal moraine), 3450 m (Stadium III); Fig 43, No. 45; Photo 71 (● above); sand 70.7%, silt 26.3%, clay 3%.

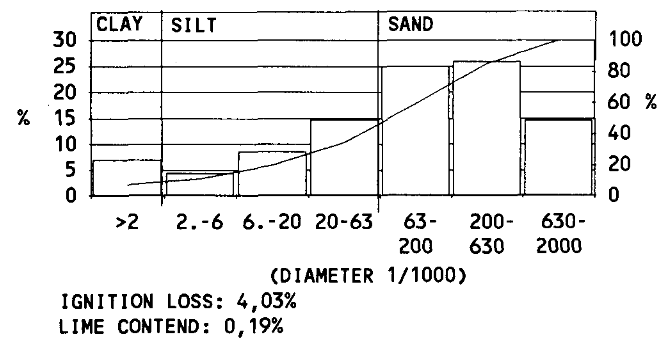


Fig 17 15.9.89/5, 3150 m asl, orographic right-hand lateral moraine terrace of the Tsangpo (Yarlung Zangbo Jiang), (Stadium IV); Fig 43, No. 45; Photo 70 (●); sand 65.4%, 27.6%, clay 7%.

excludes *immediate contact with the glacier.* Moreover, there is no known glacier which could have proceed so fast that people would not have been able to save their own skin from the advancing front of the glacier tongue. For the *climato- geomorphological landscape analysis,* however, the evidently authentic information that the glacier tongue blocked the Tsangpo (Yarlung Zangbo Jiang) at 2900 m asl, is sufficient. (Although further probing questions are always bound to be also a *control* concerning the *credibility* of the whole event). The *most convincing* variant is that of a *very fast bursting of the banks of a glacier-impounded lake* during the night, which washed away the settlement which lay just a few tens of metres above the Tsangpo. This is particularly acceptable in so far as the *unpredictability* of the bursting of the banks of an impounded glacier lake increases with the *size of the impounded river.* Such an impounded lake fills up very fast, and might well have reached the necessary *pressure to burst* after a few weeks, if not days. This is the more relevant as it could well have been a *relatively small* glacier tongue only some 300 m wide, thanks to the shape of the side valley containing it.

Apart from the completely new construction, the report of the indigenous and in part directly affected population is confirmed by the following findings in the field: on the orographic left-hand side of the Tsangpo, opposite the exit of the side valley, there is only *recently compacted moraine* (Photos 70■, 71■, and 68■; 29°37'N/94°57'E; Fig 43, No. 45). It has been pushed out of this valley and is c. 120 m high. This moraine marks the *maximal level* to which the waters of the impounded glacier lake had built up. The *ice-barrier* itself, ie the glacier body, must spread out in the shape of a hammer head, its main valley section could have a maximum of 150–180 m thick. Similar conditions have been observed this century to obtain on the Chong Kumdan glacier in the Shyok Valley (Karakoram) as well (Gunn et al. 1930, pp. 35–47; Gregory 1932, pp. 67–74). Forest, primarily of birch and larch, but also of other coniferous trees grow on this *frontal moraine;* they are only a few years old, *at the most* 20 years old. These timbers are *pioneers* on *skeletal* soils of the sort fresh moraine surfaces form under the local *humid forest climatic conditions* (Photo 70 above ■). The frontal moraine has been *built up*

Fig 18 18.9.89/2, glacilimnic cover sands on the orographic right-hand lateral moraine terrace or pedestal moraine (Stadium III), 3320 m, Fig 43, No. 45; Photo 71 (● below); sand 30.4%, silt 66%, clay 3.6%.

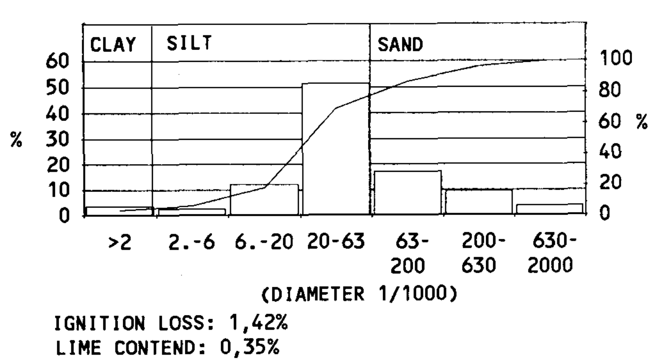
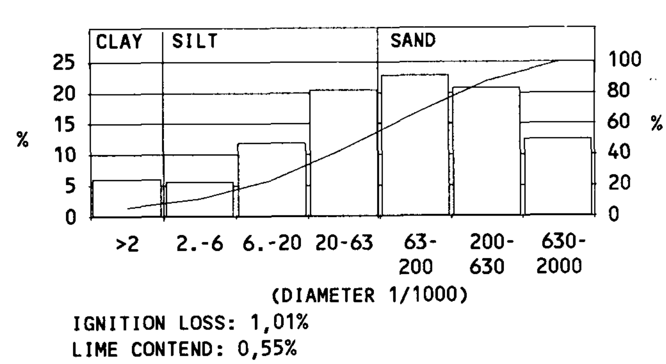


Fig 19 18.9.89/5, the same locality as Fig 18, though 30 m to the side in pure, glacio-fluvially untouched moraine material; Fig 43, No 45; Photo 71 (● below); sand 56.1%, silt 37.9%, clay 6%.



against the inner slope of a 70 m higher lateral moraine terrace of a former stage of a main valley glacier. On the higher lateral moraine the forest has long reached its *climax* stage, and by virtue of the contrast to the earlier and *far from mature* state of the forest on the frontal moraine (Photo 70 above ■) it also emphasises the latter. – Photo 68 shows the side valley under consideration, photographed from the *present-day* glacier tongue at 3900 m, looking downwards. In the background, and 1000 m below, the corresponding frontal moraine is visible (Photo 68■). In the foreground the *intricately interwoven lateral moraine covering* of the valley can be discerned (Photo 68●●). The inner slope of the most recent lateral moraines is largely *without vegetation,* apart from some isolated patches of grass, dwarf shrubs and sporadic bushes (Photo 68▼▼). Definitely still *covered and formed by glaciers* as late in 1950, these slopes are still *too steep* and thus too exposed to *erosion* to be covered by green plants within a few decades. The most important finding in this context, however, is a still more than 10 m thick remnant of dead ice below the pioneer forest on the valley bottom in the nearer background. It lies in the place where the glacier stream dips below the small hillock concerned. The *dead* ice has here been *undertunnelled* (Photo 68↓). Up-valley and down-valley this *bridge of dead ice* terminates with the characteristic, drift-impregnated *ice bars.* Though normally covering the near-flat dead ice with a *thickness* of several metres, thus *protecting it in large part* from rapid *melting,* the *surface moraine* has already *slipped* off here. In the meantime forest has grown up on this surface moraine. The *earliest* this could have begun was the time of the *melting-down* of the glacier tongue and its turning into *dead ice.* The forest now contains the same tree species as the one on the frontal moraine on the left bank of the Tsangpo (Yarlung Zangpo Jiang) (Photo 70■). Even the *height* and *trunk diameters* of the trees are similar, and the trees are therefore regarded as being approximately *of the same age.* The *remnant of dead ice* lies at about 3200 m. All these data *confirm the correctness* of the report of the indigenous population on the recent advance of the glacier down to the Tsangpo, and its blocking to create an impounded *glacier lake.*

What is the significance of this advance of a glacier in recent history for the Main to Late Glacial history of the glaciation of the Tsangpo valley? The advance shows how even today, ie under conditions of a warm period, the *lowest* valley bottom of S Tibet can indeed be reached by glacier ice. This is an indication of the continuing *climatic proximity* of even the lowest and thus warmest areas of S Tibet to glacial covering. This glacier-climatological point goes one step further than the one made above when describing the *Late Glacial varve clays* in the area of the mouth of the Nyang Qu (Fig 43, No. 38). Evidence has been given that the prehistoric Nyang Qu glacier had reached the Tsangpo (Yarlung Zangbo Jiang) valley and created an impounded glacier lake under forest climatic conditions (cf. Photos 53–55). This implies that the *Late Glacial glacier ends* entered this valley bottom under rather similar *climatic conditions* to those now prevailing. In this case it is not a Late Glacial but even a *Recent glacier* which has flowed down even *further* ie almost 1500 altitudinal metres below the forest line. Even now, ie in 1989, numerous ice streams of the Namjagbarwa and Jialabaili Feng group (cf. above) reach 500–1000 m below the *forest line.* This way of drawing analogies and conclusions shows once again how *close* to glaciation even this lowest and warmest section of Tibet continues to be. This in turn reveals how small the present, largely glacio-isostatic (Kuhle 1988a, pp. 483–485; 1989a, pp. 282/283) uplift (cf. Chen 1988) of these sections of High Asia needs to be to end up in a large-scale rise *above the snow-line.* This applies even when there is no additional cooling down by *several degrees celsius.*

So much on function and indication of this excursion into current glaciation with reference to the Main Ice Age glacial filling of the South Tibetan relief. For the sake of accuracy, however, some aspects require completing. They concern the *favourable topographical conditions* for a *sudden low-altitude glacier advance.* The fact that it was only a *very brief advance,* a surge, and not a lasting stable ice marginal situation somewhat relativizes the climatic proximity to a prehistoric, relief-filling glaciation.

Jointly forming a large ice avalanche catchment area with a wall length of 15–17km, which towers above the ELA, three glaciers of the Namjagbarwa W flank had one *common glacier* tongue. The integration took place around 1945–1947, when the two S glaciers advanced only by a few hundred metres. When they had jointly made the connection with the glacier at the foot of the N wall, a kind of "bottleneck effect" came into being, ie the smallest farther ELA depression in the large feeding area common to all three of them was translated into a relatively very important advance of the small and narrowly *pointed glacier tongue.* This meant that the *kilometre-wide glacier cross-sections* were combined in a barely more than 300 m wide glacier tongue. That glacier end would accordingly have been little larger than the recent glacier tongue (cf. Photo 68♦). Concentrated within the narrow valley it had to *advance very rapidly* therefore in order to create sufficient space for the ice pushing up behind. Prepared already during the Late Ice Age, and time and time again swept through by glaciers in Neo-Glacial times, the moraine valley (Photos 71▼; 68↓) possessed a *steepness* which became the reason for the fact that the glacier tongue can scarcely anywhere have been more than 150 m thick. Its thickness probably reached about 100 m and increased to the 150–180 m mentioned above only during the last 1.5 km of its course in the *bend of its long profile* towards the Tsangpo (Yarlung Zangbo Jiang) valley bottom thanks to the *ponding back of the ice* in the course of its *discharge* against the opposite valley wall (Photo 70■). Taken together, all these factors had the effect that a *cinematic mountain,* prepared by a *temperature drop or increase in precipitation,* ie a depression of the ELA or a positive mass balance in the catchment area and subsequent movement down the different tributary glacier streams, *swelled up considerably* in the area of their confluences and transformed the energy of this mass into a very considerable advance, a surge, with the help of a narrow glacier tongue of minor thickness. Accompanied by a slight *ponding back of the ice* and a *rise in the level of the glacier* in the area of the foot of the wall by about 100 m to a *glacier surface* level between 4800 and 5000 m asl, the relationship between the *feeding area and the depletion area* shifted considerably in favour of a still *more positive mass balance.* This applied especially to the glaciers like the ones under investigation, the *knick point of the steep wall-foot* of which was not far from the snow line. The present snow line runs at about 5000 m here. The fact that the large, flat glacier surface had fallen short of the snow line level during that de facto minor *depression of the snow line,* and had no longer run in the *scarcely areally- effective steep wall* above the glacier surface, had to result in a *repeated favouring* of the balance of masses (cf. Kuhle 1988e, p. 566 Fig 9 IIb). It is a matter of the *relief-specific qualitative leap* in glacier formation which occurs whenever the snow line, in the *process of depression within the relief,* suddenly *drops below larger horizontal areas,* thus opening them up to *glacier feeding.*

Photo 71 gives a panoramic view of the moraine valley under investigation from present end of the Namjagbarwa W glacier (▽) down to the Tsangpo (Yarlung Zangbo Jiang) main valley with its older *glacial accumulation terraces* (II–V). Even the profile of the 1950 *frontal moraine* on the other side of the river is visible (Photo 71■). The side valley, into which the Namjagbarwa W glacier has discharged, is not a primary valley cut out from the bedrock, but one let into moraine material. It is consequently a case of rule book-like interwedging of Late Glacial *main valley moraine terraces* with recent moraine material from the side valleys with the highest catchment areas. The *largest preserved moraine level* in this valley chamber, and also in the adjacent valley chambers, is situated c. 400 m above the Tsangpo level (Photo 71, III). On the basis of several C14 analyses which were carried out in the People's Democratic Republic of China, Dr. Zhang Wenjing of the Lanzhou Institute for Glaciology (verbal communication, September 1989) dated them as being older than 7000 years BP. Thus they are to be classified as belonging to the *Late Glacial period,* the last glacier advances of which would have occurred at about 11,000–9000 years BP, judging by comparisons with other mountain systems in, for instance, N Tibet (Kakitu massif and Animachin, cf. Kuhle 1987c, p. 311, XXXVII and XLIII).

Four moraine terraces are to be differentiated in the Tsangpo (Yarlung Zangbo Jiang) valley (Fig 43, No. 45). Now utilized by settlements, the lowest of them is the only one to have undergone *glaciofluvial* transformation and to be covered with glaciofluvial pebbles. A fifth terrace is a purely *fluvial pebble terrace.* It is only 5 m high (Photos 70, 71, No. 5). The *lowest* moraine terrace level is c. 80 m above the Tsangpo (Photos 70, 71, V). The few remnants preserved of the *next* moraine level reveal a relative height of about 180–200 m (Photo 71, IV). On the slip-off slope of the next down-valley loop of the Tsangpo this level forms a terrace triangle that juts out 2–3 km in continuation of a mountain spur, which is also made use of for agriculture (Fig 43, No. 44; 29°39'N/94°54'E, 3100 m asl). The most striking terrace level in this valley chamber mentioned above (Photo 71, III) is situated about 400 m above the Tsangpo (Yarlung Zangbo Jiang). It has been built up as a *pedestal moraine ramp* from the tributary glaciers of the Namjagbarwa W flank against the Tsangpo glacier. The fourth and *highest moraine level* has been most clearly preserved on the orographic left-hand as a spur on the slip- off slope at about 550 m of relative altitude above the Tsangpo (Photo 70, II). From the samples taken for *sedimentological analysis,* those dated 15.9.1989/3 and /5 (Fig 16–19) were selected as being representative. They originate in the moraine terrace bodies of levels 400 m (III) relative height (Fig 16, 18 and 19) and 180–200 m (IV) relative height (Fig 17). The selection is evidence of the *characteristic spectrum of grain sizes* of contributing glacial and interspersed glaci-limnic deposits showing that they have *primarily been below the then ELA.* The proportions of clay are consistently small (not more than 7%). Predominance between sands and silts varies. It does, however, show that the outwashed *glaci-limnic material* tends to be dominated by silt (66% Fig 18). Among the non-outwashed *morainic diamictites sands* dominate (65.4%; Fig 17; 56.1%, Fig 19). The *"lean" sandy ground mass* is typical of all kinds of mountain moraine deposits. This is a consequence of considerable relief energy and vertical distances. Even in cases of large-scale ice-stream networks of the kind that existed here, the resulting continuous addition of detritus which incorporates material into the body or the ice *throughout the mountains,* has the effect of creating this *decisive difference in the fine grain spectrum* in contrast to comparable lowland ice moraines. Not unlike the *chalk content which varies over small areas,* the formation of local bedrock influences the composition of the fine grains. It shifts the detail of proportions.

In the main valley chamber W of the Namjagbarwa a *glacierflank polish* sets in in continuation of the 180–200 m moraine terrace (IV) (Photo 70 IV ▼▼). It occurs on the *valley escarpment,* an indication of an extreme obtuse-angled re-direction of the valley glacier ice in this place, with subsequent *change* from a *form of accumulation* to one of *glacial erosion.* The *strikingly fresh state of preservation* of these traces of glacier polishing like the dating of the next older 400 m moraine terrace (III) to more than 7000 C-14 years both speak for an at most late *Late Glacial,* possibly even *Neo-Glacial* age of a few thousend years (ie older than 4165 years BP; cf. Kuhle 1986b, p. 454 Tab. 4: Sirkung stadium IV). Summarizing, it can be said that all the *moraine terraces* in the region of the Tsangpo (Yarlung Zangbo Jiang) bend around the Namjagbarwa massif supply evidence solely for the Late Glacial and more recent *glaciation picture.* Approximately 15,000–9000 years ago there was an *ice-stream-like valley glacier system* here filling even the lowest main valley with more than 550 m thick glacier ice. This leads to the conclusion that this mountain relief must have been much more heavily glaciated during the *Main Ice Age*. The *ice surfaces* were very high above the snow line at this time (Main Ice Age ELA ~ 3500 m asl, with Main Ice Age level of 4100–4900 m asl). This is the reason for the total *absence of lateral moraine terraces* at these Main Ice Age glacier surface levels. As mentioned above, there is evidence of main valley ice thicknesses of 1500–2000 m thanks to bands of polishings and very high polish lines in the valley chamber at the Jiala settlement (Fig 43, No. 44; Photo 64 - - - -). The thickness of the ice in this area was still so great that the *glacier surfaces were above the ELA*. This is the reason for the *absence* of lateral moraine deposits to represent this stage, the *Ghasa stadium (I)* (cf. Kuhle 1982a, p. 154 et seq.; 1986b p. 453 Fig 3 and 456/57 Fig 4).

Built up by tributary glaciers from the Namjagbarwa W flank, *pedestal moraine ramps* (Photos 71, III and IV; 68, IV) have developed from *ground moraine ramps* which grew up when the tributary glaciers came to overlay the *main valley ice stream*. Corresponding stratifications of tributary glaciers were first described by Visser (1938, Vol. 2, pp. 88–90, Figs 51 and 52) for recent Karakoram glaciers. The corresponding "stratification ground moraine ramps" on which the lesser tributary glacier flows off, thus *reaching the surface level of the main glacier* required for *ascent and overlay*, have been observed by the author on the Dhaulagiri and the North side of Mt. Everest (Kuhle 1982a, Vol. 2, Fig. 82, and 1983a, p. 238; 1988a, pp. 496/497, Fig. 58–60 and p. 498; 1991, p. 104 et seq.).

7. Additional Notes on the Traces of a maximal (Main Ice Age?) Glaciation in the Transhimalaya (Nyainqentanglha) in the Massifs around Lhasa (Maximal Altitude 5662 m) (29°30'–48'N/90°55'–91°38'N)

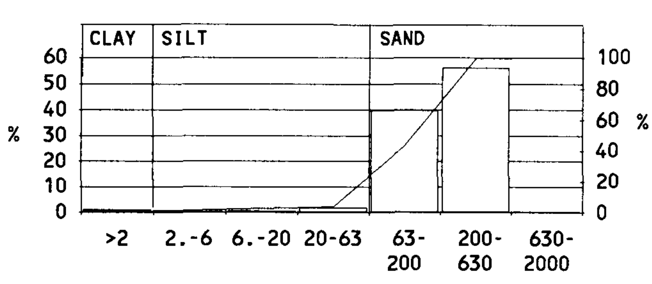
In addition to considerations previously limited to the main valley of Lhasa and to *findings made in 1984* (Kuhle 1988a, p. 459 and Fig 3), the author has carried out investigations in four side valleys in 1989. The results are as follows: well preserved *flank polishing* (Photo 72▲) were found in the 17 km long side valley of the Lhasa valley, which lies SE of the Tibetan metropolis (29°32'–38'N/91°15'E, Fig 43, No. 46) and has a mean catchment area altitude of about 5400 m, (the maximum altitude of the catchment area being 5662 m). The perspective of the photograph, which was taken at 5030 m, is evidence of *flank polishings* extending upwards to 5000 m and over, and thus of an almost *total glaciation* and filling of the valley cavity with ice (Photo 72 - - - -). In this, polishings preserved *on both sides* reach heights of more than 1000 m above the valley bottom, at the upper starting-point of the valley floor deposits at 3932 m asl. In places where the surrounding mountain ridges tower up to more than 5200 m, short troughs and corries have been inserted (Photo 72●). They show *fresher, Late Glacial* glacial forming. At this altitudinal level (Photo 72, foreground, on the right) solifluxion activity and the workings of periglacial drift sheet movements are intensive. *Late late-Glacial minor glacier insertions* and firn shields at greater altitudes provided the permanent meltwater run-off which *caused erosion*, in turn dissecting the valley slopes *vertically* to the flank polishings (Photo 72▼▼). The acuteness of the edges of the triangular areas (↓) brought about by this process demonstrates the lesser age of these cuts through their *one-sided formation* from the fluvial incisions. This is evidence that the flank polishings *cannot* be *currently converging processes*, since these polishings are now being *destroyed* by fluvial erosion.

The great thickness of ice in this side valley of the Lhasa valley, and the *upper polish line (which scarcely slopes, if at all)* towards the junction with the main valley point to a *correspondingly thick glacier* filling of the Lhasa valley. This would imply a Lhasa valley ice stream, which would have been *at least 1200 m thick* in the adjoining main valley cross-section (altitude of the valley bottom in the confluence area of the Lhasa valley: 3664 m). It should, moreover, be remembered that preserved *polish lines* can never provide more than mere *minimum values* for prehistoric ice level heights. A long lasting polishing process on the black/white boundary near the glacier surface, strong enough to *outlast the rapid frost weathering* which set in with deglaciation, was favourable to its preservation, though it did not always materialize.

Consequently it is likely that the main valley ice was even thicker during the Main Ice Age. According to the points made above, evidence of the main valley glaciation has hitherto only been indirectly inferred, but not directly established (cf. below). On the other hand, there is no other possibility for explaining the great prehistoric ice thickness in the exit of the side valley. A side valley glacier joining an *ice-free main valley* will *spread out* on the floor of the main valley in the *shape of a hammer-head*, and must therefore invariably have had a *lesser thickness at its mouth*.

30 km further W of the town, in a side valley joining the Lhasa valley from the north (Fig 43, No. 47; at 29°43'N/90°57'E) conditions are very similar. This valley, too, is 17 km long, and has *catchment areas at average altitudes* of

Fig 20 22.9.89/1, sand bank on the right bank of the Tsangpo (Yarlung Zangbo Jiang) river, c. 2820 m asl, the fluvial sand is patterned with aeolian ripple marks; Fig 43, No. 44; Photo 65 (●O); sand 96%, silt 2.9%, clay 1.1%.



IGNITION LOSS: 0,96%
LIME CONTEND: 0,36%

Photo 41
Very well preserved glacigenic flank polishings (▲) taken at 4300 m asl in a SW direction, facing the orographic right-hand flank of the large valley SE
These polishing extend up to 5900 m, though at the highest levels, where they have been free from ice for the longest time, they are already overlain i
glacier level can here be reconstructed around 5900-6000 m asl (- - - -; cf. Photo 40). Photo: M. Kuhle, 3.10.89.

Photo 43
View from the 5300 m high Tschü Tschü La from the north to the 7048 m high Qungmogangze peak (Fig 43, No. 27) across a glacial landscape of glaciated knobs (▲) with erratica and ground moraine deposits (♦). The erratic and in part very large biotite granite blocks (↓↓) are superimposed upon bedrock rhyolite rocks. The Maximum Glaciation level of inland ice ran at about 6000-6200 m asl between glaciated knobs, arêtes and peaks (- - - -). Photo: M. Kuhle, 3.10.89.

arge valley SE of the Nyainqentanglha massif (Fig 43, No. 26).
eady overlain by their sub-recent mantls rock. A main Ice Age

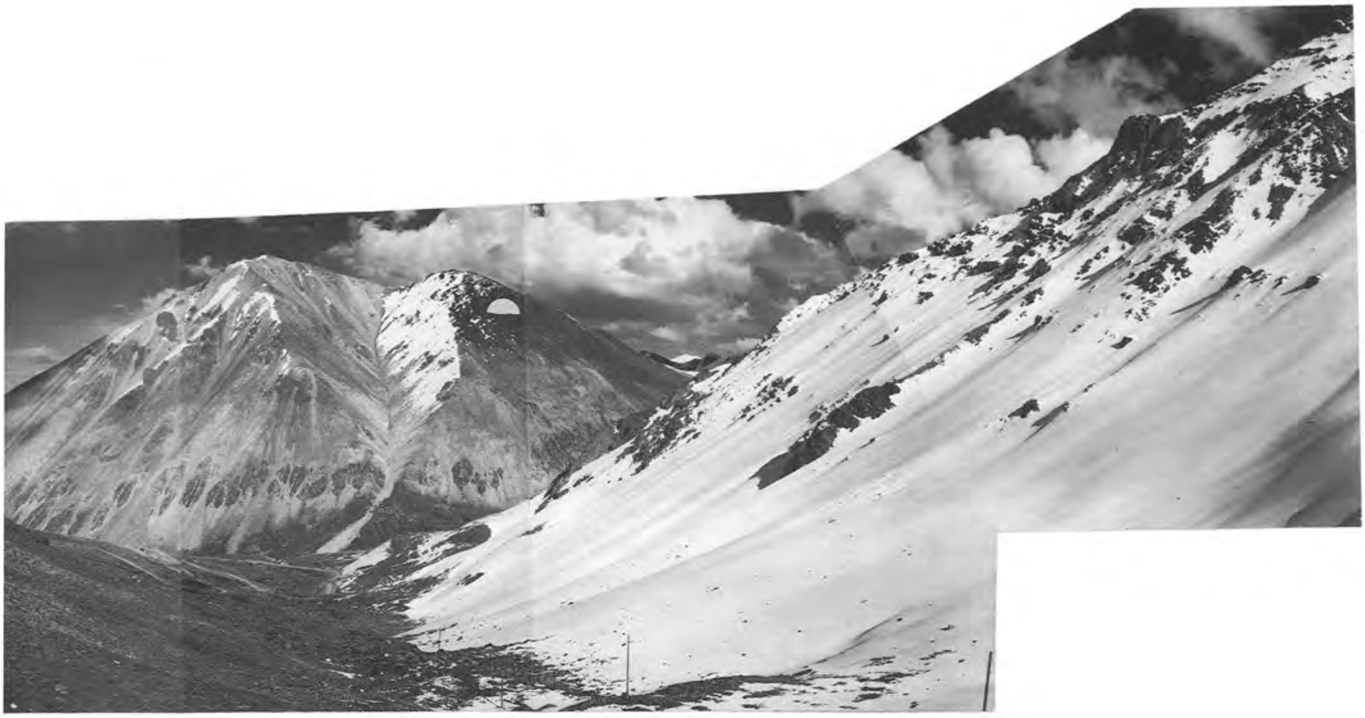


Photo 42
View taken from the 5300 m high Tschü Tschü La transfluence pass (Fig 43, No. 27), facing E in the direction of the main valley SE of the Nyainqentanglha (area shown in Photos 40 and 41). Here, on the 7048 m high Qungmogangze the relief had completely submerged below ice (- - - -). Erratic biotite blocks (↓↓) occurring up to the mountain ridges are evidence of this. They are superimposed upon bedrock rhyolite rock here. Photo: M. Kuhle, 3.10.89

Photo 44
These flank polishings (⏶) are particularly well formed and preserved between 4400 m and 4800 m asl (main valley W of the Qungmogangze peak (Fig 43, No. 28). The corresponding minimum Ice Age surface of inland ice or an ice stream network is marked ----. The acute peaks (▲) have probably pierced the ice surface only in the Late Glacial, and were only then sharpened by undercutting, whereas the Maximum Glaciation levels had towered above them. The small linear rills and incisions (↓) only formed in post-Glacial times, and are typical of present inter-glacial morphodynamics. Photo: M. Kuhle, 3.10.89.

