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The High Glacial (LGP, LGM, MIS 3-2) southern outlet glaciers of the Tibetan inland ice through Mustang into the Thak Khola as further evidence of the Tibetan ice

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ABSTRACT

A 26-31 km wide outlet glacier is evidenced flowing down from the Last Glacial Period (LGP, LGM, Würm, Marine Isotope Stage (MIS) 3-2) S-Tibetan inland ice to the S through Mustang-Thak Khola up to c. 1000 m asl. The glacier terminus reached up to the junction of the Mayangdi Khola (28°20'24"N 83°33'42"E). This 120 km long Mustang-Thak Khola outlet glacier overflowed the current watershed between Tsangpo and Ganges. At its root on Kore La it was at least 1400 m thick and did not decrease up to the Himalaya breakthrough between Dhaulagiri and Annapurna. Only on the Himalaya-S-side it decreased with a diminishing height of the level to below 4000 m, i.e. up to below the snowline (ELA). The Mustang-Thak Khola outlet glacier received inflow from the local mountain glaciations of the Tibetan and High Himalaya flanking the Thak Khola. In the N and W these are the Mustang-, Sangda- and Mukut Himal E-slopes, in the N and E the valley glaciers of the Damodar Lekh-, Damodar- and Pukhung- and Muktinath-Himal W-slopes and in the S the glaciers of Dhaulagiri and Annapurna. During the Late Glacial (Stages I-IV), with an uplifted snowline, the Mustang-Thak Khola outlet glacier built-up a pedestal moraine. Part of these decametre-thick loose rocks were cut during the Late Glacial (Stage IV) and replaced by glaciofluvial and glaciolimnical sediments. With the further melting-back of the ice from the Late Glacial up to nowadays (Stages V-XII) these glaciofluvial gravel floors, too, have been fluvially evacuated i.e. displaced.

Keywords: Proof of a Tibetan Ice Sheet, Outlet glacier, Himalaya, Ice Age glaciation, Last Glacial period, paleoclimate, High Asia, Mustang Thak Khola

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INTRODUCTION, METHODS OF EVIDENCE AND CHARACTERISTICS OF THE INVESTIGATION AREA

The aim of this investigation was to find geomorphological and sedimentological indicators of a possible former outlet glacier from S-Tibet to Mustang down into the Thak Khola-Himalaya transverse valley. In this context the question about the contact of such a Thak Khola outlet glacier with the local mountain glaciation has also to be established. In addition to the reconstruction of the maximum extent of the High Glacial (LGP and LGM) glacier cover in Mustang and the upper Thak Khola, field investigations combined with panorama photographs and laboratory analyses of samples were focused on the evidence of glacier trim-lines and -thicknesses.

This is the regional continuation of a detailed and spatially extensive reconstruction of the Ice Age glaciation in S-Tibet (Kuhle 1988a, b, 1991, 1999b, 2001b) and the Dhaulagiri- and Annapurna Himalaya (Fort 1985, 1986; Iwata 1984, Kuhle 1980, 1982, 1983, 2007). It completes the author's research on the past extent of ice and glacier thicknesses in High Asia carried out since 1973 (Fig. 1) and published since 1974 (Kuhle 1974-2010) by further observations in an area which has not been studied previously. At this point of the introduction, the summarizing sentence of decades of preparatory work as to the maximum glacial snowline depression in the Central Himalaya in Kuhle (2007: 98/99) is to be repeated: „In the meantime extensive findings obtained in the field in the course of several years yielded ELA depressions of 1200-1500 m for the Himalaya S-side (Kuhle 1980, 1982e, 1983, 1987a, 1988g, 1990a, 1991b, 1997a, 1998a, 1999a, 2001b, 2002b, 2006b, Jacobsen 1990, Meiners 1999: 370/371, 2000:127, 132, König 1999, 2002, 2003, Wagner 2005, 2007, Zech et al. 2003).

As most important literature, that does not concern the immediate topic of the paper in hand, but under consideration of the newer literature gives a detailed report on the geological context and other Quaternary sediments of the Thak Khola-Mustang area, there have to be mentioned Upreti and Yoshida (2005) and Upreti et al. (2010).

Generally, it has to be stressed that the author's research method - which in the following is once more explained - uses the common glaciogeomorphological and glaciogeological working techniques according to the present state of knowledge. So far this method has been applied in all areas of investigation and is repeated here.