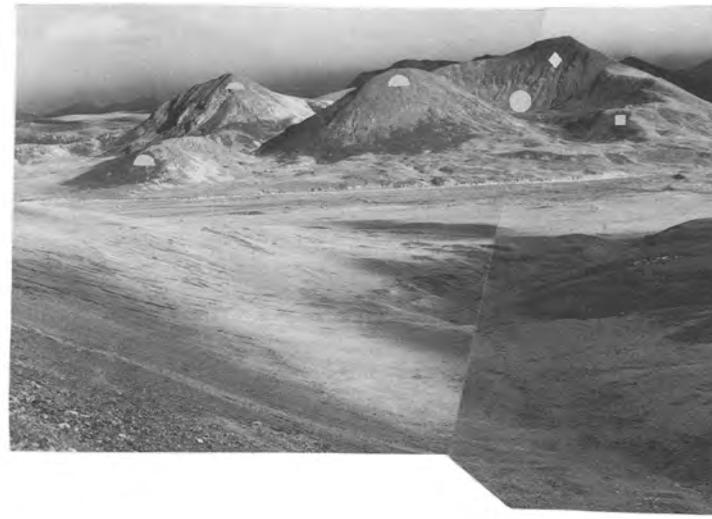
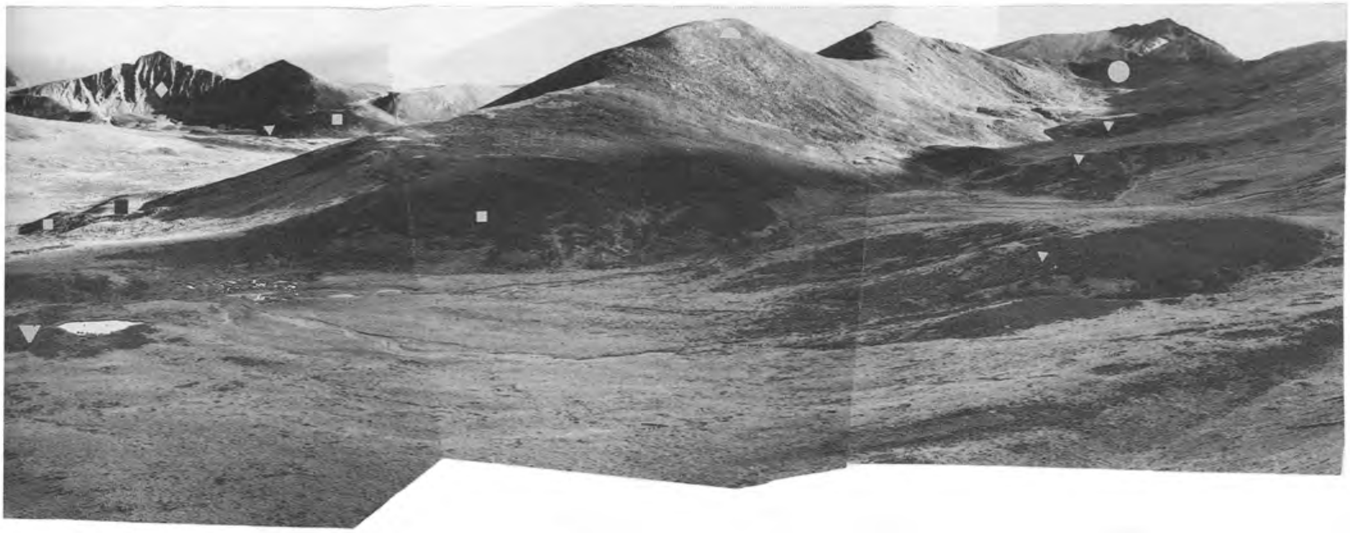


Photo 47
Alpine glacial landscape rising here to just below 5900 m asl and connected with the main valley of the Nyang Qu (Fig 43, No. 33). Below the recent glaciers (●) the view facing S into the side valley-head shows sub-recent to late Late Glacial tongue basins of hanging valleys (◆), which are framed by terminal moraines (■). The adjacent U-shaped valleys (↓) show late Late Glacial polished transfluence ridges (◓). The late Late Glacial undercutting of the flanks in turn sharpened the Maximum Glacial relief again (▲). Photo: M. Kuhle, 29.9.89.

Photo 49
Exposure of the Bayizhen moraine (Fig 43, No 35; Photo 48) at 3300 m asl, c. 100 m above the moraine base (Fig 10–13). Polymict blocks (●) "swim" in a silty ground mass. Photo: M. Kuhle, 8.9.89.

Photo 50
Glacially scratched quartzite block in the Bayi:
upper; Fig 43, No. 35) at about 3400 m asl. The str
and narrow, but some decimetres in length (↓↓



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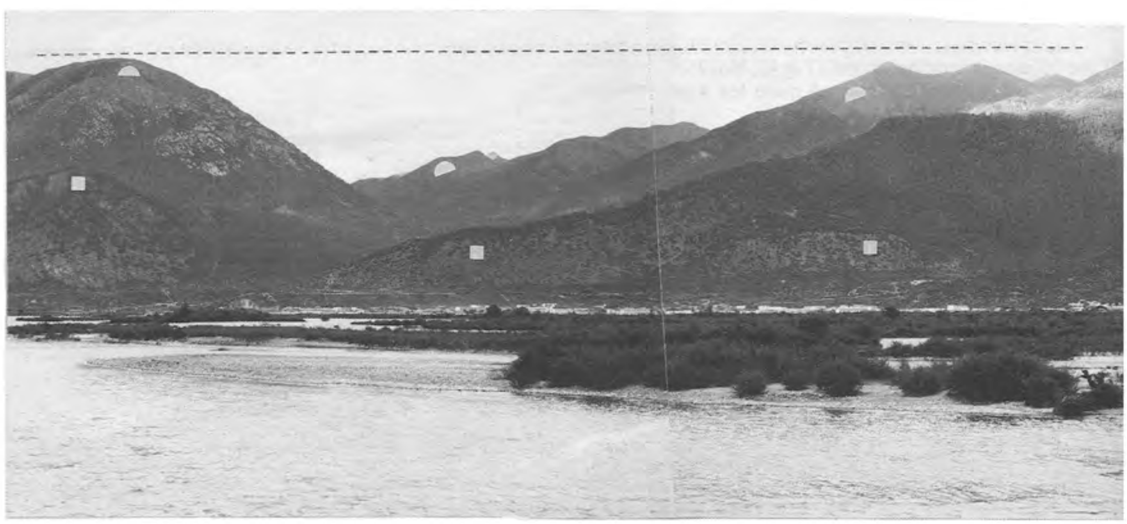


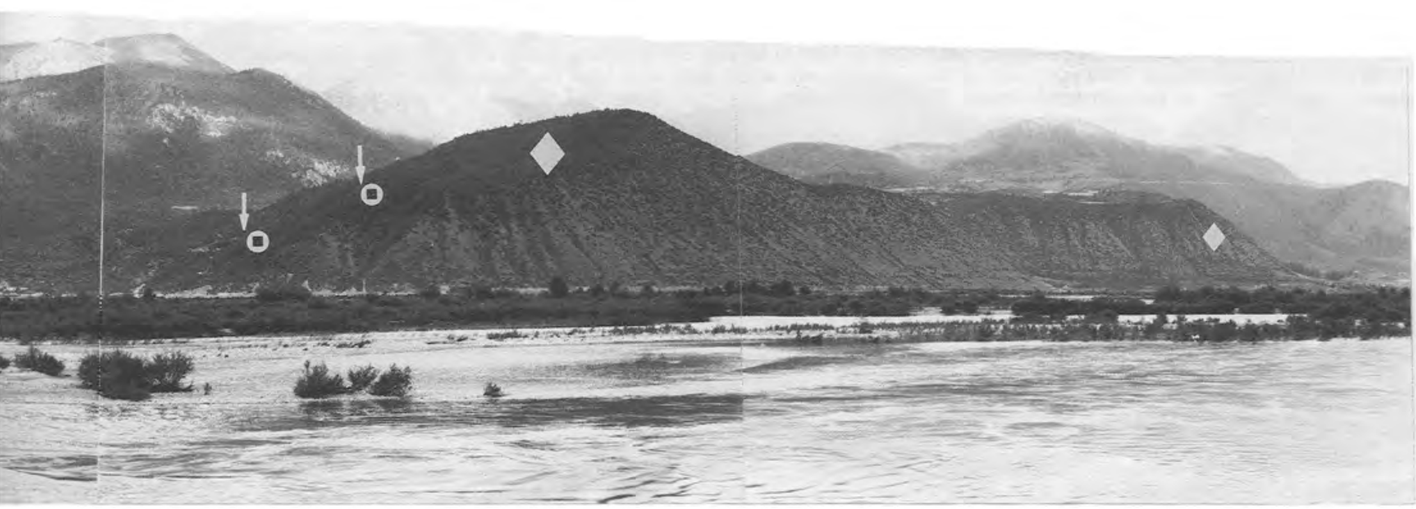
Photo 48
The large, orographic right-hand, 8 km long moraine terrace (♦) near the Bayizhen settlement (Baji; Fig 43, No. 35) in
marks further moraine remnants which are also likely to belong to the Late Glacial. Evidence of the Maximum

zhen moraine (cf. Photo 48, ↓
iae are broad and short or sharp
). Photo: M. Kuhle, 8.9.89.

Photo 51
Ground moraines lieing on the orographic right-hand flank of the lower Nyang Qu (Fig 43, No. 36; 2980 m asl). Glacigenic exaration grooves and furrows of prehistoric glacier polishing are visible in the block-saturated boulder clay, even under its vegetation cover (▼▼). Photo: M. Kuhle, 27.9.89.

45
l landscape W of the a (5300 m asl; Fig 43, 9, with Late Glacial :nic shaping by : (●), lateral moraine ■), end moraines and :d end moraines (▼) moraine lake (lake iand of ▼), seen from 1, facing W. Mountain and peaks are :nicly rounded, ie :d-over up to their ons (▲).Some of were subsequently y sharpened during te Glacial (♦). Photo: hle, 7.9.89.

Photo 46
Orographic left-hand glacial flank polish, with formation of polished trough edges (▲) in the middle Nyang Qu (-valley; Fig 43, No. 32). Polishing occurs at about 4600 m asl, and the valley bottom is at 3350 m, so that a minimal ice level (- - - -) here at least indicates the probability of a Maximum Glaciation ice stream network. Photo: M. Kuhle, 29.9.89.



he lower Nyang Qu is 450 m high and is situated at a base altitude of 3200 m (river level in the foreground). ↓ marks the localities of Photos 49 and 50. ■ Glacial ice level (- - - -) is provided by rounded mountain peaks (▲) and flank polishings (▲). Photo: M. Kuhle, 27.9.89.

Photo 52
Large granitic moraine blocks (●) exactly on the profile line of the mountain spur between Nyang Qu and the Tsangpo valley (in the area of confluence of the two valleys) at about 2950 m asl (Fig 43, No. 37). The fine material matrix of the moraine is described in Fig 28. In the background on the left the Tsangpo river. The orographic right-hand Tsangpo valley flank shows polished triangular slopes (triangular slope facets (▲▲)). Photo: M. Kuhle, 27.9.89.

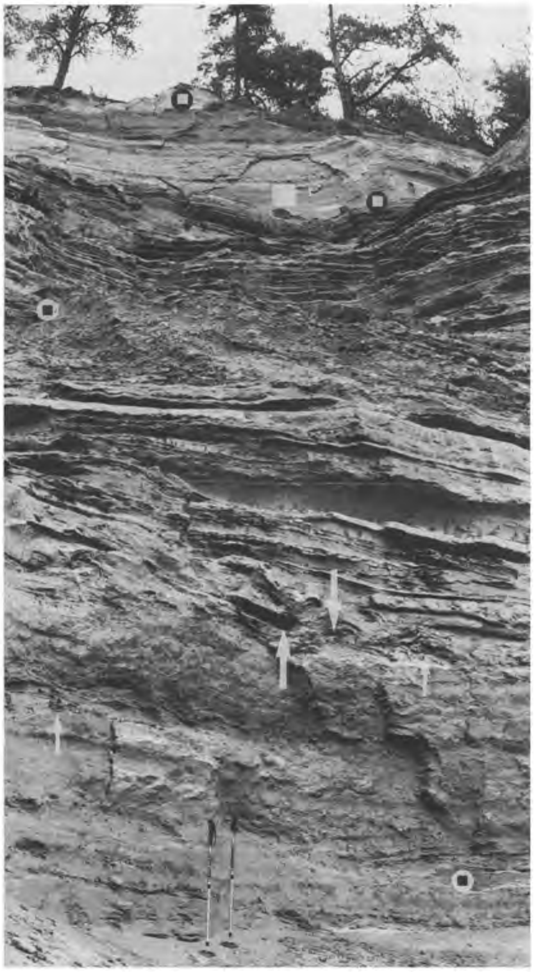
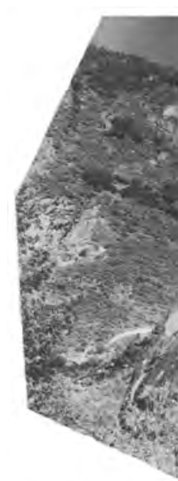


Photo 53
View of the 80 m high exposure on the right-hand side of the Tsangpo valley from the mouth of the Nyang Qu (Fig 43, No. 38; base altitude 3060 m asl; for an analysis of sediments cf. Fig 24-27). It presents glacilimnic sediments from glacier reservoirs which consists of sands and silts (↓↑) in the base areas and are covered by glacilimnic rhyolites - genuine varved clays - at the top (cf. Photos 54 & 55) (■). In the sands at the base, which have been piled up by the Late Glacial Nyang Qu glacier, together with the hanging pelite strata, coniferous trunks are deposited (↑↓) the dating (C^{14}) of which is still under way. Coniferous forests are growing here even now (cf. upper edge of photograph). Photo: M. Kuhle, 26.9.89.

Photo 56
Down-valley and immediatel
asl) these are at least 250 m
left-hand flank of the Tsangp
of this, are still visible (▼).
permit the moraine material
to be recognised from a dis

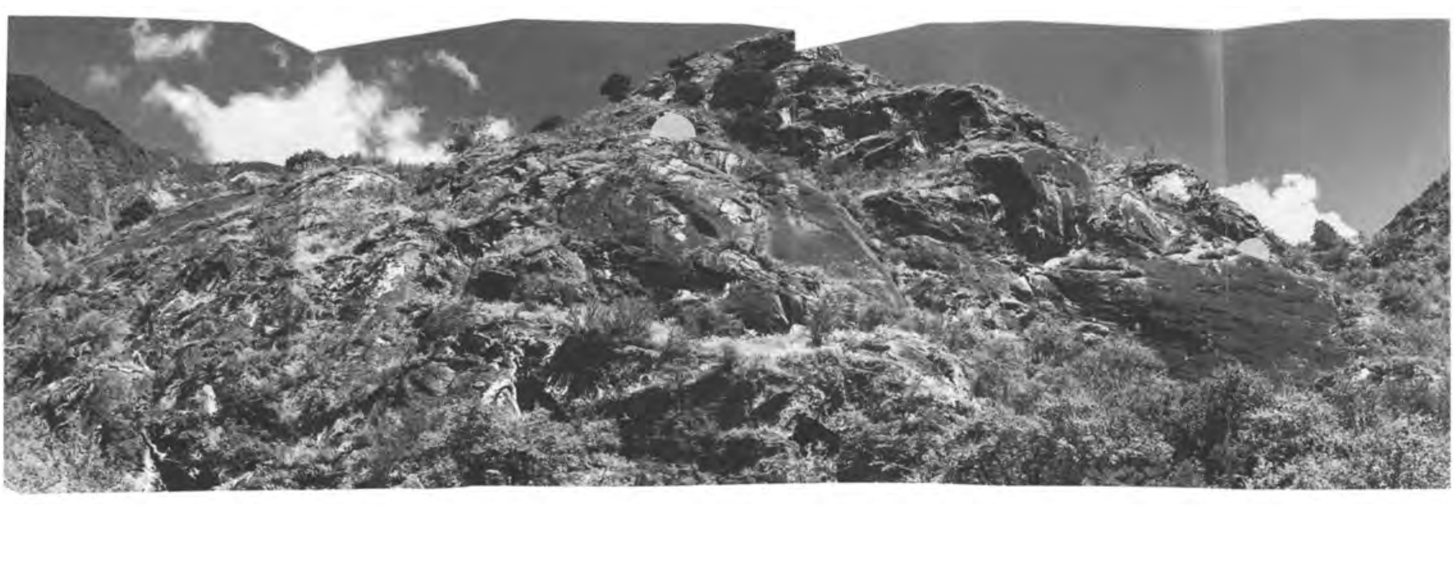
Photos 54 & 55
Two detailed photographs of varve clays shown in the exposure near the "Ganga Bridge" at 3135 m asl, c. 140 m above the Tsangpo (Photo 55, background), the valley flanks of which show boreal coniferous forests, (Fig 43, No. 38; Photo 53 ■; Fig 26). Silts (63.8% in a mixed sample) and clays (35.9% in the same mixed sample, with only 0.3% sand) - ie the dark and light strata of an average thickness of 0.9-1.3 cm, or 0.4-0.6 cm, which have been deposited in this Late Glacial glacier reservoir by seasonally alternating turns, contain 4.5% humus (ignition loss). This is the highest humus proportion of all Maximum to Late Glacial sediments normally found elsewhere in Tibet, ie this high proportion of humus is absent in moraines and drift floors, while being typical for varves. This also applies to the column-like structure the sediment reveals when it disintegrates along the lines of its dessication cracks (Photo 55↓↓). Photos: M. Kuhle, 26.9.89.



y after the entry of the Nyang Qu (Fig 43, No. 39, 2950 m
/laximum Glaciation bank formations on the orographic
o valley. Three remnants of terrace edges, which are part
Fresh gullies, which set in only on the lower slope (↙)
, which is patterned by glacigenic exaration grooves (∇),
tance. Photo: M. Kuhle, 9.9.89.

Photo 57
A lateral moraine (■) runs from a side valley on the orographic left-hand down to the Tsangpc
younger than the Tsangpo glacier, which has deposited its orographic left-hand lateral mora
glacilimnic and glaciofluvial sediments of the Tsangpo valley. Photo: M. Kuhle, 9.9.89.

Photo 58
Glaciated knob i
Glacial polishing
is now undercut



(Fig 43, No. 41; somewhat below 2950 m asl). On the corresponding valley side a moraine remnant (■) has been preserved. This side valley glacier is
ne remnants up to 150 m above the present one (▼). The quartzite sand dune (●) is 60–70 m high, and its material has been blown out from the

ı the valley bottom of the Tsangpo valley at 2850 m asl (Fig 43, No. 44).
has smoothed the outcrops of gneiss rock here (⏶). The Tsangpo river
ing the glaciated knob (↘) Photo: M. Kuhle, 24.9.89.

Photo 59
Well preserved flank polishings and glaciated knobs (⏶) are to be seen in the gneiss approximately 400 m above the Tsangpo river (here on the orographic right) (Fig 43, No. 44). Photo: M. Kuhle, 20.9.89.

Photo 60
Rounded glacigenic junction level (⏶) of a side valley on the orographic right-hand of the Tsangpo valley at almost 3000 m asl incised into a saw-cut valley (▲) (Fig 43, No. 44). Photo: M. Kuhle, 23.9.89.

Photo 61
Ground moraine material and ground moraine terrace form (■) on the valley bottom of the Tsangpo on the orographic left-hand, in part immediately above the present river (■; foreground) (Fig 43, No. 44, at about 2900 m asl). Photo: M. Kuhle, 24.9.89.

Photo 62
Moraine material deposited on the orographic right-hand above the Tsangpo valley (Fig 43, No. 44; at about 2900 m asl). This deposit corresponds to the moraines in Photo 61. For the composition of the basic mass cf. Fig 22. Photo: M. Kuhle, 24.9.89

Photo 65
View down to Tsangpo valley looking in a north-easterly direction towards the upper entry of the Tsangpo gorge (Fig 43, No. 44; 2800 m asl) with moraine exposures (▼♦) above rock walls which have been undercut by river erosion and are now breaking down (↘). Above the ground moraine ramps (▼) a polished ledge extends up to the prehistoric ice level (- - - -). Photo. M. Kuhle, 21.9.89.

Photo 66
Down-valley v
Tsangpo valley
glacial flank pol
the Maximum
21.9.89.

Photo 63
Glacigenic drag-fold (⌒) in sandy-clayey-silt (Fig 23) in the orographic right-hand moraine complex 40 m above the Tsangpo river (Fig 43, No. 44). (↘↙) are the vectors of approximately horizontally constricting forces. The fold has a slight tendeney down-valley (to the left) to the direction of the pre-historic ice flow. Photo: M. Kuhle, 24.9.89.

Photo 64
View down the Tsangpo valley from c. 2900 m asl (Fig 43, No. 44). In the background the Tsangpo gorge on the right of the 7151 m high Jialabali peak (1). The glaciated knobs (▲), polished ledges (▲) and ice-scour limits (- - - -) clearly show the Maximum Glaciation ice filling of this valley chamber and establish the probability of an ice thickness of about 2000 m. Photo: M. Kuhle, 20.9.89.

ew of the orographic left-hand flank of the from the Jiala settlement (Fig 43, No. 44) with ishing (▲) between 3000 m and 4800 m asl up to Glaciation ice surface (- - - -). Photo: M. Kuhle,

Photo 67
View into the Tsangpo gorge from about 2800 m asl down in a NNE direction (Fig 43, No. 44). Its origin is of a subglacial nature and shows breaks continuing into present times (→▲). In the background the lowest glacier tongues from the S-slope of the Jialabali massif are visible (●). Photo: M. Kuhle, 22.9.89.

Photo 68
The moraine material below the present tongue of the Namjagbarwa W glacier (◆), taken at 4050 m asl, facing W down to the Tsangpo (Fig 43, No. 45). After 1950 the glacier tongue reached the frontal moraine beyond the Tsangpo river (■). The glacier of the time is marked by the lower edge of plant growth (▼▼). In the Namjagbarwa W slope up to 7000 year old moraines from the main and side valleys are inset athwart one another (●●). Photo: M. Kuhle, 15.9.89.

Photo 69
Neo-Glacial or late Late Glacial glacier level (- - - -) of the Namjagbarwa W glacier (×) surface (with upper moraine) on the upper edge of a well smoothed, polished ledge (▲) (Fig. 43, No. 45).
Photo: M. Kuhle, 14.9.89.

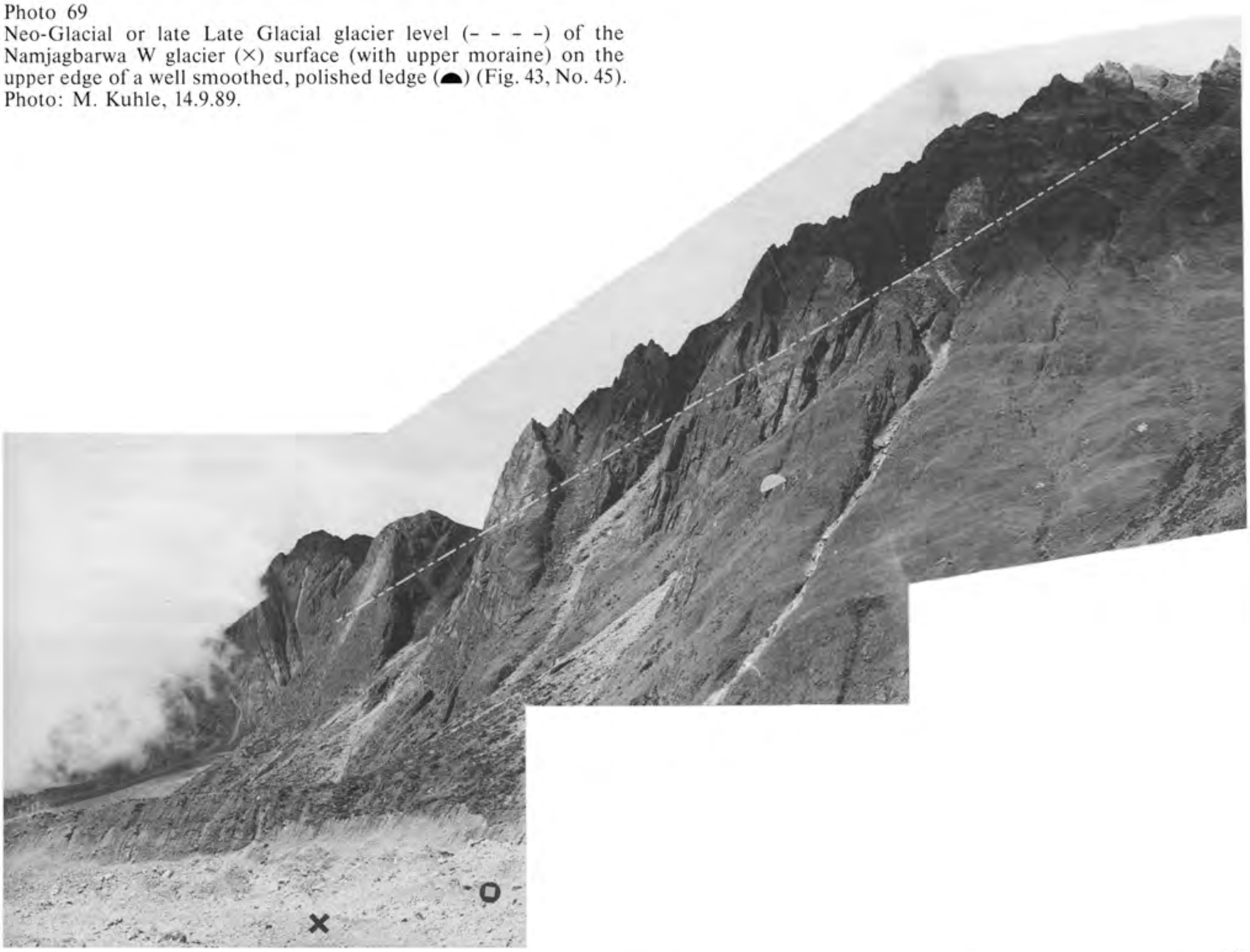


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Photo 70
The main valley ch
filled with Late Gl
oldest preserved m
III, IV), pedestal o
valley chamber wa
glacier in its Late G
Photo: M. Kuhle,

oto 72
ographic left-hand side lley of the Lhasa main lley 25 km SE of the ttlement; taken at 5030 m l, facing ESE (Fig 43, No.). The valley had been led with ice (- - - -) almost to the intermediate terfluve ridge. Below ere are classic polished dges with triangular areas ▲), with adjoining short oughs and corries (●) in e catchment area. Photo: . Kuhle, 6.8.89.

Photo 71
View from the Late Glacial orographic right-hand lateral moraine terrace of Stage III (Dhampu Stadium) facing N across the moraine landscape (V, IV, III, ■) from an altitude of c. 3000 m asl, W of the Namjagbarwa massif between 2900 m (the level of the Tsangpo, or Yarlung Zangpo Jiang to the right of ■), and the present glacier (▽) at 3900–4200 m asl (Fig 43, No. 45). During the Maximum Glaciation the relief was filled in with glacier ice up to and above the visible mountain ridges (- - - - estimated and approximate information). Glacial flank polishing ledges (⏶) occur up to the mountain ridges. Photo: M. Kuhle, 25.9.89.

ımber of the Tsangpo valley W of the Namjagbarwa (Fig 43, No. 45, at 2900 m asl) is cial (Nos. II, III & IV) and Neo-Glacial (No. V), as well as historic moraines (■). The oraine reached up to 550 m above the Tsangpo level. There are lateral moraines (Nos. dam moraines (No. IV) and terminal moraines (■). In the Last Glacial Maximum this completely filled with glacier ice (cf. Photo 71). (▼▼) shows the level of the valley lacial stage IV. At that time undercutting glacigenic flank polishing took place beneath. 11.9.89.

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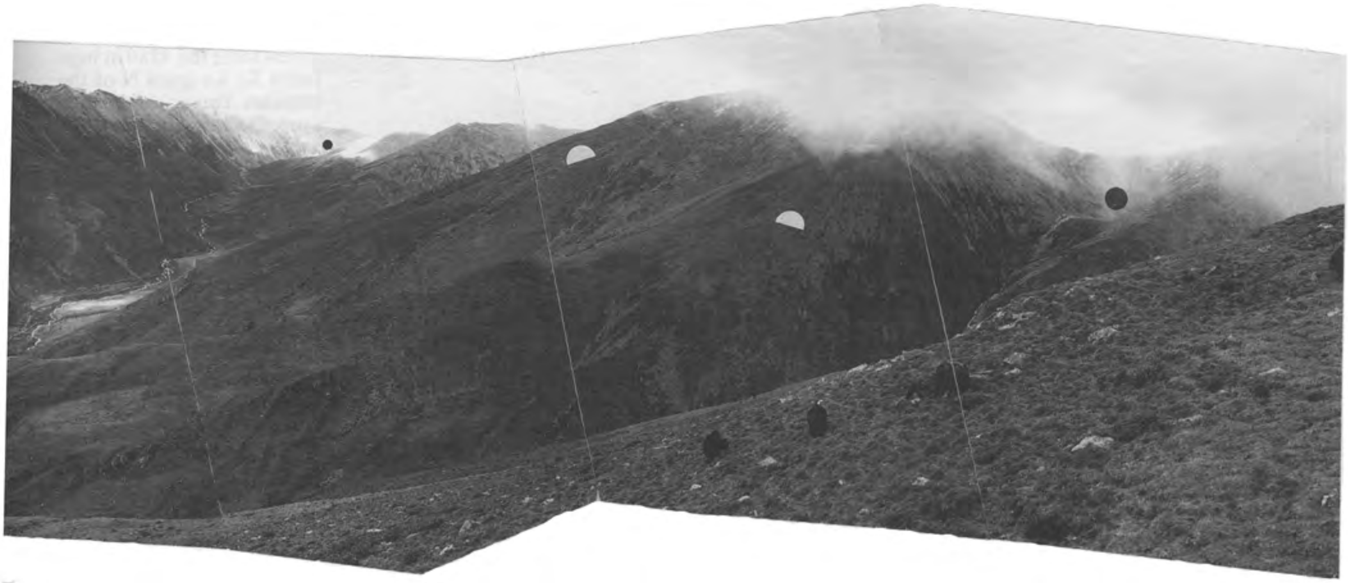

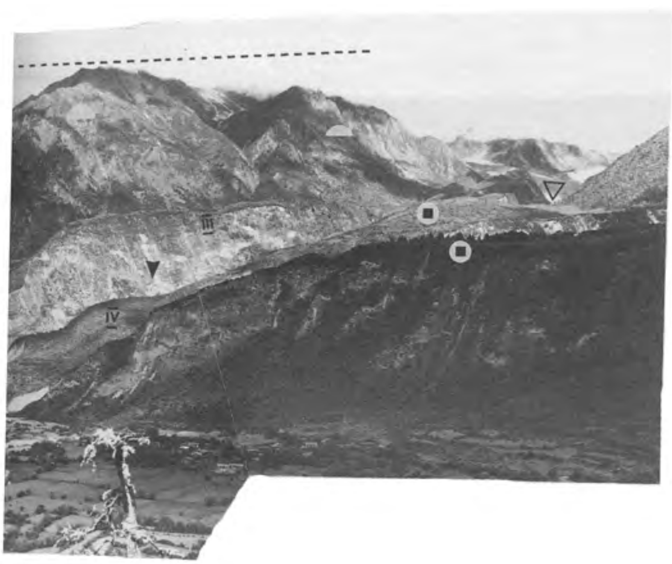

Photo 73
Orographic right-hand side and glacigenically-formed side valley of the Lhasa valley W of the town, photographed at 4600 m asl while facing W (Fig 43, No. 47). The opposite valley flank shows flank polishings (◓) up to 5000 m asl (- - - -). They are in parts overlain by sheets of ground moraine which are being exposed by regressive channel and gully erosion (↑↑). The valley flank is divided up by side valleys with glacial valley heads, corries and corroids (●). The recent fluvial incisions are new and young forms (▼). Photo: M. Kuhle, 2.10.89.

Photo 74
View from the 4880 m high Tschü Sü La (pass N of the Yamzho Yumco), facing N towards a massif beyond the Yalung Zangbo Jiang valley (Fig 43, No. 50). The massif displays the glacial-geomorphological features of a mountain completely submerged below ice: trough-shaped valleys, founded valley and mountain flanks (▲), corrie-like basins at the valley head (●); only the very steep valleys have V-shaped forms (▼). After removal of the ice erosion channels developed, which are only a few millenia old (↑↑↑). Photo: M. Kuhle, 31.10.89.

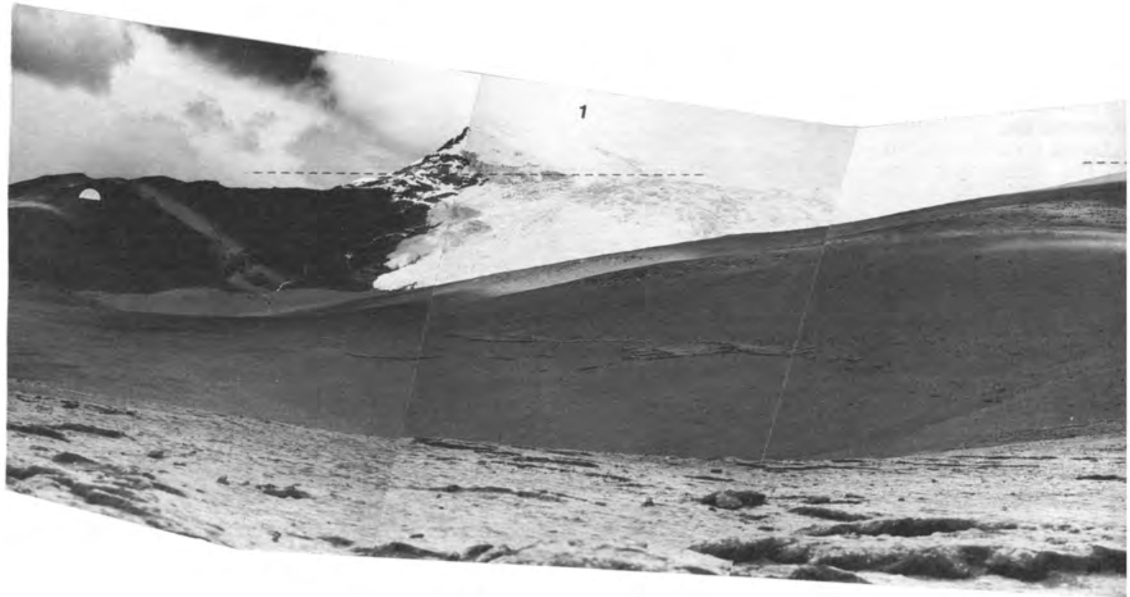

Photo 76
View taken at c. 5200 m asl, facing W across the glacially formed plateau of the Latzu massif (Lhagoi Kangri; Fig 43, No. 52). On the valley bottom (where yak pastures may be found) there are ground moraine-block sheets (■). The mountain ridges are glacigenically polished (▲). Even the glaciated 6404 m high peak has been covered by ice during the main glacial period (- - - -). Photo: M. Kuhle, 30.10.89.

Photo 78
Orographic left-hand flank of the Nyomdo valley near its confl
with the Dzakar Chu (facing E; taken at 4200 m asl, E of the P
settlement; Fig 43, No. 53), with significant banded outcrop pol
(▲). Quartzites form the projecting outcrops (↓ ↓). Photo: M. I
5.10.89.

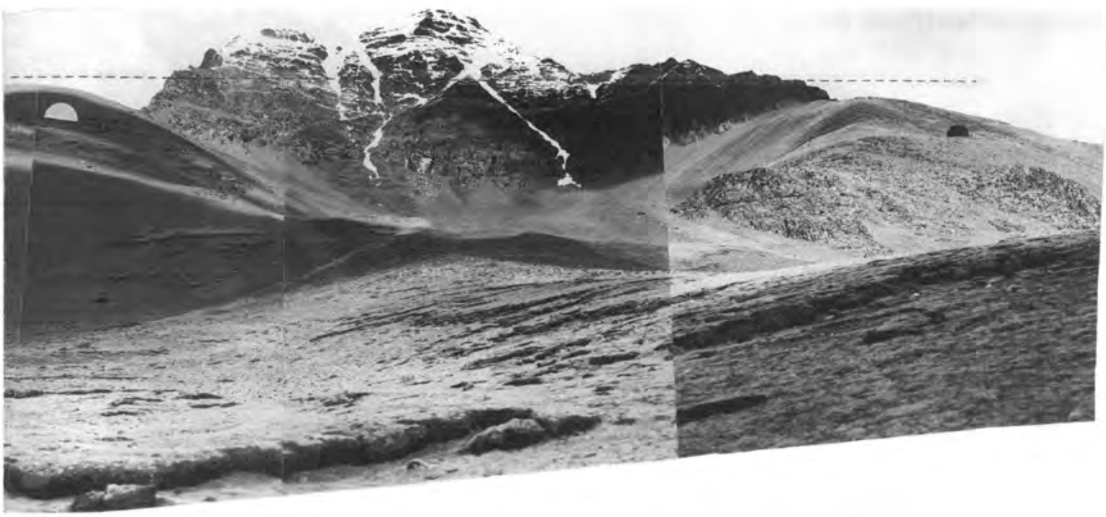

Photo 75
Orographic left-hand flank of the main valley, which runs E from the Lang La (5150 m asl) through the Nagarzé massif (Lankazi massif) down to the Yamzho Yumco (-lake) (Fig 43, No. 51). The peak (1) on the left is the highest mountain of this mountain group (7223 m). The valley flank shows glacigenic polishing, and has been formed from triangular areas between the short side valleys (▲). Above this level forms of rock walls and peaks set in, towering above the prehistoric glacier levels (- - - -). Photo: M. Kuhle, 30.10.89.

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Photo 79
Orographic right-hand glacial flank polishing (▲) in the Central Dzakar Chu at 4150 m asl, facing W (up-valley) (upper branch of the Arun source, also known as the Bong Chu; Fig 43, No. 54). Photo: M. Kuhle, 5.10.89.

Photo 77
A panorama across a SE section of the Latzu plateau (Fig 43, No. 52); cf. Photo 76), taken at 4800 m asl, facing E. The relief had been under a complete covering from an Ice Age ice cap complex up to and above 6037 m asl (- - - -). The result are the rounded forms (▲). There are granitic block deposits in the foreground (××), which build up a relief-concordant ground moraine. Photo: M. Kuhle, 30.10.89.

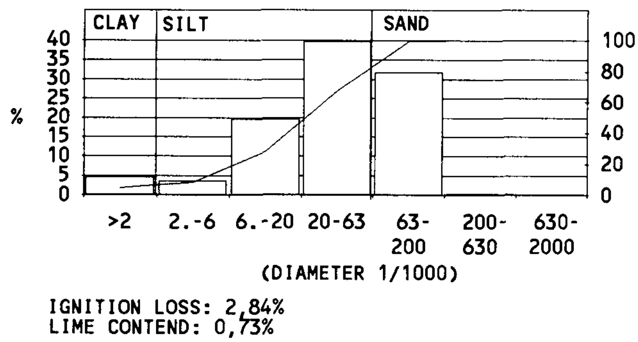


Fig 21 23.9.89/3, glaciofluvially marked sediments from an orographic right-hand lateral moraine terrace 60 m above the surface of the Tsangpo at 2890 m asl; Fig 43, No. 44; Photo 64 (◉); sand 32.3%, silt 63%, clay 4.7%.

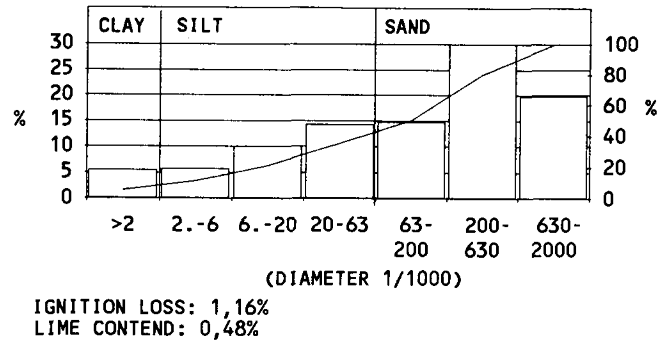


Fig 22 24.9.89/2, orographic right-hand ground or lateral moraines in the Tsangpo valley (Late Glacial) at c. 2960 m asl; Fig 43, No. 44; Photo 62 (◉); sand 64.5%, silt 30%, clay 5.5%.

about 5200–5300 m asl, the *maximum altitude of the catchment area* being 5582 m. *Corries* and *hanging troughs,* too, belong to the upper level of the catchment areas of this valley. The excellently preserved *flank polishings* (Photo 73▲) are important for our question. The valley bottom is at 3800 m in the cross-section area of Photo 73, and the *flank polishings* shown there reach 4800–5000 m (Photo 73 - - - -). This is evidence of a *glacier thickness* of at least 1000–1200 m. In an analogous way, this side valley glacier level is further evidence of a *main valley glaciation* of a thickness that exceeded 1000 m. The main valley floor is here at about 3660 m asl. This side valley junction is 8 km E and downhill from the orographic left-hand glacial *flank polishing* shown in Photo 38 (Fig 43, No. 23). The indicator there is an indirect *confirmation* of the main valley glaciation here, though there is no pointer to the thickness of the ice. This is approximately derived from the level of the side glacier here (Photo 73 - - - -). Here again, *more recent fluvial incisions* (Photo 73▼▼) are evidence of prehistoric formation of flank polishings under *entirely different conditions* than those now existing. Like the flank polishings themselves, this is another pointer to prehistoric glacier-filling of this side valley, too. In places the many metres thick *burden of ground moraine* (Photo 73 ⤍), ie a very recent and accordingly soft burden of loose rock makes it very easy for *gullies and channels to form.*

In the exits of the two side valleys near Lhasa in the Transhimalaya thus described, no terminal moraines have been preserved. End moraines in these locations could – if at all – possibly be from the Late Glacial period, ie they would have been deposited at a time when the side glacier was no longer reaching the main glacier or main valley. The numerous smaller and much more highly placed *moraine remnants* in *short troughs* and *corries* will not be gone into in this context considering that its theme is the main Ice Age glaciation. The boundary between the Main Ice Age and *Late Ice Age glaciation* would, however, be of interest. Besides the valley investigated in 1984 (at 29°43'N/91°04'E; cf. Kuhle 1988a, p. 459 with Fig 3) to the north of Lhasa, another one south of the town at 29°35'N/91°09'E (Fig 43, No. 48) provides some indicators. There is a pedestal moraine there at almost 4000 m asl, which has been brought up from a bowl-shaped *corrie* and is from 15 to a maximum of 50 m thick. The macroscopic picture is clear: *rough blocks* of up to one metre in length are embedded in a *tightly packed and finely ground mass* apart from one another. With only 27.7% *sand,* but 10.6% *clay,* the ground is comparatively 'fat', ie *extraordinarily fine-grained* for a *mountain moraine* (Fig 3) which has travelled over such a short distance only. Besides the fine-grained metamorphite rocks prevailing in the catchment area the reason for this is the distinct *ground moraine position below* instead of *in front* of the glacier, which is a feature of all pedestal moraines. The corresponding ELA in this south-facing form of a corrie is interesting in so far as its maximal altitude in the catchment area is merely 4800 m. The *mean altitude of the catchment area* of this probably *Late Ice Age – only 3 km in length – hanging glacier,* is at about 4600 m, so that the orographic, or local, snowline is found to be at about 4300 m. This is strikingly low for the Late Ice Age in this area, considering that this allows an ELA depression of about 1200 m, in contrast to the present snowline at about 5800 m, to be calculated, and that the *Main Ice Age snowline* must have been even lower. In 1984 the author, using such a moraine for his calculations, found the climatic ELA for the area around Lhasa at 4500 m, a result which was confirmed by these 1989 findings (Kuhle 1988a, p. 458, Fig 2). The then classification of this snowline at 4500 m asl as belonging to the Main Ice Age would consequently have to be corrected as belonging to the Late Glacial period. This is also suggested by the very *thick Main Glacial side glacier confluences* with the necessarily equally glaciated main valley of Lhasa (Photos 72 and 73; Fig 43, No. 46 and 47), which were previously investigated.

A side valley system joining the main valley near the Ghanden monastery settlement almost 30 km E of Lhasa from the south (on the orographic left-hand side) will only be considered in respect of a transfluence pass (29°37'N/

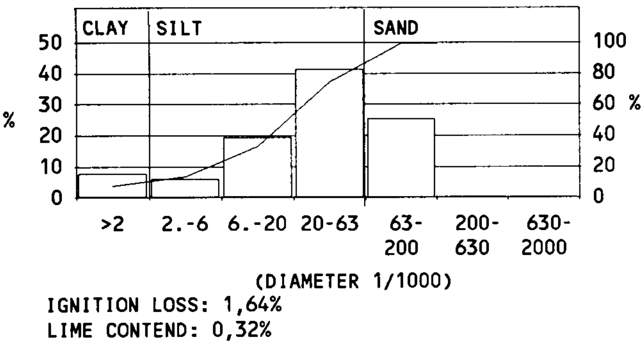


Fig 23 24.9.89/4, orographic right-hand ground lateral moraine in the Tsangpo valley, 40m away from the locality described in Fig 22, from the centre of a glacigenically compressed fold in glacio-fluvial sand of a prehistoric depression on the bank-line, which was over-run by the glacier; Fig 43, No. 44; Photo 63 (◉); sand 25.6%, silt 66.7%, clay 7.7%.

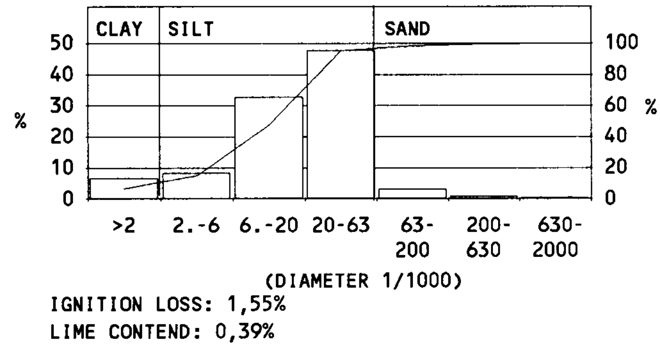


Fig 24 26.9.89/3, 3060 m asl in the Tsangpo (Yarlung Zangbo Jiang) valley upstream from the Nyang Qu mouth, 1 km SE of the Ganga bridge, basal sands of sediments from a lake dammed back by a glacier; Fig 43, No. 38; Photo 53 (◉ below); sand 4.6%, silt 88.7%, clay 6.7%.

91°23 E; Fig 43, No. 49). It lies between two valleys, the numerous feeder branches of which face S, and show talwegs of 17–20 km. All the adjoining high valleys take on *short trough forms*. The well *rounded* transfluence pass between the two side valleys is about 4500–4600 m high and laid down in phyllite-like metamorphites. The floors of the adjacent parallel valleys on both sides are at about 3800–3970 m asl, so that *ice-thicknesses* of clearly more than 500 m were necessary for the *glacier overflow*, or for *communicating valley glacier surfaces*. This transfluence pass is geomorphologically representative for a multitude of prehistoric glacier overflows in this part of the Transhimalaya (Nyainqentanglha). Samples 5.8.89/1 and 2, taken from the kilometre-long pass ridge, which is divided up by gently shaped reverse-cupolas, are to be presented as a typical confirmation of the diagnosis (Fig 4 and 5). They were taken from the loose rock immediately above the bedrock from depths of 50 and 25 cm. The *decrease of the sand proportion*, together with an *increase in silt and clay* in proportion with the the increasing *vertical distance* from the footwall bedrock illustrates the development of glacially rubbed-off drift material with rock flour to *increasingly finely-grained ground moraine substrate*. In this *vertical distance* from the bedrock implies a simultaneously *increasing, horizontal transport distance or transport-efficiency* of the overlying glacier, which is increasingly filling the ground moraine with drift. The almost 100% *increase in clay* at the expense of the 33% *sand* expressly demonstrates the *glacigenic grinding-down* of fine grains. Break down by *frost weathering* does not figure in this, as it does not normally leap-frog the silt fraction during the crushing process, as has happened here to a large extent. *Frost weathering* by contrast *concentrates* on the *crushing of sand into silt*, whilst omitting the clay fraction.

8. Additional Observations on the Traces of a Maximal (Main Ice Age?) Glaciation between the Southern Transhimalaya ((Nyainqentanglha) with the Tsangpo (Yarlung Zangbo Jiang) Valley and the Lankazi Massif (Nagarzê Massif; Max. Altitudes: 5871 and 7223 m asl) (28°50'–29°25'N/90°03'–45'E)

Taken from the 4880 m high Tschü Sü La (or the Tschüles La, ENE of the Lankazi massif on the N-bank of the Yamzho Yumco, Photo 74 shows the *glacial formation* of the 5871m massif which borders on the Tsangpo valley in the N. It is, however, not immediately clear whether the 3600 m high bottom of the Tsangpo has been filled with glacier ice. The *very considerable* glacier filling of the Lhasa valley, for instance, as reconstructed for the area around Lhasa, 60 km NE of its junction with the Tsangpo (Yarlung Zangbo Jiang) valley (cf. above, Chapter 7), speaks for a prehistoric filling with ice. Direct evidence of glaciation in this middle section of the Tsangpo valley is still lacking, however (cf. Kuhle 1988b, p. 583, Fig 2: the ice-free area between I_2 and I_3). The fact that the lower Tsangpo valley in the area of the junction with the Nyang Qu has been *filled with glacier ice* and had an approximately 2000 m thick glacier filling in the big Tsangpo loop around the Namjagbarwa massif (cf. above, chapter 6), although the valley floor there lies below 3000 m, also points to a *total glaciation* of the 700 m higher middle Tsangpo valley. Photo 74 shows a relief which had undergone round polishing from its base at 4000 m asl to its peak in a strikingly *consistent* way, and further shaping by classic *trough forms* with intermediate *triangular areas* (Photo 74▲) (Fig 43, No. 50). Equally consistently developed from bottom to top, *dissection* and *gullying* have made inroads everywhere into the otherwise large-scale gentle contours of the slope and mountain forms (Photo 74↑↑↑). The steeper, shorter hanging valleys have *saw-cut cross-profiles*, the talwegs of which are now undergoing *fluviatile*

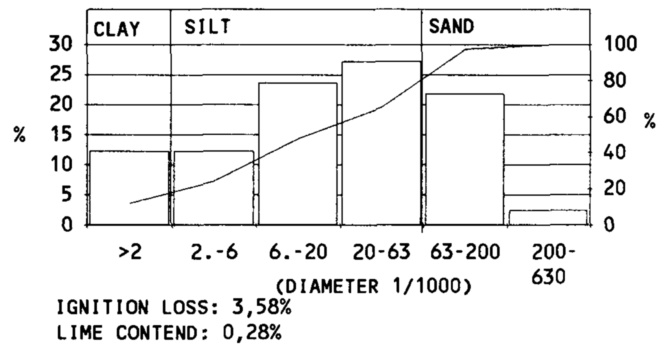


Fig 25 26.9.89/12, 3082 m asl, sediments from a dammed-back lake, in the same locality as in Fig 24; Fig 43, No. 38; Photo 53 (◉ centre); sand 24,8%, silt 63%, clay 12.2%.

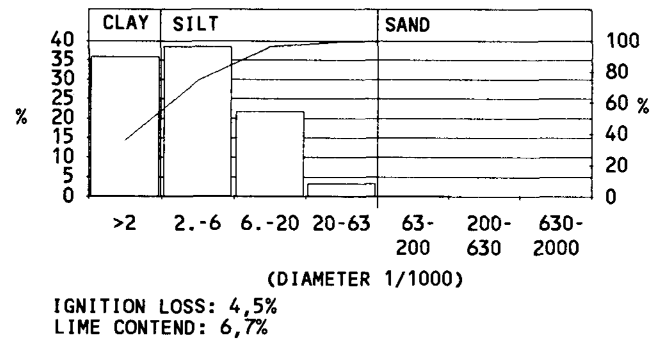


Fig 26 26.9.89/15, 3135 m asl, varve clay, same locality as in Fig 24; Photo 53 (◘ above); Photo 55 (◘); sand 0.3%, silt 63.8%, clay 35.9%.

chiselling (Photo 74▼▼). *Corries* and *short troughs* have developed towards the valley-head depressions by following an old surface level (Photo 74●●).

In order to supplement fieldwork carried out during the 1984 expedition in the Lankazi massif (Nagarzê massif) (Kuhle 1988a, pp. 477–481) further observations on prehistoric glacier thicknesses were made on the Lang La (c. 5150 m asl); at 28°54'N/90°11'E; Fig 43, No. 51) in 1989 (Photo 75). Although it is a matter of thin strata of metamorphites which have been severely affected by frost-weathering during Post-Glacial times to this day, the *glacially rounded* rock ridges have been well preserved since deglaciation set in during the Late Glacial period. These roundings and polishing forms (Photo 75▲) stop above the altitude of 5600–5800 m where the summit walls begin and rise to 6000 m and even above 7000 m (Photo 75 ----). This implies *minimum ice-stream thicknesses* of 450 to 650 m on the pass. This pass forms the *ice-shed* between the large decametre-wide valley chamber that joins on in the W (cf. Kuhle 1988a, pp. 480/81, Fig 37) and the E basin, in which the Yamzho Yumco (or Yang Cho Yung Hu or Yamdrok-Lake) lies (cf. Kuhle 1988a, p. 476, Fig 32). The high peaks had towered above the ice stream network as *nunatakr.* Considering that this is a *transfluence pass,* the minimum thicknesses of the ice stream above are considerable, since the ice flowed steeply down both sides of the pass (within short distances) to areas below 4500 m asl.

9. Additional Notes on the Traces of a Total (Main Ice Age) Glaciation in the Lhagoi Kangri Massif (Latzu Massif or Ladake Shan) and in the Pazhug Massif (Panga La Massif) (Max. 6458, 6404 and 5905 m High) (28°26'N/86°50'-87°17'E)

Taken at an altitude of 5000 m, Photo 76 shows the glacially-shaped plateau and the mountain ridges of the Latzu massif towering above it (Fig 43, No. 52; Lhagoi Kangri). These are in turn topped by the 6404 m high peak, which continues to be covered by an approximately 4 x 4 km glaciation. The relief here is considerably *rounded* (▲) up to the still glaciated high peak, and is now on the one hand overlaid by *sheets of concordant solifluction material,* and on the other hand by acutely incising and *destructive gully-wash* (Photo 76↓↓). In the kilometre wide and very shallow valley chamber in the middleground, there is a shallow valley floor which consists of ground moraine outwash with a large component of rough blocks (Photo 76■■). Evidence of total glaciation in the immediately contiguous areas of the Latzu massif (Lhagoi Kangri massif) has been provided by geomorphological observations and sedimentological analyses of the team's expedition in 1984 (cf. Kuhle 1988a, pp. 463–467). Nevertheless, these confirmatory observations of the 1989 expedition are sufficiently unambiguous to be a significant complementary feature.

8 km to the SW of the point where Photo 76 had been taken, a panoramic view from NE to SE was photographed from the same plateau unit, which is situated between 4800 m and 6037 m asl (Photo 77) (28°50'N/87°20'E). The framing heights, which are part of the catchment area, and are covered by snow, are 15 km away. They present all the characteristics of a *totally glaciated* mountain relief (▲). A minimal Main Ice Age *thickness of ice* far in excess of 1000 m is thus probable in this area. Mountains reminiscent of a *Scandinavian fjell landscape* form the backdrop to a slightly undulating *ground moraine landscape.* Its large-scale construction is based on *boulder clays with erratica* (Photo 77×××). These are up to several metres long blocks of dioctahedral mica- granite and biotite-granite which rest as outliers on the polished floor of the recumbant bedrock (cf. Kuhle 1988a, pp. 466–467, Fig 20–23). These far-flung *boulder clays* can neither be explained by fluvial processes nor by mur-like dynamics. The latter must be excluded on the grounds of the absence of a

catchment area, ie the lack of sufficient steepness of relief. Largely counterless ground moraine areas of this kind are accordingly unequivocal evidence of a thick and completely shrouding inland-ice or ice-cap sheet (Fig 43, No. 52).

In the S exposition of the Panga La massif (S of the Pum Qu), well preserved bands of polishing on outcrops (altitude at base: 4200 m; 28°27'N/87°02'E) have been found (Photo 78▲), which supplement the findings of the 1984 expedition (cf. Kuhle 1988a, pp. 471–476, Fig 28 and 29). They extend upwards over 700 m from the bottom of the Nyomdo valley as far as the acute edge of the ridge and expose the *differences in the hardness* of alternating soft, marly-sandy *flysch* rocks to sandstone or very resistant quartzites (Photo 78↓↓) (Fig 43, No. 53). This finding shows that a *glacier which filled the entire valley „container"* must have left the Nyomdo valley and flowed into the Dzakar Chu from the N. If a glacier of such dimensions (more than 700 m) poured out of a less than 6000 m high massif like the "Panga La massif" it becomes possible to estimate what an *enormous influx of ice* the valley must have received from the 7000 m high *Tibetan Himalaya* that joins on in the S, and the much more than 8000 m high High Himalaya, during the *Main Ice Age* and even during the *Late Ice Age!* This important point leads on to the next chapter.

10. The Prehistoric Glaciation of the Arun Valley (Pum Qu), Including the Dzakar Chu as the Continuation proper of the Catchment Area of the Tibetan and the High Himalaya (28°–28°30'N/87°–87°30'E)

Investigated in 1989, this area is the E continuation of the upper and middle Dzakar Chu (or Bhong Chu, the S feeder of the upper Arun valley) which had been studied in 1984. From the exit of the Nyomdo valley downwards, the Dzakar Chu (sometimes referred to as Dzakar Qu) follows on towards the E with its 15 km long and up to 3 km wide valley floor, which has been let into metamorphic sedimentary rock. From the gravel floor between 4150 and 4000 m asl up to an altitude far beyond 5000 m, the latter have been subjected to glacial polishing (Photo 79▲) (Fig 43, No. 54; 28°23'N/87°08'E). It seems unnecessary to list all the apparent *stretches of flank polishing* in this section of the valley and define their exact locality. Almost everywhere in the valley the post-glacial detritus covering the slopes is so thin and translucent that the barely weathered glacigenic rock polishings on both sides are clearly visible for miles.

The importance not only of the *ice transfluence* but also of the production of *ground moraine* and its *drifting* is shown by a decametre-thick *ground moraine* deposit within the *gorge-like* continuation of the Dzakar Chu down valley. Examined more closely, it proves to be a 150–250 m *deep gash* which has been sub-glacially cut into the valley bottom of a very narrow valley cross-profile here (Fig 43, No. 55; 28°22'N/87°10'E, altitude of talweg, 3950 m asl). Strikingly rich in *fine materials, the diamictite and bedrock material* shown in Photo 80 characterizes *ground moraines* which have been sedimented under high pressure from their *load* (lodgement till) (■■) Re-exposed in the meantime, gneiss-like bedrock is visible near the *gorge talweg* (●●). The *inner stability* consequent upon *compaction* through the *glacier load* is immediately made clear by the existence of some natural bridges (▼▼) created by recent erosion of slopes. The floor of the Ice Age glacier covered a large area of the much wider rock floor of the full-bottomed *valley cross-section above the gorge.* At the same time the *sub-glacial meltwater run-off* into the *gorge* was eroding the bedrock gneisses. Later, when a decametre-deep gorge had already been incised, the *upper gorge edges* were increasingly *broken down* and *widened* by the hanging glacier bottom (Photo 80 ↓).The ice then widened the *upper gorge area* more and more in this way and created a *gorge-like saw-cut valley.* The glacier workings thus followed the *hydrostatically accelerated meltwater erosion.* The gorge then became a *ground moraine trap* – increasingly so towards the end of the glaciation of the valley – with the ground moraine material from the hanging glacier bottom *pressing into* the gorge, where the *roughness* and *resistance* the gorge presents in the otherwise smoothly polished bottom of the valley floor stripped them from the base of the glacier (cf. Kuhle 1991, pp. 102/103, Photo 57).

When proceeding up the Dzakar valley from the gorge stretch to the area of the junction with the Nyomdo valley, and still further up to the Rongbuk settlement (at about 4600 m asl), the appearance of the valley is particularly striking for the almost total absence of *talus cones and talus slopes.* The alluvial fans moreover, which, having been poured out from the side valleys, are inserted into the Late Glacial pebble floors *(sander)* in the valley bottom of the Dzakar Chu, are small and of only minor thickness (cf. Photo 81). Repeatedly mentioned above (for instance in the case of the Nyang Qu), this phenomenon of the "clean valley landscape" is not only evidence of glaciation but also of recent deglaciation of the valley. Its *pre-glacial rock waste* has been cleared away by the glacier. The formation of detritus here now takes place very fast at the periglacial altitudinal level and in the sedimentary bedrock, so that the *small amount of debris under these* conditions confirms that the distance in time until *deglaciation* amounted to *only a few thousand years.*

The two panoramas (Photos 81 and 82) turn to the area of the *confluence* of the Dzakar Chu and the Arun valley (Pum Qu) (Fig 43, No. 55; 28°18'N/87°22'E; 3750 m asl). Photo 81 shows *flank polishing* (▲) and the *paucity of detritus* (cf. above) of the lower Dzakar Chu. Gneiss-like migmatites predominate. This section of the valley had been totally filled with glacier ice, and thus *polished* the valley *round* up to and *beyond* the mountain ridges. The *large-scale glacier roundings* of these mountains are best diagnosed by Photo 83 from a distance of 16–20 km upstream from the S Arun valley (- - - - in the background). In this section of the valley the ice had been *more than 1800 m thick.* Besides these rounded mountain ridges and cupolas, evidence of this can also be assembled

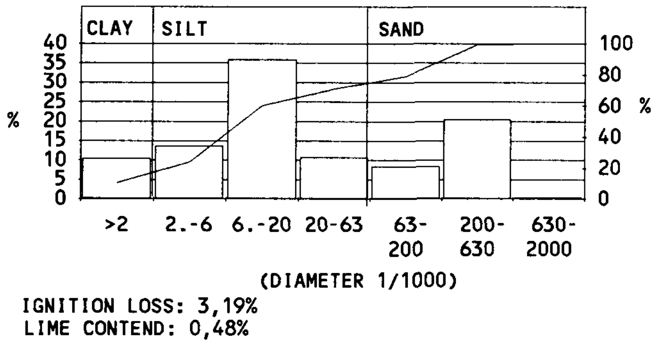


Fig 27 26.9.89/17, 3140 m asl, same locality as in Fig 24; the varve clays are overlain by coarser still-water sediments mixed with pebbles near the upper edge of the exposure; Photo 53 (● at the very top); sand 29.3%, silt 60.3%, clay 10.4%.

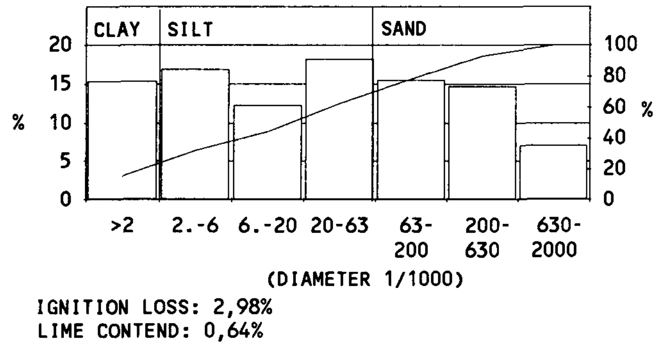


Fig 28 27.9.89/2, 3110 m asl, median moraine triangle between Nyang Qu and Tsangpo valley (in the area of confluence of both valleys), 160 m above the present Tsangpo level, Fig 43, No. 37; Photo 52 (◉); sand 37.2%, silt 47.3%, clay 15.4%.

by findings of moraines and erratica 20 km outside the valley (cf. below, Photos 83–86). The small, orographically left-hand side valleys (Photo 81■■) have a noticeably *bigger* chamber, ie they form a much larger cavity than the volumes of the alluvial fans in their valley exits (▲▲) could possibly fill. This implies that the *age* of the little valleys is *greater* than that of the *alluvial fans* transported from them. The small valleys are consequently of *pre- glacial* age and the smaller waste volumina of these alluvial fans were washed out during post-glacial times, *after* deglaciation. The 300–500 m wide valley bottom has been covered with *glacio-fluvial pebbles*. They stem from the *numerous glaciers* which end below the catchment areas of the side valleys since the deglaciation in the Late Ice Age.

On the right of Photo 81 (●) and on the far left of Photo 82 (●) a classic *transfluence pass* or *glacigenic confluence level* is shown. Originally, ie in the pre-Pleistocene, it was the junction of the upper Arun valley (Pum Qu) with the lower Dzakar Chu, which is subsequently downstream from this point, known as the Lower Arun valley (Fig 43, No. 55). In the course of the *Pleistocene glaciations* the talweg with the Arun river found a course further to the SE; it now flows around the 5458 m peak (Photos 81, No. 1, and 82, No. 1) through a strikingly fresh, ie *recent fluviatile gorge* stretch (Photo 82↓) with very steep flanks. Accompanying regressive erosion taking place in glacial and inter-glacial periods has washed out the upstream floor of the Arun valley down to 4050 m (4048)m. By this a counter-inclination has developed, which led to the formation of a transfluence-pass culminating in 4400 (4408)m (Photo 82●). As the fluvial long-profile was *below* the *Main Ice Age snowline* (which was between c. 4300 and 4675 m asl, cf. Kuhle 1988a, p. 458, Fig 2), its incision must have taken place sub-glacially. This hydrostatically re-inforced erosion must therefore have been particularly effective.

During the Main Ice Age the ice flowed over the 5458 m high peak, as evidenced by the *triangular area with homogeneous polishing* that extends to the peak (Photo 82⌒, below No. 1). During the Late Ice Age this mountain flank pierced the glacier surface. This is shown by lateral moraine ledges left behind above and in the extension of the *glacigenically rounded confluence level* (●) on the mountain flank (Photo 81××).

Following the orographic left-hand valley flank further down the Arun valley, glacial flank polishing appears which is preserved in substantial dimensions, and extends upwards beyond the summit level (Photo 82▲▲). The difference in height between the upper peaks of the down-polished *triangular areas* (▲) which reached up to altitudes of 5000–5600 m, and these high peaks which the glacial polishing did not reach, is more than 1000 m (Photo 81, cf. ▲ with Nos. 2 and 3). These high peaks, which reach a maximum height of 6752 m asl, have steep walls, ie they are *perfectly acute*. This proves that they towered *above* the surface of the ice stream network and were *undercut* by glacier margins (Photo 81, No. 2 and 3). The upward petering out of triangular areas into *pointedly acute rock ridges* – as appears particularly clearly and repeatedly, in conformity with the law of nature, in Photo 82 (▲▲), ought to be stressed as a characteristic feature of a *glacigenic shaping of macro-forms* in high mountains. Attention is once again drawn to the corresponding formation of the Dovrefjell (Snöhetta peak near 62°N/08°W) in Skandinavia, as a classic example from the European inland ice area (see above).

Besides the preserved banded polish of outcrops, which picks out the differences in the hardness of particular gneiss and less metamorphosed phyllite banks through approximately horizontal strips of rock which run parallel to the slope and are rounded at the front (Photo 82 +), there are also *Late Glacial strips of lateral moraine* present on the triangular areas (Photos 83, foreground x; 84, foreground x; 85, foreground x, 86↓↓). They belong to a period of glaciation during which the ice surface was already *below* the gradually risen ELA. Still later, during the

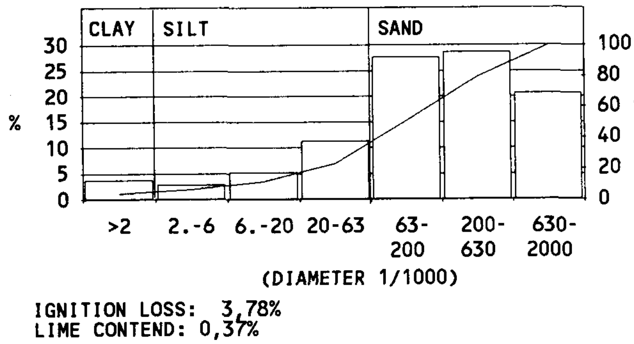


Fig 29 7.10.89/2, orographic right-hand in the area in which the Karda (Kharta) valley joins the Arun valley, 3950 m asl, end moraine material which was shifted from a S side valley during the Late Ice Age; Fig 43, No. 57/56; Photo 87 (◉); sand 76.9%, silt 19.3%, clay 3.8%.

Late Glacial period, orographically left-hand *side glaciers* had just managed to reach the Arun valley and to deposit *terminal moraines* ("valley exit moraines") in the area of the confluence (Photo 82⧫). These valley exits were also the origins of *glacio-fluvial alluvial fans* (cone sanders or pebble floors) which were poured out and placed upon the valley bottom of the Arun valley. This happened frequently in combination with *deposits of rock wall cones* (Photo 82■). The lowest *recent glacier tongues* in these side valleys end at 5100–5500 m asl. There are moraine lakes in their historic to neo-Glacial *tongue basins*, the occasional leakage of which has led to those *rockwall cones* or *mudflow sediments* in the main valley (■).

8 km upvalley from the Arun gorge proper (that is the area where the valley floor stops and the steepening of the gradient caused by backward erosion announces the breakthrough through the High Himalaya), a 600 m high barrier mountain blocks the here still almost 3 km wide valley chamber (Fig 43, No. 56; 28°10'30"N/ 87°22'E, between 3630 m and 4210 m asl). It is perfectly *rounded by glacier polishing* (Photos 86▲ and 84▲), and some large *erratic blocks* of granite were found on its summit (Photo 84↓). In the place where the barrier mountain joins the flank of the Arun valley at 4190–4300 m, on the orographic left-hand (the Arun river runs on the other side at 3630 m asl), a *Late Glacial lateral moraine*, several decametres thick, has been deposited along the valley (Photo 83, foreground). This *moraine strip* consists of a whole bundle of small lateral moraine walls next to one another, jointly forming a characteristic washingboard-like surface form. In some stretches these grooved forms may also interpreted as *glacial exaration lines*. These moraine strips consist of *polymict blocks;* they are more than one metre in length and occur in all kinds of fractions down to a *sandy to clayey intermediate mass*. The rounded, facetted and sharp-edged blocks consist of at least three varieties of granite, five varieties of gneiss, and numerous metamorphites like crystalline shales and siltstones, as well as other migmatites. This moraine lies on very course crystalline bedrock augengneiss which is *not part* of their petrographic spectrum. Further *moraine ledges* of very similar petrographic composition and decametre-high inner moraine slopes lie above the barrier mountain on the triangular slope – which reaches 5680 m asl – at 4420 and 4680–4760 m. They occur at least 1130 m above the present talweg of the Arun valley (Photos 84, foreground, ××; 86↓↓). These moraines were walked, sampled and mapped. The two upper moraines have retained all, or part, of their particular wall forms. Together with the valley slope the moraine ledge further up the mountain continues to form a bank-basin (Photo 85↓). Facing up the main valley, Photo 86 shows that the *bottom* lateral moraine wall of the three on the orographic left-hand (↓ left) has been piled up by a *side glacier tongue located next* to the main valley glacier – probably during the later Late Glacial period. It was the side valley glacier tongue (Fig 43, No. 56), which, coming from the 6212 m high massif 1.2 km further N joined up from the E. The condition for this high location of the side glacier tongue is the *filling of the main valley* by the main valley glacier from S Tibet. It was still about 700 m thick at this time, and its left-hand edge extended up to c. 4300 m asl. At this time the ice of the main valley increasingly found itself in the *process of melting down*. Due to its comparatively very *substantial mass, however, it lagged* behind the *progress of back-melting shown by the side valleys*. This is a compelling explanation for the fact that the lowest tips of the tongues of the *short and steeply descending side glaciers,* though coming from great heights, as – for instance – the one under discussion, the maximum catchment area of which at 6200 m asl continues to be glaciated – had already *melted back* several hundred metres *higher* and terminated high above the main valley floors (here at 700 m above), when the *main valley ice* was still ending far more than 1000 altitudinal metres *further down* the main valley. To argue the other way round, this relationship is evidence of the continuing existence of *very substantial,* and therefore in their reaction much more inert ice masses of the Late Ice Age ice stream network in the border area from S Tibet to the Himalaya. The smaller masses of the side- and hanging glaciers, on the other hand, permitted a *rapid adaptation of their mass balance* to *the rising snowline* (ELA). The classification of main and side glaciers belonging to the *Late Ice Age* is convincingly suggested by *findings of lateral moraines,* since moraines of that kind could not be deposited *anywhere but below the snowline.* The ELA must consequently have been *above* 4760 m, ie the altitudinal position of the uppermost lateral moraine (Photo 84×, 85× and 86↓, the highest on the right). The lower lateral moraines, amongst them the one at 4300 m asl, which had been piled up by the side glacier tongue, belong inevitably to an ELA that had risen even further, suggesting the later Late Ice Age as the time of their formation. In the Main Ice Age the ice level (see above) was far above 4760 m (Photo 82 and 86– – – –), which is the reason for preserving only those flank

polishings on the triangular areas to far beyond 5000 m asl, but also for the absence of lateral moraines. In the valley chamber of the Kada settlement (Kharta, Karda or Kata; 28°07'N/87°20'E) the post-glacial Holocene *pebble floor terraces* are of exemplary distinctiveness for the middle Arun valley above the Arun gorge (Photo 86▼▼). There are two very marked *terrace levels* at about 25 m and 40 m above the present river level.

At the upper starting-point of the Arun gorge the *tributary glacier streams* of three large and more than 30 km long side valleys joined the Arun glacier and filled up the still 5 km wide main valley chamber with *glacier ice* (28°06'N/87°21'E; Fig. 43, No. 56). Though *narrow* and barely 2 km wide half-way up its flanks, the Arun gorge was the *only* exit route for the ice flow, thus causing the *ponding back of the ice*. The extent of the ponding-back was not completely compensated for by the greater valley gradient either (Photos 86 - - - -, 87 - - - -). These three orographic right-hand side valleys of the Arun are not only relatively long but, as a result of the considerable heights of their catchment areas, also contributed *major ice streams*. The valleys join the *largest contemporary* glacier areas of the Tibetan Himalaya (also known as the Inner Himalaya) N of the Mt. Everest group with their 6-10 km long valley glaciers, like, for example, the Karda glacier. From the E, ie from the left flank of the Arun valley, on the other hand, nothing but short, *steep hanging troughs* join up, contributing at most 5-7 km long Main Ice Age ice streams (Photo 87●). As shown in Photo 84, 86 and 87, there was an approximately *relief-covering glaciation* of the Main Ice Age (- - - -) in the area of the valley chamber above the Arun gorge, which is being considered here. The mountain which had been enveloped by the glacier coat as a typological part of an *ice stream network*, have been transformed by the ice into gently-shaped, ie *rounded rock ridges*. The rounded ridges reach up to altitudes of at least 5400 m, or 5680 m (Photo 84, 86 and 87 - - - -). The *ponding of ice* up-valley of the Arun gorge mentioned above, together with an ice level, or ice thickness, which has thus been raised even further, has thus been re-inforced by the Main Ice Age Karda (or Kharta) glacier, since the Kharta valley exit faces NE, and thus approximately in the opposite direction to the Arun valley, which faces S (28°06'N/ 87°20'E; Fig 43, No. 57). The principal Arun glacier was thus *held back* and *impounded still higher*. Here in the area of the mouth of the Karda (or Kharta) valley, flank polishing through further *triangular areas* and *rock polishings* with only a thin post-glacial drift cover are frequent and extend in parts so as to cover whole areas (Photos 86 and 87▲). The lower half of the Karda valley, as an *exemplary* side valley of the Arun valley, has been analysed in detail as to its *Main Ice Age glacial formation*. Photo 87 (+) shows one of the numerous moraines blocking the valley, which have been pushed out of the orographic right-hand side - ie in this case, southerly side valleys (Fig 43, No. 57). Corresponding *moraines* from the later *Late Glacial period* block the Karda valley at 28°05'30"N/87°12'E (Photo 88 +); 28°04'N/87°15'E (Photo 89 +); 28°04'N/87°16'20"E and 28°04'30"/87°19'E (Photo 87 +). These moraine walls, all of which show the same features of end moraines of pedestal moraine character, supplied samples of fine material (samples 7.10.89/2; 28.10.89/2 and 5; cf. Figs 29, 40 and 41). In accordance with the gneissic or granitic basic rock they contain a *high proportion of sand* (max. 80.68%) and only very *little clay* (1.2-3.8%). The best defined sedimentological approach to this material is the direct *macroscopic* one. The exposures consistently show large *polymict blocks* "swimming" in the fine material matrix, described above, apart from one another. Photo 87 (+), 88 (+) and 89 (+) show the perfectly preserved recent geomorphology at this and at higher lying *late Late Glacial local moraines* (Photo 90+), which contain *more and more rough blocks* (Photos 89, 90●) as the altitude increases, ie their *transport distance decreases*. The side valley moraines which have pushed into the main valley talweg of the Kharta valley are being *undercut* by the confined present-day river of the main valley (Photo 87 +). Tending to have been deposited at altitudes of more than 4000 m and up to 5300 m asl, all these local moraines *reshape* the picture of almost *complete valley-filling* and *total* glaciation of the relief. The flank polishings (Photos 88, 90 and 91 - - - -) are evidence of minimal Main Ice Age *polish boundary altitudes* of 4800-5200 m (Fig 43, No. 57) on the orographic left-hand slopes of the Kharta valley. On the valley flanks concerned there are next to no peaks towering noticeably above these flank polishings. The *angular, pointed peaks* scattered among the rounded ones have received their form from the post-Main Glacial flank polishing of the side glaciers as a result of slope *intersections* belonging to the *side valleys*. The immediate flanks of the Kharta valley itself, however, have been *polished* and *rounded* up to those peaks. This amounts to evidence for an ice thickness of 1400 m in the Kharta valley. In places where the Kharta valley is not blocked by local moraines from the side valleys, a *40-110 m outwash plain terrace* has formed, ie a terrace form that is constructed from glaciofluvial sander pebbles (Photo 88■■). The accumulation of this sander continued up to the later-Late Glacial period, and its dissection set in with post-glacial or Holocene times, ie some thousand years ago. The age of the pebble floor terrace can be estimated with the help of the *talus cones* which are implanted into its surface (Photo 88▼▼). Rapid high continental frost weathering has the effect of relatively very fast overlaying and reshaping of the *glacigenic U- and V-shaped valleys* (Photo 89■ and 91■) (cf. Trinkler 1932, p. 75; Granö 1910, p. 92; Merzbacher 1916). The *minimum thickness of the ice stream network* which found large-scale confirmation in the *concurrence of glacier levels* in the Arun and Kharta valleys (see above), is proved again by the *major transfluence pass* of the Tsao La (Tso La, 4890 m asl; 28°00'30"N/87°16'E) (Photo 92 and 93, No. 0). This pass enabled the S Tibetan ice or the icestream network of the Tibetan Himalaya to cross over into the area of the High Himalaya, the Karma valley in this case. The transfer of ice was diminished by the *lack of friction* in the glacier outflow towards the S through the directly descending, ie counter slope-free, Arun gorge only 12 km further E. This steep Himalayan gap was able to divert the ice of the Kharta valley much more *directly* than the Tsao La. Evidence of the *ice transfer* that took place nonetheless is available in relatively well preserved traces of glacial polish, like ice scour basins and thresholds (Fig 43, No. 58). Separated by trough thresholds, the ice-scoured basins in the bedrock rock bottoms are the containers of three largish, up to 1000 m long and 500 m wide, *lakes*. The glacial convex forms bear all the marks of *glaciated knobs* with preserved *rock polishing* and *glacial striae* in places (Photo 92▲, ↓↓ and 93▲ ↓). All these forms have been developed between 4600 m and fully 5000 m asl. In respect of their state of preservation, the *glaciated knobs* in the gneiss rocks are reminiscent of corresponding *indicators of inland ice and icestream networks* in the *upper reaches of Scandinavia's mountains*. This shows the influence of an *Ice Age glacier-feeding* which became progressively *much more humid and monsoon-induced* from here to the S. But the *lesser*, post-glacial *frost weathering* of this *wetter* climate contributes to this good state of preservation, too. Similar geomorphological indicators of a *glacier transfluence* from the Kharta valley to the parallel Karma valley to the S of it have been observed in the Kala La valley 11 km further WNW. In this case the ice transfluence took place by way of the c. 5300 m high Kala La (28°03'25"N/87°10'30"E). On the flank of the 6135 m high peak next to the transfluence pass *Ice Age flank polishing* extends to far beyond 5300 m. In common with many Ice Age landscapes, the area of the Kharta valley is subject to a disfiguring roughening by numerous block glaciers. They are *permafrost phenomena* which have formed from the *end moraines* in the exits of smaller hanging side valleys (Photo 89● and 90↑↑). The *larger proportion of rough blocks* of bedrock gneiss weathering in this rough block way is an additional reason for the *formation of block glaciers* from moraines of *blank ice glaciers* (Photo 90, foreground, left hand ●).

Beyond, ie S of, the intermediate valleyshed between the Kharta and the Karma valley there is another, almost *entirely glacially shaped* mountain landscape with comparatively short recent glaciers. S of the Tsao La (Photo 94, No. 0) *glacially-scoured* short troughs, separated from one another by pointed *nuntakr* and polished *transfluence passes*, meet in the *complete valley trough* of the "southern Tsao La valley" (Photos 94, 95 and 96).

The *trough head* shows classic *confluence steps*, across which the hanging side trough valleys feed into the main trough (Photo 94●●); Fig 43, No. 58; 28°00'N/87°15'E). Meanwhile somewhat buried by drift (↗) from later rock (■), this *confluence step* is 400 to maximally 600 m high. Here, too Late Glacial to Neo-Glacial moraines in the exit area of the side valleys have been transformed to block glacier flows with a Holocene permafrost core (Photo 94+). In many places, periglacial sheets of creeping waste dislocated metre-thick ground moraines, which are pierced by bedrock convex forms of glaciated knobs and smoothly polished rock thresholds (Photo 94▲). The polished peaks (nunatakr) at the valley head are between 5000 and 5400 m high (Photo 94▲▲), and approximate indicators of the *mean* Main to Late Glacial *glacier surface* (- - - -), which ran *somewhat below*. Being at about 4000 m (4068 m, when including the drift floor) asl, the bottom of the trough must be assumed to have been polished by a *1000 m thick ice cover*. The reason for the failure of the ice to become yet more substantially thicker is the topographic situation of the very steep valley gradient southward through the Himalayan main ridge and down into its S slope. The main Ice Age ice was consequently able to flow down steeply, again following straight along the "southern Tsao La valley" (Photos 95 and 96), and subsequently the Karma valley. This allowed the glacier ice to overcome a distance of only 14–15 km from a valley floor at 4000 m or the bottom of a short trough at almost 5000 m to a valley floor altitude of merely 2200 m asl, where the glacier reached the bottom of the Arun gorge in the confluence area of the Karma valley behind a 200 m high *confluence step* (27°51'45"N/87°26'E; Fig 43, No. 59). In the Arun gorge the *confluence* with the Arun glacier took place. The latter descended *directly* from the north; it has been possible to reconstruct its extent in the area which begins above the c. 15 km long gorge (see above).

11. The Main to Late Ice Age Glaciation of the Karma Valley (Kangshung Valley) on the E-Slope of the Mt. Everest Massif with its Continuation in the S-Slope of the Tibetan Himalaya and the N-Side of the High Himalaya (27°54'–28°04'N/ 86°55'–87°17'E)

Apart from the *indicator forms of glacigenic erosion*, *lateral moraines* in *high places* also provide reference pointers to prehistoric glacier thickness, like the lateral moraine ledge at 4500–4650 m on the orographic right-hand in the "southern Tsao La valley" (Photo 95▲▲; Fig 43, No. 58). There are two *generations* of *moraines* to provide evidence of a c. 600 m thick ice filling the valley in the "southern Tsao La valley". With a substantially deeper incision, reaching down to 3780 m, the bottom of the main valley (Photo 95↓ and 96), the Karma valley, must have simultaneously have contained an 800 m thick valley ice stream. Evidence of this exists in the *mountain spur or triangle location* of these moraine walls, which conform to the position of the *medial moraines*. Corresponding lateral moraine terraces have also been preserved in the Karma valley near the mouth of the "southern Tsao La valley" (Photo 97▼). They are on the orographic left-hand of the "southern Tsao La valley" and fall away directly and immediately from there to the talweg of the Karma valley. To be more precise: there are at least three lateral moraine terrace levels at about 350 m (Photo 97, IV), 490–510 m (III) and c. 650–700 m (II) above the talweg. The main valley bottom proper, consisting of bedrock which was polished during the Ice Age, could well have been some decametres below the present talweg, which lies in loose rock (Photo 96 and 97↓).

Sample 25.10.89/6 (Fig 39) was taken from the body of the 490–510 m lateral moraine (III), fully 50 m below the *moraine terrace surface* at 4240 m asl (Photo 95 ↘). On the

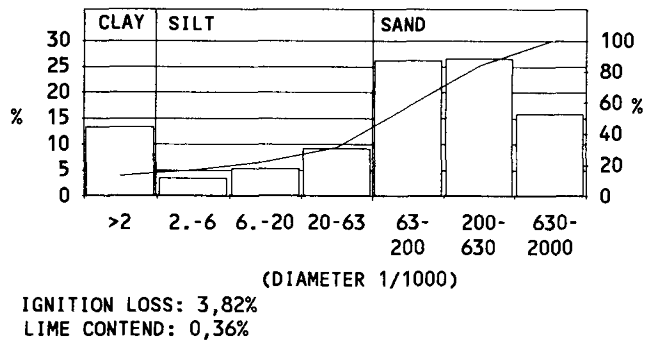


Fig 30 10.10.89/2, Late Glacial lateral moraine on the orographic left-hand in the Karma valley, 4580 m asl; a moraine which had been piled up from a N side valley; Fig 43, No. 58; Photo 98 (◉ above); sand 68.6%, silt 18.0%, clay 13.4%.

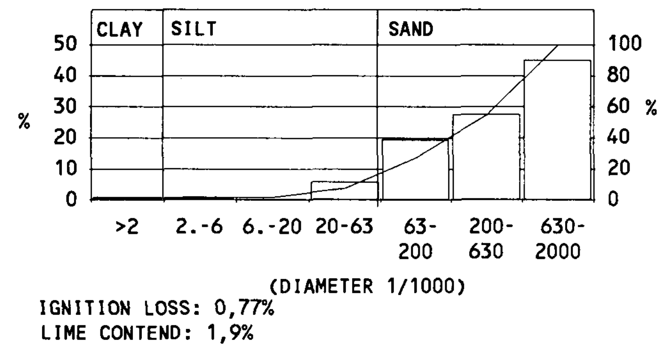


Fig 31 17.10.89/1, 5400 m asl, decimetre-thick upper moraine of the Kangshung glacier; Fig 43, No. 60/61; Photo 103 (◉), sand 92,2%, silt 6.8%, clay 1%.

basis of the considerable proportion of granitic sand it shows once again, the typical *preponderance in the sand fraction* (with 83.28% an extremely high proportion) and at the same time an extremely small *clay component* of only 0.6%. This substrate has been glacigenically sedimented *in situ,* and has not gone through a secondary process of slope erosion or solifluction resulting in this arrangement. It is the *sandiest* Late Glacial moraine sample to have been taken. Moraine samples taken further up the Karma valley, and also from the orographic left-hand and from the Late Glacial period (10.10.89/2; 24.10.89/2; 25.10. 89 2/4) vary from 43.7% to 68.6% sand, with the proportion of clay accordingly rising to 3.3–13.4% (Fig 30 and 36–38). The general reason for the *high proportion of coarse material* in these moraines is, besides the granitic (coarsely crystalline) parent rock, the large proportion of prehistoric *upper moraine material* in the composition of the lateral moraine. Samples taken for test purposes from the upper moraine of the present-day Kangshung glacier, which is the remnant of the prehistoric Karma valley glaciation, provide a clear answer. Samples 17.10.89/1 and 18.10.89/1 (Fig 31 and 32), though presenting the same coarse-crystalline petrography, show a *prevalence of sand* of 92.2% and 86%, with only 1.0% and 0.4% of clay. The longer the glacial drift is, or has been, transported as upper moraine on top of the ice stream, the more clay, and even silt, has been taken away by *meltwaters,* which are *continuously active on the ice surface.* The particular, directly ice-borne or *supra-glacial outwash* transportation of the drift is decisive in the locally *varying* proportion of sand and clay in the same moraine body.

Relatively *higher lateral moraine terraces* (ie terrace I) than the maximally 650–700 m high terrace (II) are not preserved in the Karma valley and have probably *never existed* there either. *Rock roundings* and *polishing forms,* however, reach up much further (Photos 97, 98▲). This proves that the *point of reversal* in the *glacier mass balances* has been beyond 700 m above the valley floor in the area of the confluence of the "southern Tsao La valley" (Fig 43, No. 58). When the *glacier surface* was higher, it was *above* the

Fig 32 18.10.89/1, 5350 m asl; surface moraine of the orographic left-hand sub-stream of the Kangshung glacier, which is descending from the Rapui La; the thickness of the moraine varies from decimetres to metres here; Fig 43, No. 60/61; sand 86%, silt 13.6%, clay 0.4%.

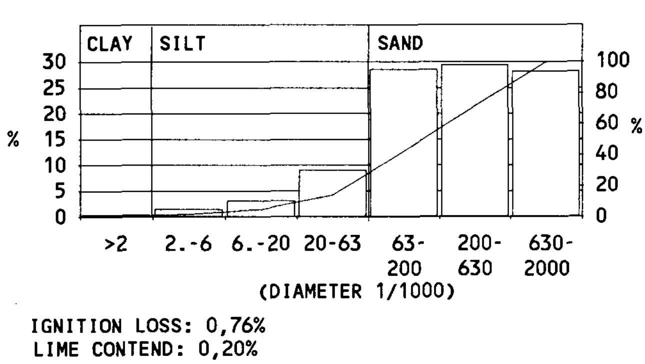
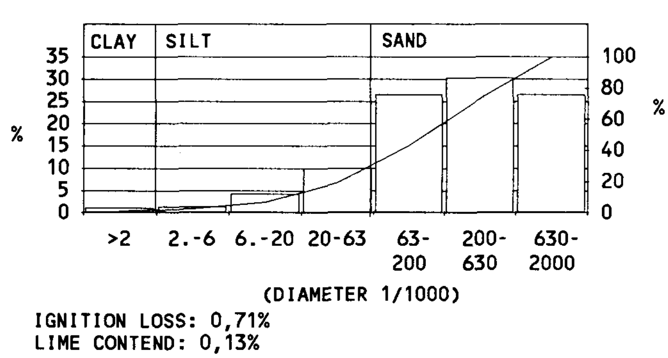


Fig 33 18.10.89/4, orographic left-hand lateral moraine source of the present Kangshung glacier, 5400 m; Fig 43, No. 60/61; sand 83.32%, silt 15.64%, clay 1%.



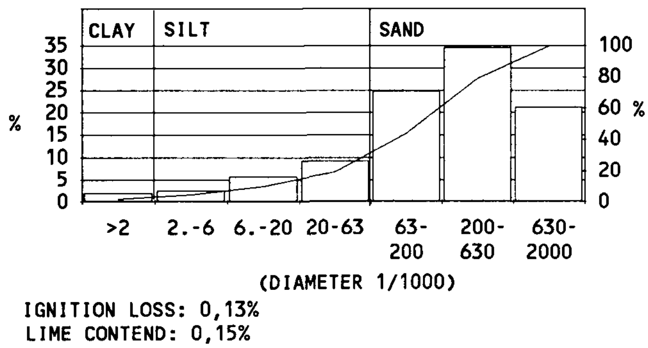


Fig 34 21.10.89/1, 5620 m, glacio-fluvially outwashed moraine material in the orographic left-hand flank of the Karma valley in the foreland of a cold hanging glacier in the S-exposition of the Tibetan Himalaya; Fig 43, No. 60; Photo 105 (●); sand 80.5%, silt 17.5%, clay 2%.

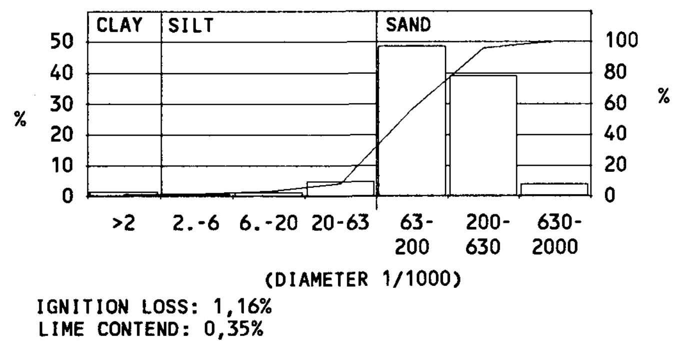


Fig 35 23.10.89/1, 5020 m asl, paraglacial soils (marginal *sandurs*) on the left bank valley of the Kangshung glacier; Fig 43, No. 58–60; Photos 102 and 104 (●); sand 91.7%, silt 6.9%, clay 1.4%.

ELA. For that reason it was *not possible* for *higher moraines* to be deposited. As the level of the snowline in the upper reaches of the Karma valley must have remained approximately constant for physical-climatic reasons, the prehistoric lateral moraine terraces of the same *absolute* altitude must become *more and more recent up-valley.* For this reason the *lateral moraine terraces* with the *greatest relative altitude* above the valley floor are found furthest down the valley in the Karma valley (see above) (Photos 97, 98 II). Up-valley, the more recent lateral moraine terraces at the corresponding level of about 4480 m asl have been preserved in an accordingly noticeably *fresher* state – though they only reach a relative height of c. 500 m (niveau: Stadium III), – as, for instance, in the form of a series of small lateral moraine ridge walls (Photo 98↓↓) which are normally the first ones to be eroded or distorted past recognition (27°59'N/87°11'E; Fig 43, No. 58) (Photo 98, III).

Fresh *side glacier moraines* coming from the side valleys on the orographic left-hand have been superimposed upon the older, Late Glacial, ie the highest, *lateral moraine terraces* of the main valley (Photos 97, 98, 99+), suggesting *overthrusts* of the side glacier across the main glacier. This seems particularly likely in the view of the absence of frontal moraines and pedestal-like ground moraine ramps *break-off* more or less exactly at the left edge of the main valley, or are *exposed to the atmosphere.* It is a matter of at least three side valleys (parallel valleys), the exits of which in the confluence area with the Karma valley contain these *overthrust moraines* (27°58'40"N/87°12'20"E, Photo 97 +; 27°59'N/87°11'35"E, Photo 98 +; 27°59'10"N/87°11'E, Photo 99■) (Fig 43, No. 58). Since the *upper catchment area* of the Karma valley (in the area of the recent Kangshung glacier) is 3000 m higher than the glacier catchment area of the three side valleys as the result of the formation of Mt. Everest, Lhotse, Peak 38, and Makalu (all of which are around, or far in excess of, 8000 m high), but also because of *more glacier-favourable E exposition* of the Karma main valley glacier, the Karma valley *must* have continued to be filled with glacier ice at the time when the S-facing side glaciers *still reached the main valley,* so that they *had to thrust* themselves upon the Karma glacier. On the hanging

Fig 36 24.10.89/2, c. 4650 m orographic left-hand lateral moraine in the area of the confluence of the Late Glacial Karma Changri glacier with the Karma glacier (Kangshung glacier), with cover-sands of a marginal *sandur;* Fig 43, No. 58; Photo 101 (●); sand 54.4%, silt 38.7%, clay 6.9%.

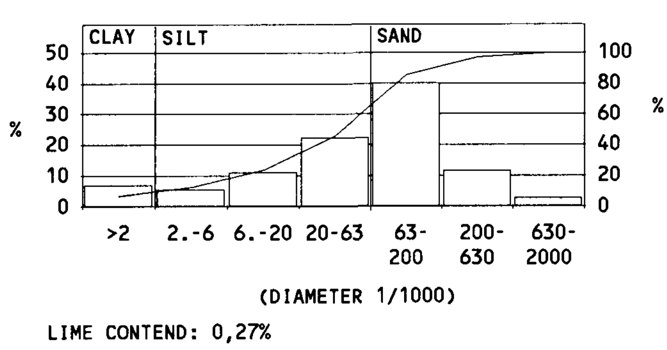
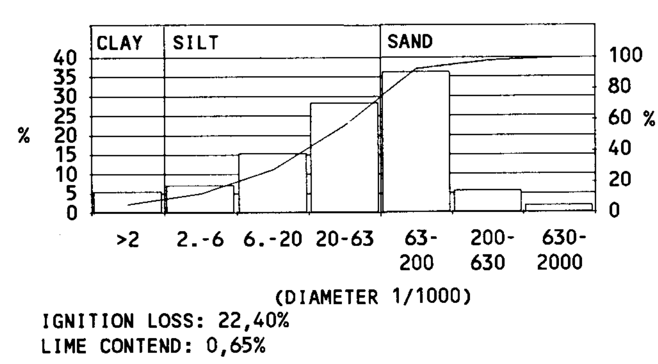


Fig 37 25.10.89/2, 4480 m asl, material of the orographic left-hand lateral moraine terrace; Fig 43, No. 58; Photo 98 (● below); sand 43.7%, silt 50.8%, clay 5.5%.



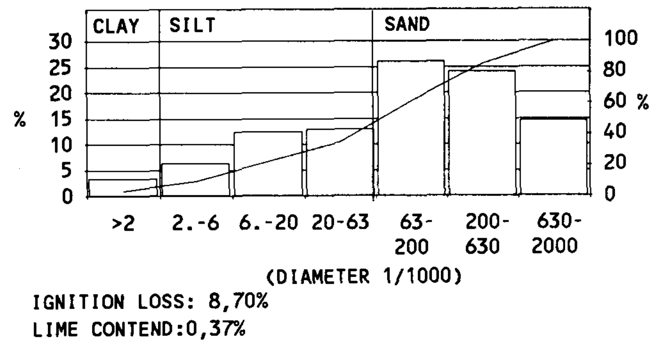


Fig 38 25.10.89/4, 4470 m asl, orographic left-hand side lateral moraine down valley from Fig 37, in contact with the lateral moraine spur of a side valley (Late Glacial); Fig 43, No. 58; Photo 97 (◉); sand 64.8%, silt 31.9%, clay 3.3%.

valley floors the retreat stages of these side valleys have left *moraine lakes* behind in positions of *tongue basin lakes* (Photo 99↓).

The 5647 m high mountain group that joins the side valleys in the N shows a *present-day glaciation of its slopes (Photo 100●●)*, and is characterized by an *alpine, prehistoric glacial landscape* with hanging short troughs and corries along with round-polished discordant junctions and confluences, polished thresholds and glaciated knobs. The lower intermediate valleysheds are also rounded (Photo 99▲), whilst the higher ones have undergone glacial *sharpening* (Photos 99 and 100▼). In this section of the valley the orographic right-hand flank of the Karma valley only contributed very *steep hanging glaciers* from the 5803 m peak to the ice stream in the main valley (Photo 100 ↓).

Evidence of the climatic vicinity of the Karma valley floor to a *prehistoric glacier filling* is provided by the numerous glaciers which continue to reach the valley floor *to this day*. The one to flow down the furthest is the fully 14km long valley glacier from the eastern flanks of Makalu (8481m) and Chomo Lönzo (7804 m) (Photo 96■; Fig 43, No. 59). Completely covered by upper moraines, its tongue ends at 3580 m - about 650 m *below* the local *climatic timber line. Above* the glacier tongue *dams back* recent *pebble floor sediments* in this Karma valley chamber (Photo 96♦). The Kangdochung glacier and the Kangshung glacier (Kangxung glacier), too, reach the Karma valley floor, and that at c. 4300 m and 4500 m asl (Photos 101■■ and 102■; Figs 43, No 58). They flow down from the Chomo Lönzo NNE- flank (7565 m) and from the E-face of Mt. Everest (8848 or 8874 m), as well as from the NE-wall of Lhotse (8501m) (Photo 103). They, too, are completely covered by upper moraine; in 1989 they were in the process of *recession* (Photos 100■ and 102■).

Taking up a *great deal of room* over the entire longitudinal-and cross-profiles of the valley with their enormous volume, the Late Glacial, Neo-Glacial and even the historic *moraine deposits* in the Karma valley are characterized by their position along the orographic left-hand valley flank (Photos 104♦, 102♦; 100 V and IV; 98+, II and III; 97+, IV, III and II). It is the N side of the valley, which, facing S is exposed to more intensive *solar radiation*. Presently, as well as in prehistoric times, an *ablation valley*, which has become progressively wider as the glacier level fell, is gradually being *infilled* with moraine sediments (Photos 101♦; 102♦; 104♦). The orographic right-hand valley was and continues to be in the *radiation shade* of the very high and steeply descending main ridge of the Himalaya; this is the reason for the *valley edge of the glacier* having been immediately - ie without intermediate lateral moraine - adjacent to the bedrock valley flank. There are now four glaciers on the orographic right-hand flowing from the N flank of the High Himalaya (Photos 101■; 102+) and nine valley and hanging glaciers lying on the left-hand Karma flank in the wider sense (Photos 101●, 102○), and flowing from the S flank of the Tibetan Himalaya. The side valleys containing these present glaciers are connected with the uppermost and most up-valley 25 km of the Karma valley, so that in Neo-Glacial times (Nauri stadium V, Kuhle 1987d, p. 205, Tab 2; 1986b, p. 454, Tab 4) the majority of these side valleys were linked to the Kangshung glacier

Fig 39 25.10.89/6, 4240 m asl, moraine triangle in the confluence area of the "southern Tsao La Valley" with the Karma valley; Fig 43, No. 58/59; Photo 95 (◉); sand 83.28%, silt 16.13%, clay 0.6%.

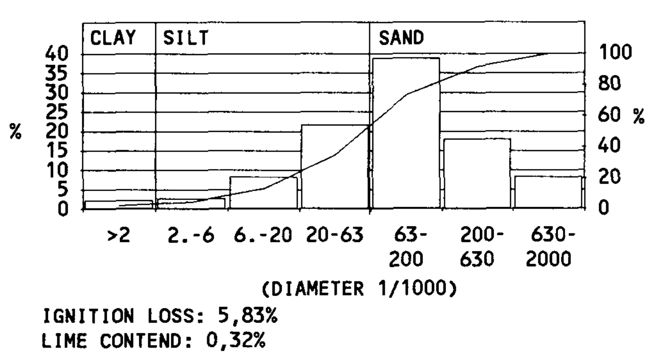
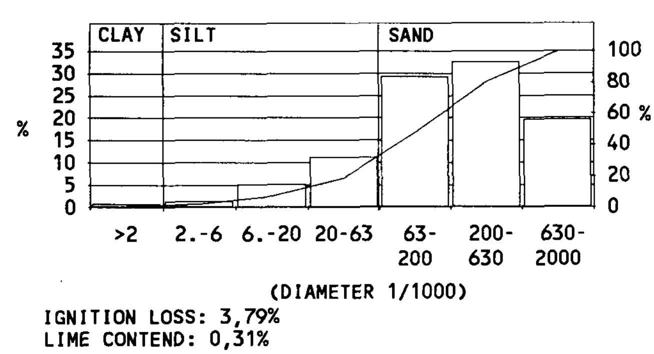


Fig 40 28.10.89/2, 4470 m asl, orographic right-hand flank of the Karda (Kharta) valley c. 13 km down-valley from the present Karda glacier; sample from the lateral moraine crest-line (Late neo-Glacial); Fig 43, No. 57/58; Photo 91 (◘); sand 65.2%, silt 32.6%, clay 2.1%.



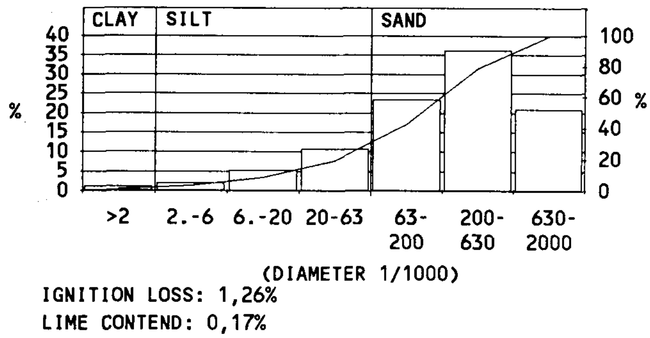


Fig 41 28.10.89/5, 4100 m, Late Glacial frontal (pedestal) moraine in the area of the confluence of the N Tsao-La valley with the Karda valley, 16 m above the Karda *talweg;* Fig 43, No. 56/57; Photo 90 (◉); sand 80.68%, silt 18.1%, clay 1.2%.

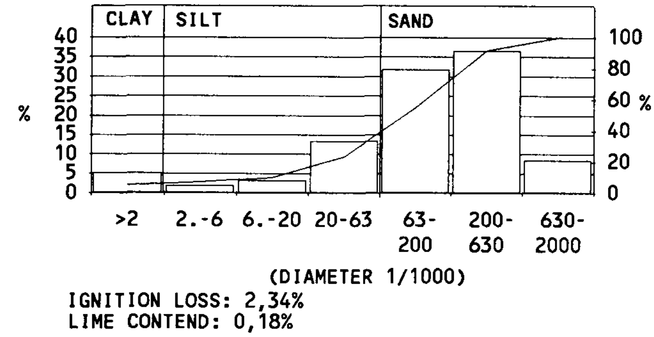


Fig 42 3.11.89/1, ground moraine in the large valley SE of the Nyainqentanglha, c. 4200 m asl; Fig 43, No. 19; Photo 24 (◉); sand 76.7%, silt 18.2%, clay 5.1%.

(Karma valley glacier). In the course of historic glacier advances three glaciers from the S-flank of the High Himalaya still reached the main glacier; ELA depressions of only 50–100 m were sufficient for this (Fig 43, No. 58). The *Holocene main valley junction* of the Karma Changri SE glacier is particularly impressive; from a catchment area of a maximal altitude of 6382 m (or 6437 m) in the area of the left-hand Karma valley flank it flows down to 4400 m asl. This c. 12 km long glacier ends at a horizontal distance of 1900 m from the main valley talweg. Photo 100 (IV, V) shows the junction of the "Karma Changri valley" and the corresponding *lateral moraines* on the orographic left-hand (Photo 101, IV and V). In the foreground of Photo 100 (■) the Kangdoshung glacier is visible. In historic times it still formed a *common glacier tongue* with the Kangshung glacier (cf. Photo 102■), and flowed down to the junction with the "Karma Changri valley" mentioned above. Metre- to decametre-high end moraine walls, as well as ground moraine hills forming a shallow tongue basin - which is covered with a still irregular vegetation pattern - are evidence of it (Photos 100X; 101X). Following on behind and above are the *Holocene lateral moraine terraces* of the Karma Changri glacier (Photos 100 IV, V; 101 V, IV). They were deposited at three still *angular lateral moraine terrace levels* (28°N/87°10'25"E) at the time of the last *confluence* with the Karma main valley glacier (Kangshung glacier). The altitudes of the lateral moraine levels range from 4550 m (Nauri stadium V) to 4600–4660 m (Sirkung stadium IV) (Fig 43, No. 58; Photos 100 and 102, IV-V). A fourth one reaches 4800 m (Dhampu stadium III), and is noticeably *older,* and has for this reason undergone considerable *solifluidal* rounding (Photos 100 and 101, III) (cf. Kuhle 1982a, Vol. 1, pp. 154–168). Sample 24.10.89/2 (Fig. 36) shows the composition of material in the *fine material spectrum.* Here, too, the *proportion of sand* (54.4%) is to be explained by the large proportion of granitic sand in the granite parent rock *and* by the glaciofluvial morphodynamics on the ice margin (formation of bank sanders in the basins on the banks; paraglacial shifting of materials). The relatively high proportion of silt (38.7%) as well as the clay proportion (6.9%) are evidence of the *contact* the sampling locality had *with ice,* which is equally proved by the *proportion of scattered coarse blocks* and the *morphology of the moraine crests* (Photo 101↓↓). The following samples concern the same *geomorphologically systematic* context; they were taken in the upper Karma valley on the orographic left- hand area of the Kangshung glacier and the foreground of adjacent hanging glaciers to the N. They are the samples 18.10.89/4, 21.10. 89/1 and 23.10.89/1) (Fig 33–35). The first sample was taken from the orographic left-hand *lateral moraine crest,* 150 m below the present-day Kangshung glacier surface (Photo 105, left), thus keeping the glaciofluvial influence down as far as possible. Nonetheless, the proportion of sand is 83.32%, with that of clay reaching a mere 1%. This is contrasted by a proportion of 80.5% sand and, after all, of 2% clay from the second sample, which came from the *glaciofluvially-*affected fore-field of an orographic left-hand hanging glacier (Photo 105↓, right). This difference in spite of a concurring petrography of the parent rock is explained by more *effective pre-sorting* of material transported by the Kangshung glacier as *upper moraine* (cf. Photo 104●, right). By contrast, the small hanging glacier, being a blank ice glacier, has *no upper moraine* (Photo 105, foreground). If the material of the lateral moraine of the Kangshung glacier undergoes additional glaciofluvial *washing through the formation of bank sanders,* and thus washed fluvial sedimentation in the bank valley, the proportion of sand is increased to 91.7% at the expense of the proportion of silt (6.9%). (Sample 23.10.89/1, Fig 35; location - see Photos 102 ⌒ and 104).

After these remarks concerning the more recent glacier history of the Karma valley since the Late Glacial period, which is characterized by moraine deposits (which stand for an already high level of the post-Main Ice Age snowline in this valley, since they could otherwise not have been deposited in the course of the upper 32 km of the Karma valley (Fig 43, No. 58), attention will now be drawn to the traces of *at most prehistoric,* ie *Main Ice Age* glacier cover. Piled up to more than 4900 m asl (Photos 101 and 100 II; 99

II; 97 II), and up to 800 m above the valley floor of the Karma valley the *latetral moraines* which have been deposited the *highest*, and therefore the *earliest*, are already evidence of *ice thicknesses* of more than 800 m. They also show convincingly that the snowline must have been above 4900 m during the time of this thickness of the valley glacier. *At present* the *climatic snowline* in the Karma valley runs at about 5650 m asl (N-exposition: 5500 m, S-exposition: 5800 m). This permits the assumption that during the sedimentation of the highest lateral moraines in the Karma valley, the snowline was depressed by about 700 m (Taglung stadium II, after Kuhle 1982a, Vol. 1, pp. 155–156). That is a *typical Late Glacial value for the snowline depression*, which has reached little more than *half* the *Main Ice Age* ELA depression (c. 1200–1500 m) (cf. Kuhle, idem, pp. 150–152; 1990a, pp. 418–421, Fig. 9). In the Kangchendzönga massif (Tamur valley system) fully 100 km to the E, the author was able to find evidence of a *Main Ice Age depression of the snowline* even amounting to 1660 m down the S-slope of the Himalaya (Kuhle 1990a, p. 420). During this expedition in summer 1989, however, it proved impossible to define any Main Ice Age ELA, as the team was unable to reach the end moraines of the Arun glacier they had expected to encounter beyond the border with Nepal approximately at about 1000 m asl. This will be left to a future expedition to the S- and E-flanks of the Makalu massif from the Nepalese side. This *gap in the information* can, however, be more or less overcome by comparison with known altitudes of ice margin positions in *adjacent areas*, where the lowest ice margins during the *Main Ice Age* occurred between 890 and 1200 m asl. The altitudes calculated for the snowlines of the Central Himalayas from these figures are given as 3900–4300 m asl (Kuhle 1980, p. 246; 1988a, p. 458, Fig. 2, p. 492; 1990a, p. 420).

The conclusion formed by analogy from the Karma valley area under discussion is that a Main Ice Age ELA ran *below*, and further down-valley, *at* the *level of the valley bottom*. A snowline that had been depressed so *far* (down to the valley bottom) into high mountain relief, *must* have led to the *filling* of the relief with glacier ice. With *maximal glacier feeding* by *primary snow precipitation* (because of the great altitude of the glacier surface) throughout the year the *altitude of the surface* of this prehistoric *ice stream network* was dictated by its *run-off velocity*. It depended on the gradient of the valley bottom and the *breadth*, or *spaciousness* of the *valley cross-profile*. As the Photos 100, 97 and 96 show, the Karma valley becomes progressively *narrower* as the *valley bottom* becomes more *deeply incised* further down-valley. This resulted in a Main Ice Age *glacier ponding* in the upper, 4 to 7 km wide valley chamber (breadth of valley bottom to breadth of cross profile at half the height of the profile) which had been linked to much *more widely ranging glacier areas* by way of side valleys (Photos 102, 104 and 105). *Back-ponding* or *retarding* of ice run-off did occur in the Karma valley, which is a longitudinal valley, in the almost *right-angled area of the confluence* in the gorge-like and narrow Arun valley (Fig 43, No. 59), which is the main drainage and a transverse valley at the same time. In the lower part of the Karma valley, the maximal *Main Ice Age glacier level* can be approximately reconstructed with the help of clear *remnants of polished ledges* (▲), with rather imprecise *polish boundaries* (Photo 96 - - - -). These orographic right-hand *flank polishings* reach from the valley floor at 3560 m up to at least 4800 m asl. On the orographic left-hand they reach an altitude of c. 4725 m in the same valley chamber (27°56'–58'N/87°13'–14'E; Photo 97 - - - ; Fig 43, No. 58/59). In this area the form of the valley alternates between a flat-bottomed V-shaped valley and a box-shaped trough valley with pebble floor. According to the omni-visible *flank polishings* (Photos 96, 97, 98▲), even the profiles of V-shaped valleys which were filled with an at least 1240 m thick valley glacier ice in prehistoric times, are primarily glacially-shaped profiles, as they are typical of steep valley floor gradients and the correspondingly greater proportion of tractive power within the glacier against the existing pressure (cf. Visser 1938, Vol. II, p. 139; Kuhle 1983a, p. 154 et seq.). Up-valley trough profiles (Photo 97 and 100) tend to be steep on one side (on the S flank) and on the other are blocked by Late Glacial lateral moraines. The talweg is correspondingly *assymetric*, and runs in a cut past *present talus cones* and- *slopes* (Photo 97 and 100▽▼). The *further up-valley* one searches for flank polishings and the more recent they become, because they are in still glaciated valley profiles, the *poorer*, ie less distinct in the state of their preservation (Photo 102+) they are. This applies especially to the *very high* and still glaciated flank segments on the right of the Karma valley (Photo 102 and 104▲, and above all to *areas with steep flanks* (Photo 105+). In both cases the *denudation of slopes* and walls is forced, and has the effect of rapidly obliterating the glacier polish.

The highest prehistoric polish levels can therefore be reconstructed best with the aid of the flatter, left-hand valley flank, although they, too, only allow minimum heights of the Ice Age glacier surface to be calculated. The left-hand flank of the Karma valley, N of and above the Kangshung glacier had been totally covered by glacier ice up to at least 5900 m asl. Covered with *sheets of ground moraine*, or just with a *scattering of rough morainic blocks*, the *rounded* and *polished rock ridges* and *glaciated knob forms* in the gneiss are evidence of this; their peaks (from W to E) are at 5730 m, 5870 m, 5742 m and 5800 m, 5897 m and 5842 m asl (Photo 104 and 105↓↓↓; Fig 43, No. 60/58; 28°–28°01'N/86°59'–87°03'E). The glacier filling up to altitudes of more than 5900 m asl is particularly strikingly displayed (Photo 104▲), by wide-ranging polished and moraine waste covers overlain upon mountain ridges from the observer's perspective on the present-day Kangshung glacier surface at 5200-5300 m, or when moving from the orographic left-hand sub-recent lateral moraine crest of this glacier up into the left-hand valley flank. In places the ice level has most likely been around and above 6000 m; towards the S *transfluence passes* (Fig 43, No. 60) steered it over into the S slope of the Himalaya. The prehistoric ice in the vast and even now largely glaciated level between

Karze (6550 m) in the N, Mt. Everest and Lhotse (8848 or 8874 and 8501m) in the W and Peak 38 (7590 m), Pethangtse (6738 m), the Makalu structure with its N pre-summit, the Kangshungtse (7640 m), as well as the Chomo Lönzo N-summit (7565 m) in the south *communicated* with the *S Tibetan ice stream network,* which was linked to the Kharta (Kadar) valley in the N (cf. Photos 105, 104 and 102). The ice had a *considerable influx* from the flanks of the high peaks mentioned above. At the same time, however, it was limited by the *direct overflow* of ice into the Himalayan south-slope. The Barun valley (Fig 43, No. 60) drained this ice overflow steeply down to the S, thus keeping the ice thickness there on the low side. The 6107 m high transfluence E of the Pethangtse (Photos 104, No. 0 ; 102, No. 0) was overflowed as well as the 6177 m high ridge W of Pethangtse (Photo 105 left No. 0), though both these ice *transfluences* are likely to have had thicknesses of at most 100–150 m. Situated at the lower starting point of the Makalu NW-ridge still further to the E, the 6311m high pass is too far down-valley to have been overflowed. In spite of these transfluences into the Himalayan S-slope the Main Ice Age *glacier run-off* principally followed the Karma valley, so that another *ice-scour edge* formed on the orographic right-hand reaching up to an altitude of 5500– 5700 m (Photo 104 and 102▲). Higher up *forms resulting from polishing* are *covered* by present glaciation, and can no longer be ratified. Further indicators of the maximum ice level can be gleaned from the valley head which is formed by the Mt. Everest E-wall. This head wall towers 3300– 3400 m above the recent Kangshung glacier surface (Photos 103; 27°59'N/86°56'E; Fig 43, No. 61). The *Main Ice Age glacier level* (- - - -) was where the firn-covered wall pillars gradually merge with the moderately inclined slant of the firn ice of the peak above (Photo 103●), ie between 6300 and 6800 m asl. *Inter-glacial periods* always produced *linear avalanche erosion* as a result of cascades of ice cliffs, as they may currently be observed. It was avalanche erosion that carved the six marked wall gorges out of this flank (Photo 103●). The origins of the wall gorges, however, are *not* essential for the *reconstruction of ice levels,* in so far as their backward erosion causes them to retreat higher and higher from one inter-glacial to the next. The *wall-pillar heads* referred to above, on the other hand transmit the lowest preserved niveau of the ice level. The basis for such a reconstruction of the ice level is the *preserving effect* of the 800–1300 m thicker glacier deposit for the foot of the steep wall. The glacier in the valley *must* have *prevented* the backward relocation of the wall by such gorges.

These indicators for the *approximate* Main Ice Age minimum glacier level (which must have existed sufficiently long to imprint itself upon the relief as distinctively as described above) combine to produce the overall picture of the glacier cover on the E and NE slope of the Mt. Everest massif on the S edge of Tibet: approximately there where the largest glacier area of the region is now situated, the centre of which is over-towered by the 7230 m high Khartaphu that was once, during glacial times, piercing the glacier cover *like a nuntak,* a *cupola-shaped ice centre* of the time of the Main Ice Age existed. Linked on its E side to the area investigated in 1984 (cf. Kuhle 1988a pp. 505–507), this glaciation did *completely fill* a large part of the mountain and valley relief, in the centre even up to 6500 m. All the surrounding and adjoining valleys like the E-Rongbuk valley (present bed of the Rongphu Shar glacier and the E-Rongbuk glacier) and the two feeder arms of the Kharta Chu together with the present Kharta Changri glacier and the Kharta glacier as well as the numerous more or less directly linked side valley ice streams had been connected with one another up to and above their edges, or numerous transfluence passes through an *ice stream network system with communicating surfaces.* At the time of maximum ice levels a significant overflow of ice occurred, for instance, also from the Kharta valley across the 6084 m high Karpo (or Karbo) La and many *transfluence passes* joining in the E (Photo 105, No. 0 , right) like the above-mentioned Kala La (5300 m) and Tsao La (4890 m) into the Karma valley joining in the S. These *transfluences* moved into the steeper longitudinal valley which is linked to the south-slope of the Himalaya. Another corresponding *ice overflow* occurred from the E Rongbuk glacier valley across the 6548 m high Rapui La (Rabü or Raphü La, 6510 m) (cf. Kuhle 1988a, pp. 502, 503,Fig 67 and 68) and over into the Karma valley. Even nowadays some ice flows over from here into the catchment area of the Kangshung glacier (the recent Karma glacier) (Photo 105, No. 0). Interrupted or towered over only by individual very high and large mountain massifs of the High Himalaya, like the Mt. Everest-Lhotse-Makalu group (Photo 105 over - - - -), or by otherwise, if anything narrow ridge-sheds and crests, all these extensive Main Ice Age *glacier areas* were situated between 1300 and c. 2500 m *above the snowline.* At the same time the *climatic upper limit for glaciers,* which is now running at 7200 m asl, had been depressed to an altitude of about 6000 m (Kuhle 1986c, p. 161; 1986d, p. 344). It follows that the *Ice Age glacier feeding* must have taken place by way of the large flat or only gently sloping firn areas at 5500–6500 m, whilst avalanche feeding had largely receded at that time. This must also have applied to the very high Himalayan walls, which continued during Ice Age times to tower more than 2000 m above these firn areas. There was no glacier formation on these walls *above the upper glacier limit,* as the cold and therefore uncompacted snow cover kept being blown off without first being able to form hanging glaciers with ice balconies – as they are now found when climatic conditions are warmer. Whilst *firn and glacier feeding* is now completely dominating the glacier balance, it was the other way round at the time of the Ice Age. Primary snow precipitation provided all the feeding. Only in Late Glacial and Neo- Glacial times did the transition and change to present glacier feeding take place together with the upward advance of the snowline. At the same time, the thermal upper glacier limit continued its steady rise (Kuhle 1988e, pp. 545–567).

12. Synopsis of the Maximal Ice Cover in the Ten Areas under Investigation from Central to South Eastern and Southern Tibet

All the areas investigated during the course of the 1989 expedition (Fig 1, No. 9) bear a *close network* of traces from *large-scale and substantial ice covering* during the last Ice Age. It was possible to provide detailed evidence of the largely *continuous* ice cover extending from central Tibet (Tanggula Shan) to the S edge of the plateau (Namjagbarwa and Arun valley), ie to the Himalaya (see indicator map Fig 43). The provable maximum ice thicknesses vary between 1000 and 2000 m. The only area possibly *not entirely covered by ice* could have been the Tsangpo valley (Yarlung Zangbo Jiang or Dogzung Zangbo) between Nagamring and Chumba, that is the middle Tsangpo valley between c. 87° and 93°E at valley bottom altitudes of about 4200 to 3300 m asl. This if anywhere, could have been the dividing line between the central Tibetan ice area (I_2) and the S Tibetan ice stream network (I_3) (Kuhle 1988b, p. 583, Fig 2) the author described as *ice-free* in 1984 (1985a, pp. 40, 41, Fig 2 and pp. 43 and 48). This does not, however, apply to the whole of the lower Tsangpo valley which follows on from here to the E, as there was an up to 2000 m thick *ice-filling* stretching down from above the junction with the Nyang Qu (29°20'N/94°00'E; Fig 43, No. 37–45) and into the adjoining Namjagbarwa massif (Namche Bawar). It continued in a reduced form, even during the Late Ice Age, and that although the Tsangpo valley floor in this SE-Tibetan area falls short of the 3000 m isoline. But not only the *unambiguous indicators* in this area of the Tsangpo 'knee' up to about 100 km up-valley in the Tsangpo gorge, but also the traces of the more than 1000 m thick *side valley glaciations* in the Lhasa area (Fig 43, No. 22, 23, 46–51) speak for a *total glaciation of the entire Tsangpo valley,* though no corresponding terminal moraine could be found. In this case there would not have been a dividing line between the inland ice areas I_2 and I_3, but the *central Tibetan* ice would have been linked to the *South Tibetan ice stream network.* The complete glaciation of the Tsangpo valley would be the *only fundamental difference* to the picture of the *inland glaciation of the c. 2.4 million km² area of Tibet* which the author had reconstructed between 1984 and 1988. The areal gain achieved by this valley glaciation is, of course, almost negligible. Only an *at least 100–200 m lower course of the snowline* would thus suggest itself and be made probable.

The investigations of the 1989 expedition have resulted in further confirmations of a sub-tropical inland ice in the area under investigation (Fig 1, No. 9) in Tibet during the Last Ice Age. Evidence of this ice, which covered the entire Tibetan plateau, is the more compelling as it contains evidence of the most central areas of the highland. Vast ground moraine sheets with erratica as well as forms of glacier polish and glaciated knobs that rise up to 6000 m have been found. The entire wealth of glacial forms as shown in the scheme of Fig 2 was mapped in *unequivocal site relationships* (Fig 43). Details of it have been underpinned by *sample analysis,* and in its topographical association have been brought home in an inter-subject sense, by means of photographic panoramas.

Summary

The joint German-Chinese expedition for the *glacial-geomorphological reconstruction of the Pleistocene glacier cover of Tibet* was carried out in the summer of 1989. In the course of this enterprise, which took place in the period July–November, and moved from central to southern Tibet, large-scale *glacial-geomorphological sequences and series* were analysed at altitudes between 2700 m and 6000 m asl. The result is the reconstruction of a complete, ie *inland ice-like glaciation of High Tibet* between the Tanggula Shan at its centre and the Himalaya on its S edge. The Ice Age snowline (ELA) ran on this N–S profile almost everywhere *at or even below* the level of the Tibetan Highland. There is evidence of the inland ice *being at least 1000 to 2000 m thick.* The indicators upon which the evidence of glaciation rests are glacial-geomorphological key-forms of the erosion area, such as trough valleys, glaciated knobs, polished basins and thresholds, polished areas and polish boundaries and glacial striae, as well as those of accumulation areas like ground moraine sheets with erratic boulder clays, lateral moraines, erratic blocks on mountain flanks and on transfluence passes, and also the glacial sediment characteristics which were extracted during the course of sample analysis.

Glacier areas which the author had been reconstructing in High Asia since 1973, and especially the views on a *sub-tropical glaciation of c. 2.4 million km² in Tibet* during the Ice Age held by the author since 1981, both had to be confirmed afresh by the 1989 investigations. The following *enlarging modification* has, however, grown out of this: the findings provide evidence of a glacier filling of the *lower* Tsangpo valley no older than the *Late Ice Age,* so that a *total glaciation of the Tsangpo valley during the main glacial period* must by now be inferred. However, the author had hitherto been of the opinion that the Tsangpo valley E of 84–85°E had been free from ice.

Acknowledgement

The author wishes to thank the Deutsche Forschungsgemeinschaft (DFG), the Max Planck-Gesellschaft (MPG) and the Academia Sinica for the financial support of the German-Chinese joint expedition 1989. He also expresses his thanks to Frau Britta Bielefeld, Herrn Thomas Berger, Herrn Ulf Kossel, and Herrn Jens Walter for the sedimentological working-up of the samples, Herrn Andreas Flemnitz for the cartographic work, and Frau Sigrid Meiners for the co-operation in the collecting of samples during the expedition. My wife, Sabine Kuhle, prepared the photographic copies for printing.

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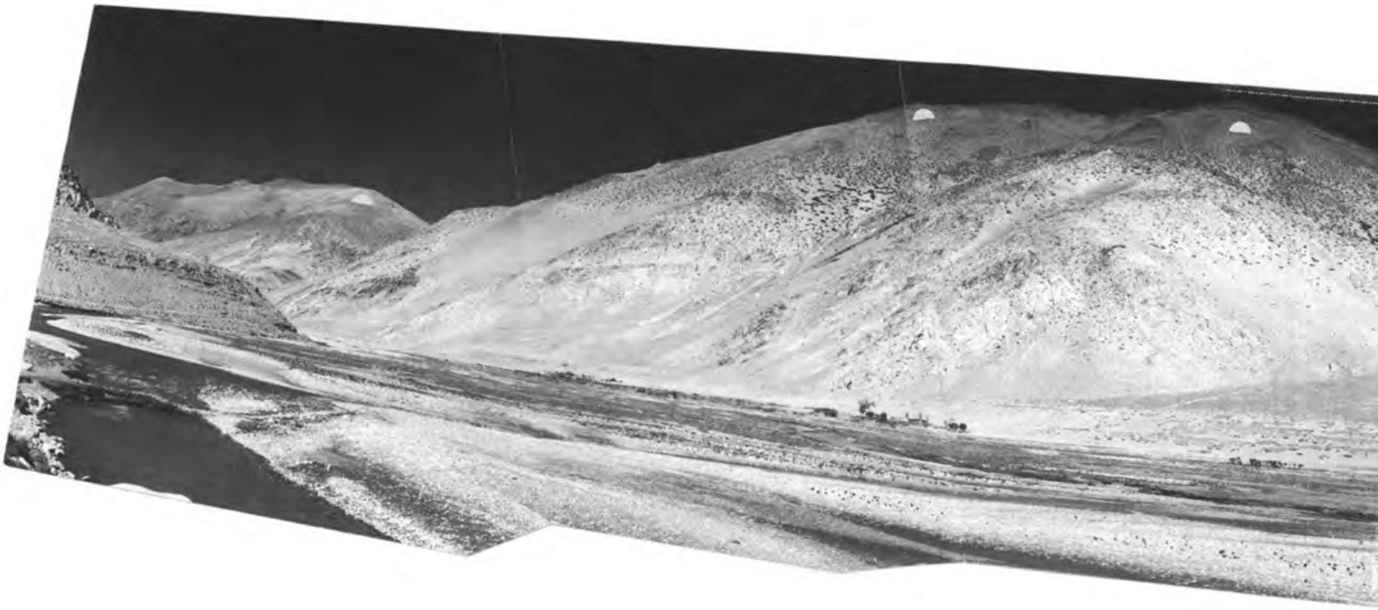

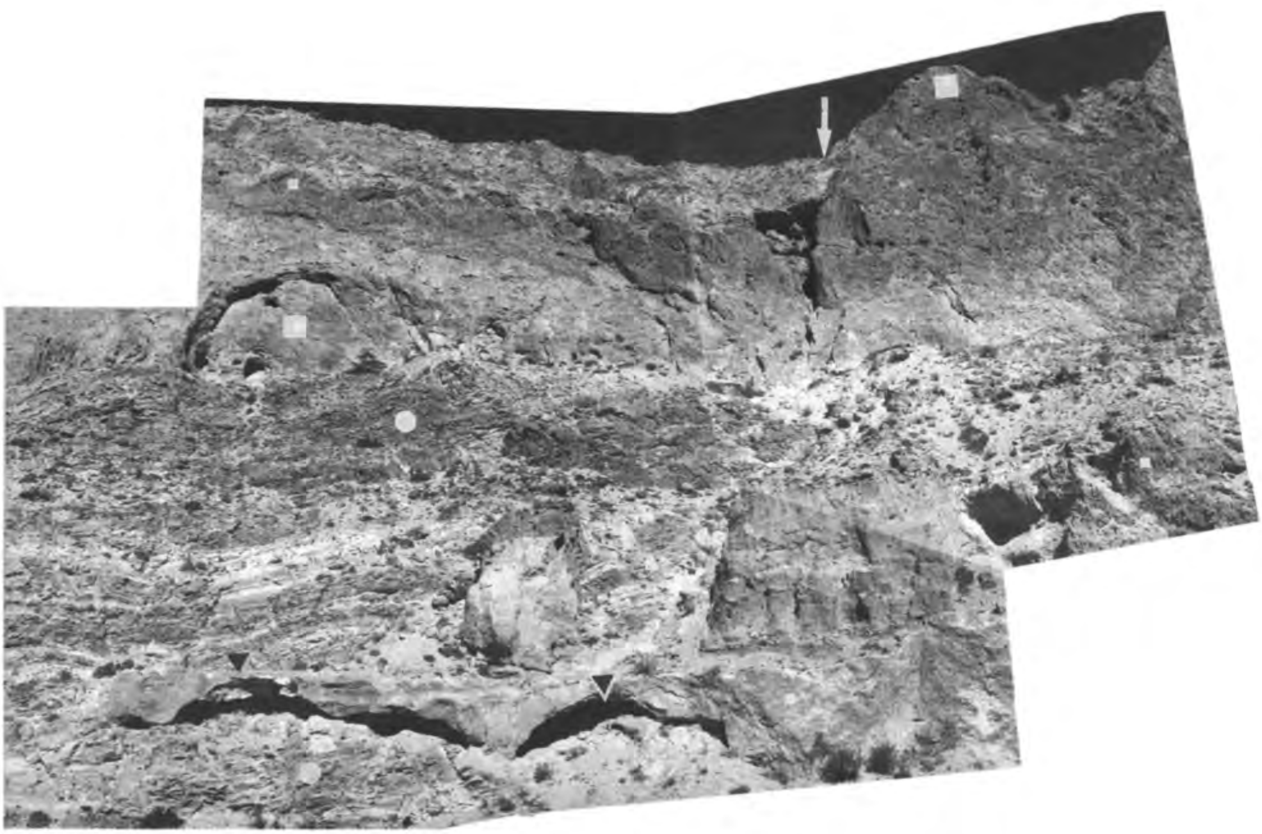

Photo 80
Decametre-thick ground moraine (lodgement till) (■) deposited in a sub-glacially cut section of a gorge in the lower Dzakar Chu (Bong Chu, upper Arun valley, or Pum Qu), the altitude of the *talweg* being 3950 m asl (Fig 43, No. 55). It is superimposed upon the strata of the bedrock gneiss (●). Recent erosion created natural bridges (▼). Photo: M. Kuhle, 29.10.89.

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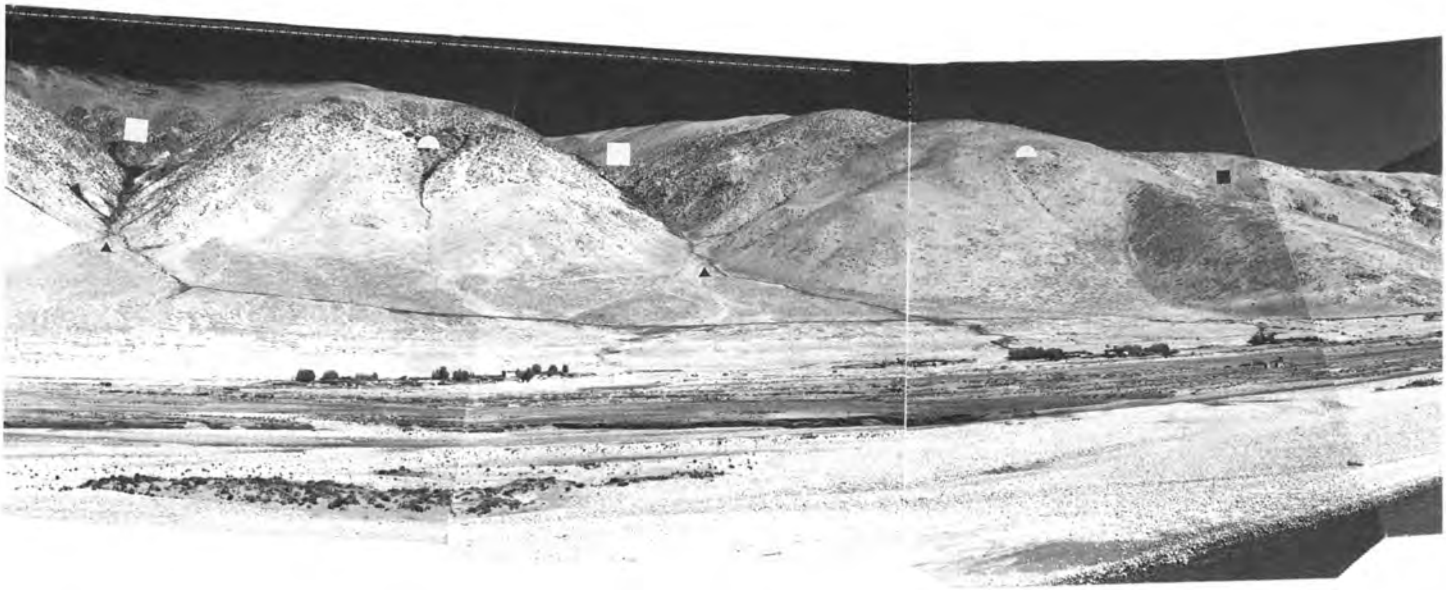


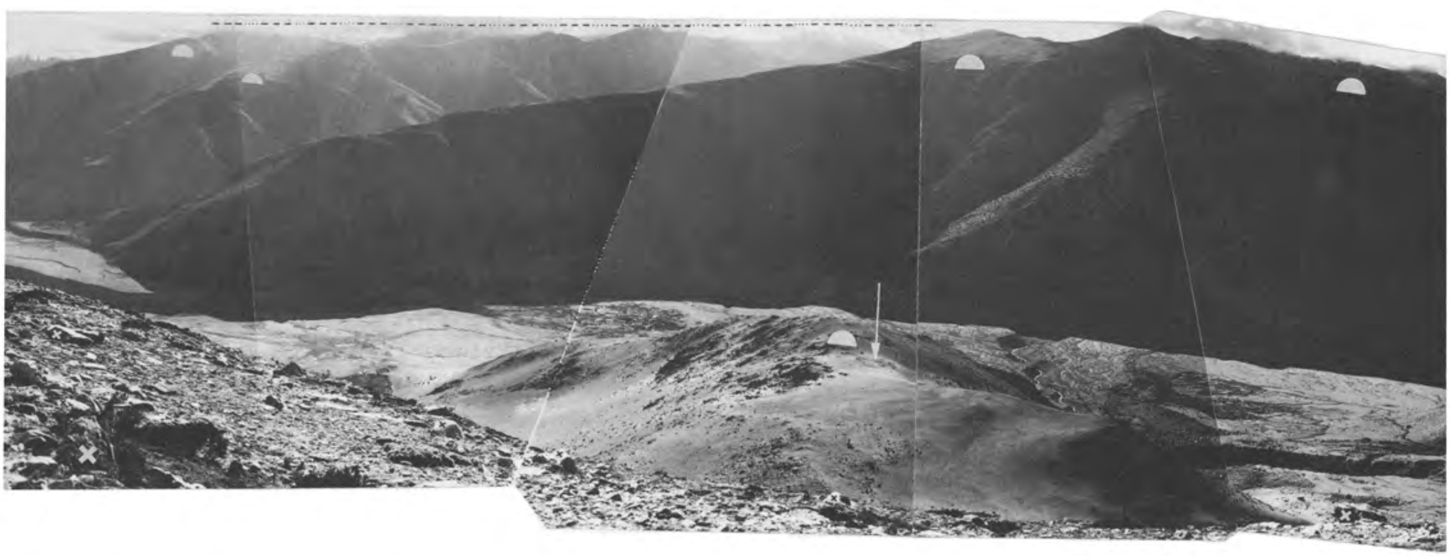
82
' panoramic view (in a N to practically S direction) down-valley
:he confluence of the Dzakar Chu and Pum Qu (at 3770 m asl;
3, No. 55) across the glacigenically-shaped Arun valley. The
ıphic left-hand flanks have been totally polished parallel to the
(▲). The prehistoric glacier level must have been up there
-). Accordingly triangular glacigenic areas (▲) which coalesce
·ds in acute, glacially polished ridges and peaks (▲) are situated
en the side valley exits. In some places glaciated knobs (▲ far
consisting of acid crystalline rock mass sit on the valley bottom
: M. Kuhle, 29.10.89.

Photo 81
Panoramic view in the area of the confluence of the Pum Qu (Arun valley and Dzakar Chu from 3750 m asl, taken from NW to NE (Fig 43, No. 55). The orographic left-hand flank polishings (◓), which extend up to the peaks of the mountain ridges, are evidence of an almost total infilling of the relief with glacier ice (- - - - minimum glacier level during the Ice Age). Only the acute points of the high peaks (No. 2 & 3), which continue to be covered by glaciers to this day, were clearly towering above the polished triangular areas, and thus the Maximum Glaciation ice surface (cf. Photo 82). (●) marks the transfluence pass from the upper Pum Qu. (××) indicate Late Glacial lateral moraines. Photo: M. Kuhle, 29.10.89.

Photo 83
Orographic left-hand lateral moraine (foreground) in the Arun valley (Pum Qu; Fig 43, No. 56) at 4300 m asl. It consists of polymict blocks (××) and is separated from the valley slope by a depression on the bank (⬇). In respect of the locality cf. Photo 86, the lowest (↓) on the left. In the background the glacially polished shape of the valley upwards towards the (▲), as well as the Maximum Glaciation ice level (- - - -). Photo: M. Kuhle, 6.10.89.

Photo 86
The Pum Qu (Arun valley) (Fig 43, No. 56) taken in the context of a panorama ranging from a northerly to easterly, and eventually a southerly, direction from the Kada settlement on the lower glacier outwash plain terrace (▼) at almost 3700 m asl. The geomorphology of the entire valley area is explained by the glacial forms of flank polishing (▲), which, reaching up to about 5700 m asl, suggest the altitude of the Maximum Glaciation ice level (- - - -). The orographic left-hand lateral moraine walls (↓↓↓) belong to a previously depressed glacier surface of the Late Glacial (cf. Photos 85 and 84). Photo: M. Kuhle, 5.10.89.

Photo 85
Orographic left-hand lat
No. 56; cf. Photos 84 and
polymict erratic blocks (
depression in the bank
when the ELA had alr
background the catchme
facing N. M. Kuhle, 6.1(



:al moraine wall at 4760 m asl (××) (Fig 43, 36 ↓ upper right-hand corner). Built up from :×), it is separated from the valley flank by ↓). The wall belongs to the Late Glacial, :ady passed beyond this altitude. In the t area of inland ice (left). The photograph is 89.

Photo 84
View from 4760 m asl from the highest distinctly Late Glacial lateral moraine (××) on the orographic left in the Pum Qu (Arun valley; cf. Photo 86 ↓, right-hand side; Fig 43, No. 56) – a panorama taken from NW, westwards to the SSE. The valley flanks are here glacigenicly polished (▲) up to altitudes of about 5680 m (▲ far left), and the Arun river flows on the upbuilding of the valley floor at 3630 m asl. This implies that the Arun glacier (Pum Qu glacier) reached a thickness of at least 1130 m during the Late Ice Age, and of about 2000 m during the last Glacial Maximum (- - - -). Photo: M. Kuhle, 6.10.89.

Photo 87
View from the Kharta valley, above the Dschupar settlement (Jupar; Fig 43, No. 56/57) at 3900 m asl towards the ESE into the Pum Qu (Arun valley at the upper end of the Arun gorge). The main valley flank (Pum Qu) on the orographic left-hand has been glacigenically polished (▲) up to the side valley ridges, ie here to about 5400 m asl (- - - -). The hanging side valley troughs (●) dissect this valley flank so as to form triangular slopes. (+)marks a valley-blocking side glacier moraine (cf. Fig 29). Photo: M. Kuhle, 7.10.89.

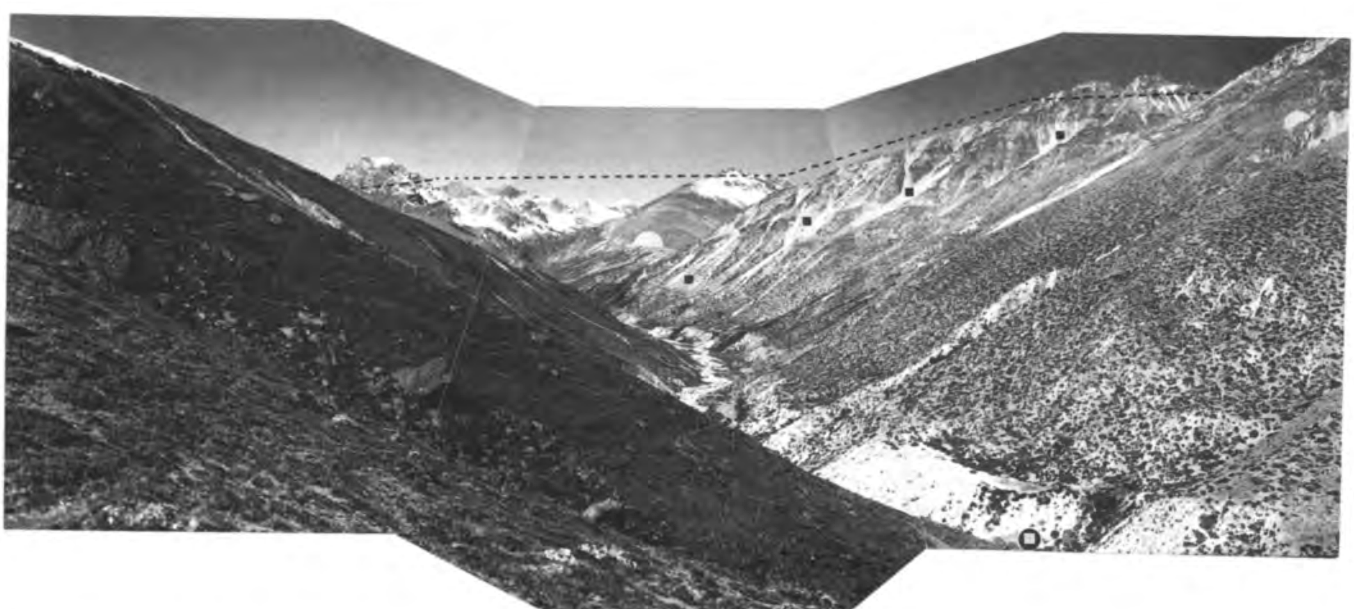


Photo 91
(- - - -) marks the reconstructed Maximum Glaciation ice filling of the relief in the central to upper Karda (Kharta) valley (Fig 43, No. 57; cf. Photo 88 down-valley). Photo taken at 4850 m asl, facing W, altitude of valley bottom: 4500 m asl. The higher flank polishings (▲) reach at least 5700–5900 m asl. Photo: M. Kuhle, 28.10.89.

Photo 88
The Karda (or Kharta) valley, taken up-valley, facing W from c. 4200 m asl (Fig 43, No. 57). The valley had been completely filled with glacier ice from the Maximum Glaciation (- - - -), as evidenced by the flank polishings (▲). More recent (Late Glacial to neo-Glacial) side glacier moraines (+) block the *talweg*. An increasingly higher glacier outwash plain terrace (■) belongs to the Holocene as well. Recent talus cones have been placed upon its surface (▼). Photo: M. Kuhle, 27.10.89.

Photo 89
Southern hanging side valley c
orographic right-hand, the jun
of which contains Late Glacial
form of arcuate wall and pedes
No. 57, 4200 m asl; cf. Fig; 40 &
view of the U-shaped valley,
terminal moraine is modified i
(●). Photo: M. Kuhle, 27.10.8

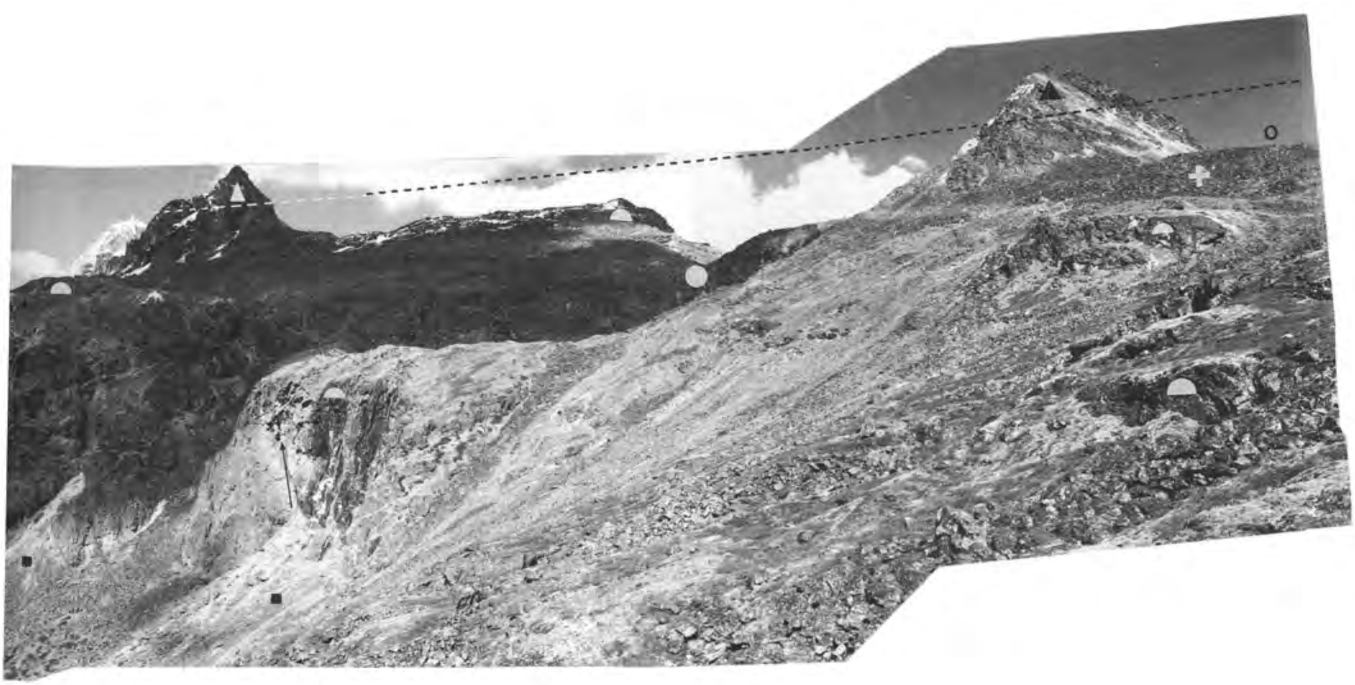
Photo 93 on pages 222–223

Photo 92
Relatively well preserved glaciated knobs (▲) at 4650 m asl with polishings and glacial striae (↓↓) in bedrock gneisses (Fig 43, No. 57/58) on the "Northern Tsao La Valley" bottom. The view is northwards. In the background evidence of glacial forms of polishing (▲) reach up to the mountain ridges. The relief had been completely filled with glacier ice (- - - -; cf. Photo 93). Photo: M. Kuhle, 9.10.89.

Photo 94
A panoramic view taken at 4550 m a
landscape of glacial erosional feature
the polishing and junction thresho

'the Karda valley on the
tion and valley exit area
erminal moraines in the
ıl moraines (++) (Fig 43,
41). This is an up- valley
ıcing S. A more recent
to a block glacier tongue

Photo 90
View into the "Northern Tsao La Valley" down-valley across the Karda (Kharta) valley, facing N, taken from c. 4600 m asl (Fig 43, No. 57/58). In the foreground Late Ice Age sequences of terminal moraines and tongue basins (●+), in the background glacigenic polishing (◓), recognizably extending almost to the very top, permits the reconstruction of an Ice Age level of the ice stream network to approximately 2000 m above the valley bottom (- - - -). At present small block glaciers are flowing off this flank (↑↑). Photo: M. Kuhle, 9.10.89.



across the valley head of the "Southern Tsao La Valley" facing W to N (Ice Age transfluence pass No. 0 Tsao La 4890 m) across a complete
Fig 43, No. 58). The Maximum to the Late Glacial ice level (- - - - 4900-5300 m asl) lies half-way between the landscape of glaciated knobs with
(◓) and the angular c. 5000-5400 m high nunatak-like glacigenic rock horns (▲). Photo: M. Kuhle, 26.10.89.

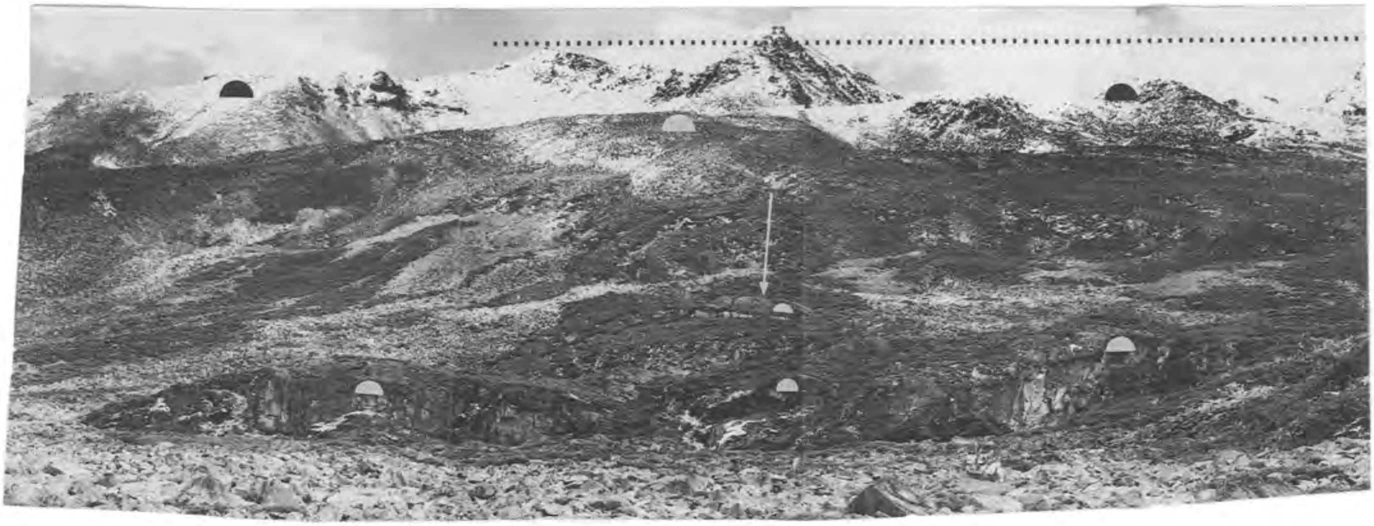


Photo 93
Classic landscape with glaciated knobs at 4650–5300 m asl in the area and north of the 4890 m high Tsao La (pass breach No. 0) (Fig 43, No. 57/58). The well preserved glaciated knobs (▲) in the foreground and middleground even show polishings and glacial striae (↓). They have been formed in massive crystalline rock (gneiss and granite). Only the highest, and invariably angular and sharp mountain peaks towered like nunataks above the ice surface of the Maximum Glaciation (- - - -). The photograph is facing E. Photo: M. Kuhle, 9.10.89.

Photo 95
Taken from approximately the same position as Photo 94, but facing SSW down-valley into the "Southern Tsao La Valley" (Fig 43, No. 58, 4550 m asl). In the background the Makalu (No. 3, 8481 m) and the Chomo Lönzo (No. 4, 7804 m) peaks, in front the Karma valley (↓). On the orographic right-hand two lateral or medial moraine walls (▲▲) at an altitude of 4500–4650 m. Photo: M. Kuhle, 26.10.89.

Photo 96
Situated at 3780 m asl, the valley bottom of the Karma valley (⧫) seen from the junction of the "Southern Tsao La Valley" at about 4180 m asl, facing S (Fig 43, No. 59). The bottom of the Karma valley continues to be reached by the Makalu-Chomo Lönzo E glacier (■). The Ice Age level of the ice stream network (- - - -) has been reconstructed with the help of polished ledges and glacial flank polishings (▲). On the left recent-Late Glacial lateral moraine (IV). Photo: M. Kuhle, 10.10.89.

Photo 98
View from 4500 m asl in a S direction down the central Karma valley (up-valley from the position taken for photo 97) across the orographic left-hand Late Glacial to late Late Glacial lateral moraine landscape (Fig 43, No. 58). With their terrace surfaces lying at the same level (4480 m asl) the lateral moraines are of more and more recent origin further up the valley. The moraine of Stadium III in the foreground thus has the same level as that of Stadium II in the background. The relative height of the moraine above the valley bottom decreases and its form becomes fresher and fresher. In the foreground the moraine of Stadium III even retains the neat moraine crests which were formed during the original process of moraine deposition (↓↓). Photo: M. Kuhle 25.10.89.

Photo 100
View from the area of the Hol
(probably historic) landslide (△) abov
Kangdoshung glacier (■), taken at c. 4
asl down to the Karma valley (Fig 43, N
(cf. Photo 101 ▷). From the N (from th
Middle to Late Glacial and neo-G
lateral moraines (II, III, IV, V) have
deposited in the area of the mouth c
"Karma Changri Valley" (cf. Photo 101
The foreground displays the neo-Glac
historic glacier history (×). The (
Stadium I, the oldest Late Glacial
(Kuhle 1982a) is no longer represent
moraines in this section of the c
Karma valley, nor is the glaciation fro
Maximum Glaciation as the ELA wa
too low at that time. The Main Ice
glacier surface is marked - - - -. Phot
Kuhle, 24.10.89.

Photo 97▲
View taken from the Late Glacial lateral moraines on the orographic left-hand of the Karma valley at 4440 m asl, down-valley, facing E (Fig 43, No. 58). It is a U-shaped valley, substantially filled with lateral moraine terraces (II, III, IV) and side valley end moraines (+) from the orographic left, ie the N Tibetan side. Glacigenic flank polishings and smoothing (◓) are evidence of a Maximum Glaciation ice level ranging from 5200 m (- - - -, on the left) to 4000 m or 3500 m (- - - -, on the right). Photo: M.Kuhle, 11.10.89.

◄ Photo 99
An orographic left-hand (N) junction of a side valley in the central Karma valley, taken at 4480 m asl, facing NW (Fig 43, No. 58). A pedestal moraine (■) has been pushed from this valley exit into the main valley (on the left). This is superimposed upon by a still very fresh glacier tongue basin with tongue basin lakes (↓↓). The moraine forms (+) are so finely undulating and so recent that they must be regarded as belonging to the late Late Glacial or neo-Glacial period. Above them are older Late Glacial moraine triangles leading on to the next, westerly, side valley (III, II) (cf. Photos 100 & 101). Higher up they are followed by early Late Glacial to Main Glacial rock polishings (◓), which contrast with the above forms of ridges (▼) and allow the level of the ice to be traced. Photo: M. Kuhle, 11.10.89.

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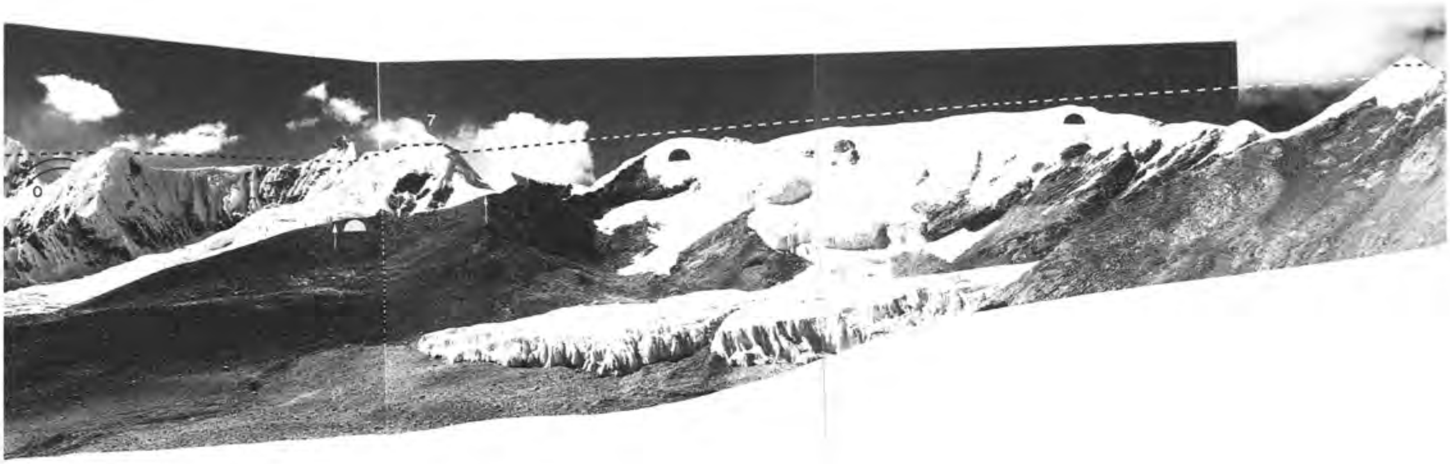
Photo 101
View from an altitude of about 4660 m asl, facing NW in the Karma valley across the area of the "Karma Changri Valley" mouth (Fig 43, No. 58). In the background the glacier tongue ends of the Kangdoshung and Kangshung glaciers (■). In the foreground, half way to the right, there are neo-Glacial to Late Glacial orographic left-hand lateral moraines (V, IV, III, II). They are followed above by old Late Glacial to Maximum Glacial rock rounding and glacier polishings (▲), and are thus evidence of an ELA which had been depressed so far at the time as to prove that this entire valley area north of the Himalaya main ridge must have been above the ELA (snowline). This no longer applied after the middle of the Late Glacial. Photo: M. Kuhle, 11.10.89.

Photos 102 and 103 on pages 228 and 229

Photo 104
Panorama showing the highest section of the Karma valley from the present right-hand lateral moraine of the Kangshung glacier, taken at 5300 m asl, facing NW by way of E (down-valley) to the SE (including Chomo Lönzo No. 4, 7804 m and Makalu, No. 3, 8481 m asl) (Fig 43, No. 60). The snowline still dropped below this valley floor during the late Late Glacial period so that only the most recent moraines of the last Late Glacial advance or moraines of the 2000–4000 year earlier neo-Glacial period may be found here (▼▼). The present glacier surface is on the right (●), whilst (- - - -) marks the reconstructed Maximum Glaciation ice surface (cf. Photo 105). Photo: M. Kuhle, 23.10.89.



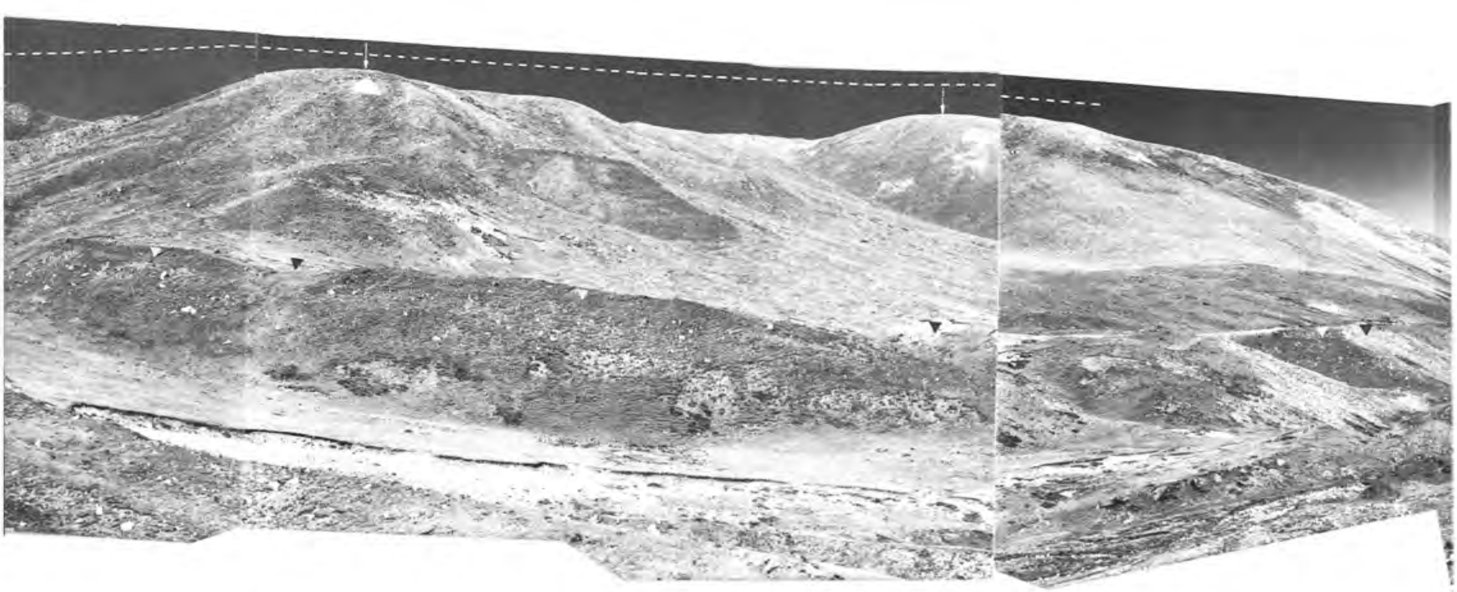
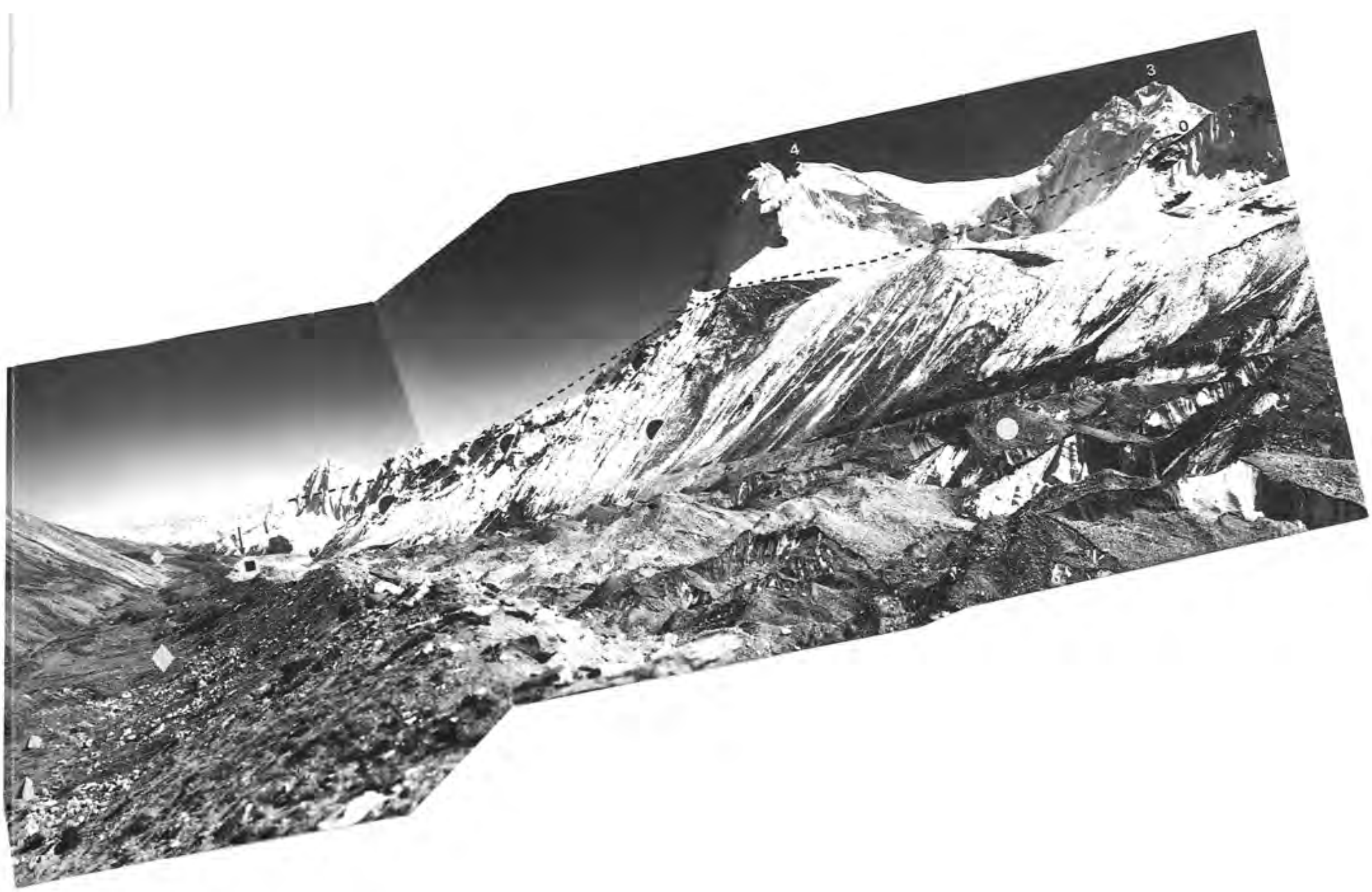


Photo 105
View from 6000 m asl, from a mountain flank ESE of the Karpo La. Panorama from the S, (No. 6 Pethangtse, 6738 m) via Peak 38 (No. 5, 7590 m), Lhotse (No. 2), Mt. Everest (No. 1) and Karze (No. 7, 6550 m) to the region of the Tibetan Himalaya in the N (↶). To the west is the 6548 m high Rapui La (No. 0 ↶↶) (Fig 43, No. 61). Underneath Lhotse and Mt. Everest there is the firn cauldron basin from which the present Kangshung glacier springs, ie from whence it receives its ice avalanche feeding from the more than 3000 m high walls. In many places, and up to an altitude of 5900 m there are moraine sheets and erratic blocks (↓↓) on the glaciated knob forms (▲). In many places, however, flank polishing has been destroyed or made indistinct (++) thanks to current glaciation which proceeds at right angles to the prehistoric one. The reconstructed Maximum Glaciation ice level (- - - -) sketches out a transition from a total covering of relief by an ice cap in the N to an ice stream network of a thickness of 1500 m or more on the N edge of the High Himalayas, with ice transfluences into the steep S slope of the Himalayas (No. 0 ↶ right). Photo: M. Kuhle, 22.10.89.



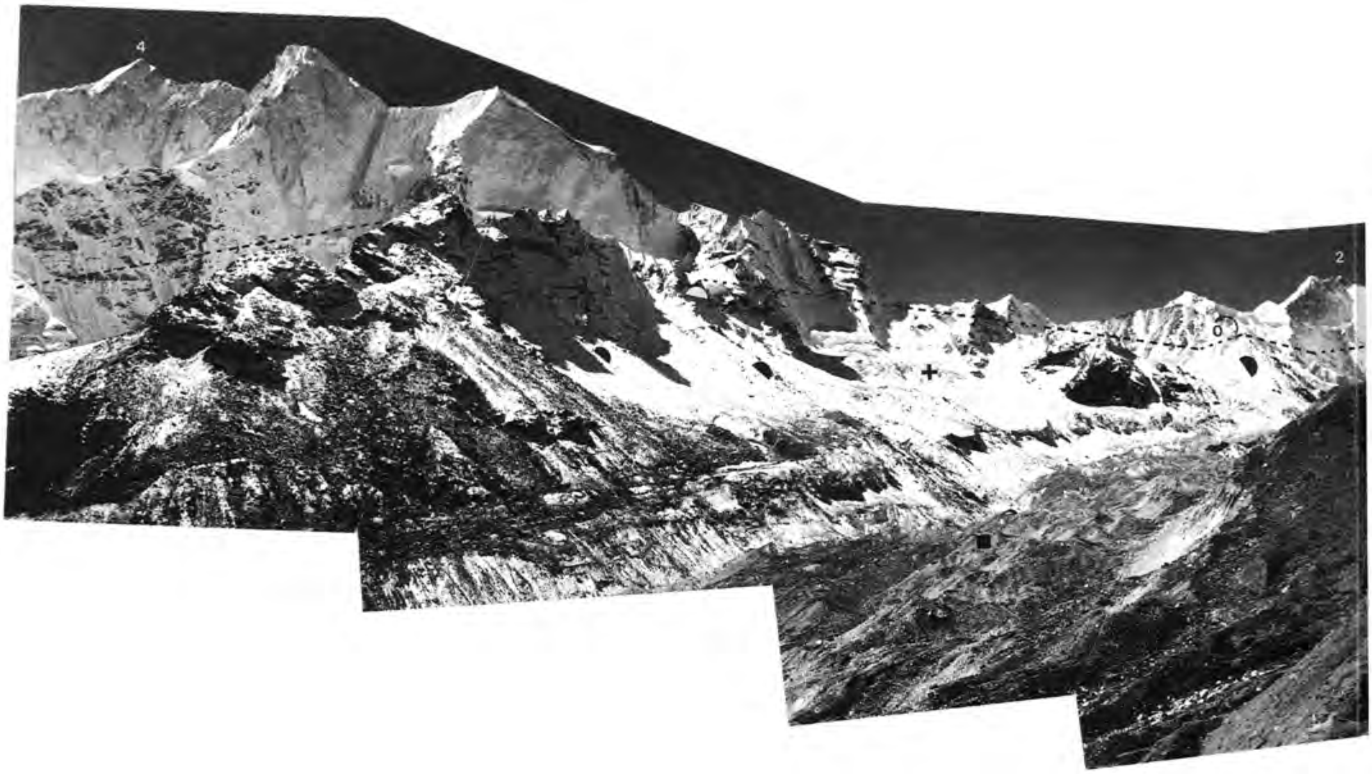


Photo 102
Photograph of the upper and currently still substantially glaciated chamber of the Karma valley from an altitude of c. 4700 m asl, facing W (Fig 43, No. 58/60). In the background Mt. Everest (No. 1), then Lhotse (No. 2, 8501 m). Below, on the left, a main glacial transfluence pass leading into the Himalaya S slope (E of Pethangtse, no. 0 ◠). No. 4 marks the 7804 m high Chomo Lönzo main peak. Preserved merely in remnants, the line of glacial polishing, ie the glacier level (- - - -) runs along the orographic right-hand flank of the valley, which forms the N of the Himalayan main crest (cf. Photo 103, 104 and 105) from 6300–6800 m asl in the background down to about 5500–5800 m in the foreground (right and left - - - -). The predilection for the formation of moraines (◆) on the N side of the glacier is a result of the southerly exposition of this side, which is favoured by solar radiation. Photo: M. Kuhle, 24.10.89.

Photo 103
The E wall of Mt. Everest rises from the valley glacier surface, upon which the giant avalanche cone has been placed (■) to 5500 m asl, ie by 3300 m (Fig 43, No. 60/61). The convex bend in the wall between c. 6300 and 6800 m, in the place where the pillarheads (●) form a level, marks the Maximum Glaciation ice level (- - - -). Avalanche erosion maintains the steepness of the lower wall only during interglacial periods. Photo: M. Kuhle, 23.10.89.

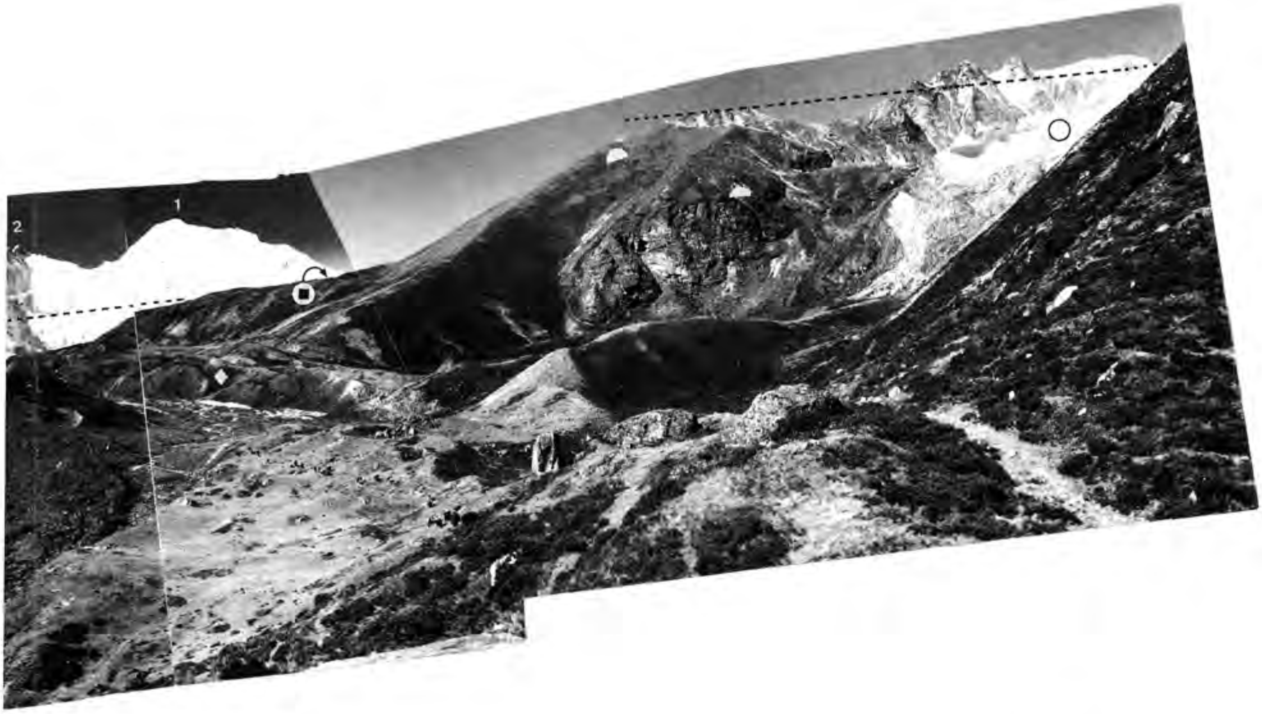
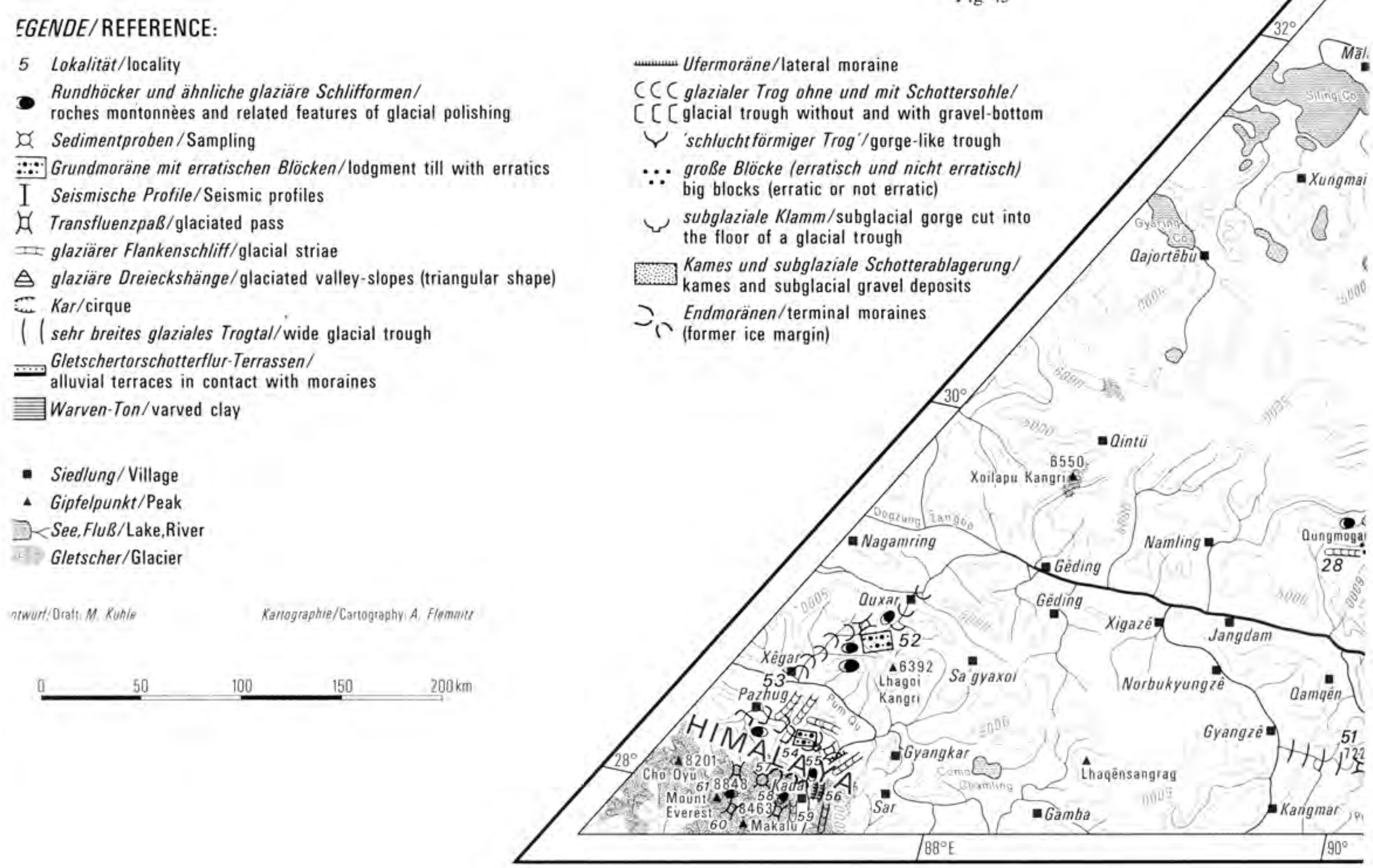

1
2

Fig 43


EGENDE/REFERENCE:
5 Lokalität/locality
Rundhöcker und ähnliche glaziäre Schliffformen/ roches montonnèes and related features of glacial polishing
Sedimentproben/Sampling
Grundmoräne mit erratischen Blöcken/lodgment till with erratics
Seismische Profile/Seismic profiles
Transfluenzpaß/glaciated pass
glaziärer Flankenschliff/glacial striae
glaziäre Dreieckshänge/glaciated valley-slopes (triangular shape)
Kar/cirque
sehr breites glaziales Trogtal/wide glacial trough
Gletschertorschotterflur-Terrassen/ alluvial terraces in contact with moraines
Warven-Ton/varved clay
Siedlung/Village
Gipfelpunkt/Peak
See, Fluß/Lake, River
Gletscher/Glacier
ntwurf/Draft: M. Kuhle
Kartographie/Cartography: A. Flemnitz
0 50 100 150 200 km
Ufermoräne/lateral moraine
glazialer Trog ohne und mit Schottersohle/ glacial trough without and with gravel-bottom
'schluchtförmiger Trog'/gorge-like trough
große Blöcke (erratisch und nicht erratisch) big blocks (erratic or not erratic)
subglaziale Klamm/subglacial gorge cut into the floor of a glacial trough
Kames und subglaziale Schotterablagerung/ kames and subglacial gravel deposits
Endmoränen/terminal moraines (former ice margin)
N
32°
30°
28°
88°E
90°
Siling Co
Xungmai
Qajortêbu
Qintü
6550
Xoilapu Kangri
Nagamring
Gêding
Namling
Qungmogai
28
Quxar
52
Xêgar
53
6392
Lhagoi Kangri
Sa'gyaxoi
Xigazê
Jangdam
Norbukyungzê
Qamqên
Pazhug
HIMALAYA
Gyangkar
Gyangzê
51
8201
Cho Oyu
8848
Mount Everest
8463
Makalu
Kada
54
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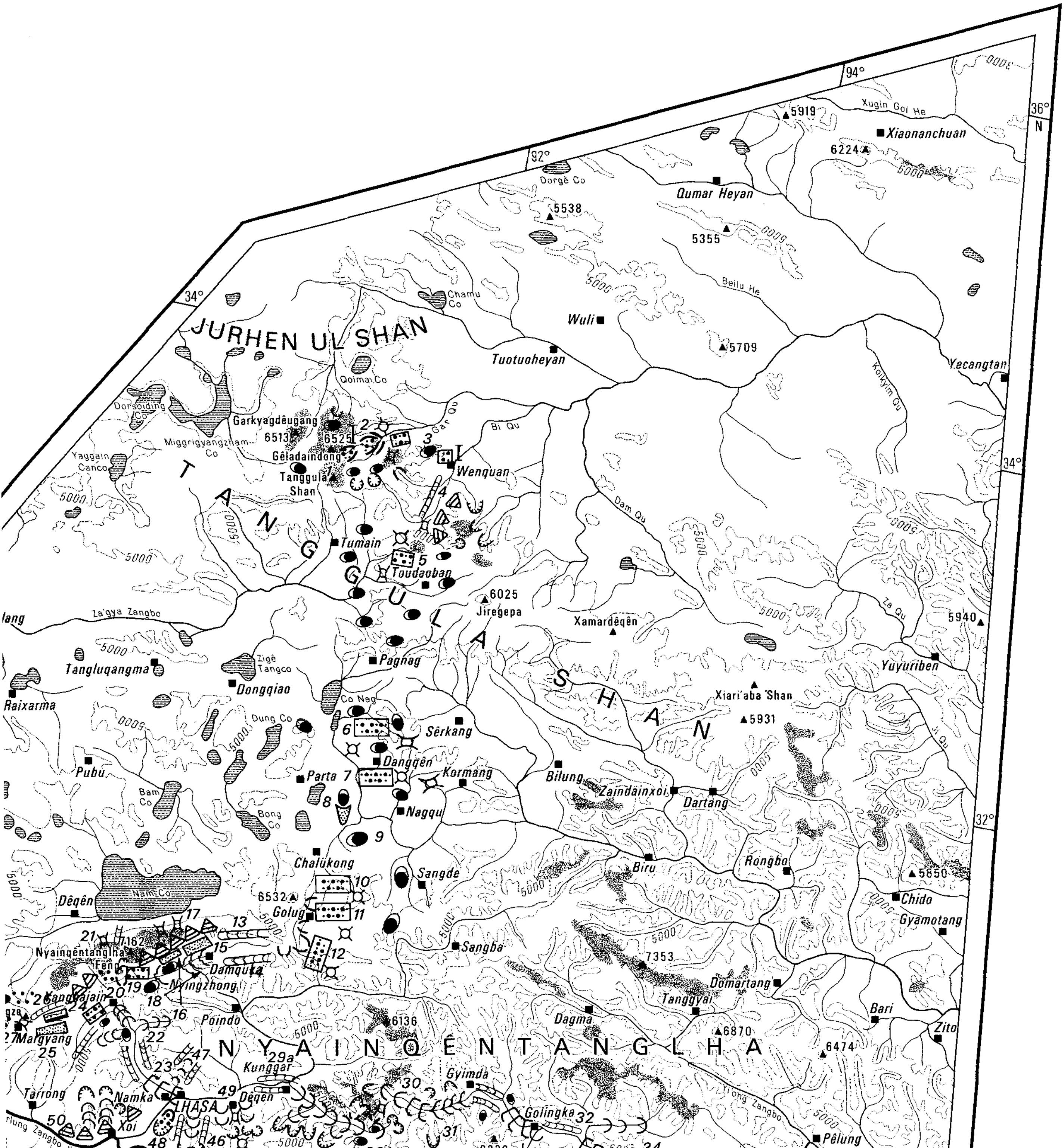
58
59
60
61
Sar
Lhaqênsangrag
Gamba
Kangmar


JURHEN UL SHAN
TANGGULA SHAN
NYAINQÊNTANGLHA
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Qumar Heyan
Dorgê Co
Chamu Co
Wuli
Tuotuoheyan
Beilu He
Xugin Goi He
Qoima Co
Dorsoidong Co
Garkyagdêugang
Miggrigyangzham Co
Yaggain Canco
Gêladaindong
Tanggula Shan
Wenquan
Bi Qu
Gar Qu
Dam Qu
Kolkyim Qu
Yecangtan
Tumain
Toudaoban
Jiregepa
Xamardêqên
Za'gya Zangbo
Za Qu
Yuyuriben
Tangluqangma
Zigê Tangco
Dongqiao
Paqnag
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Dung Co
Sêrkang
Dangqên
Kormang
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Ramba
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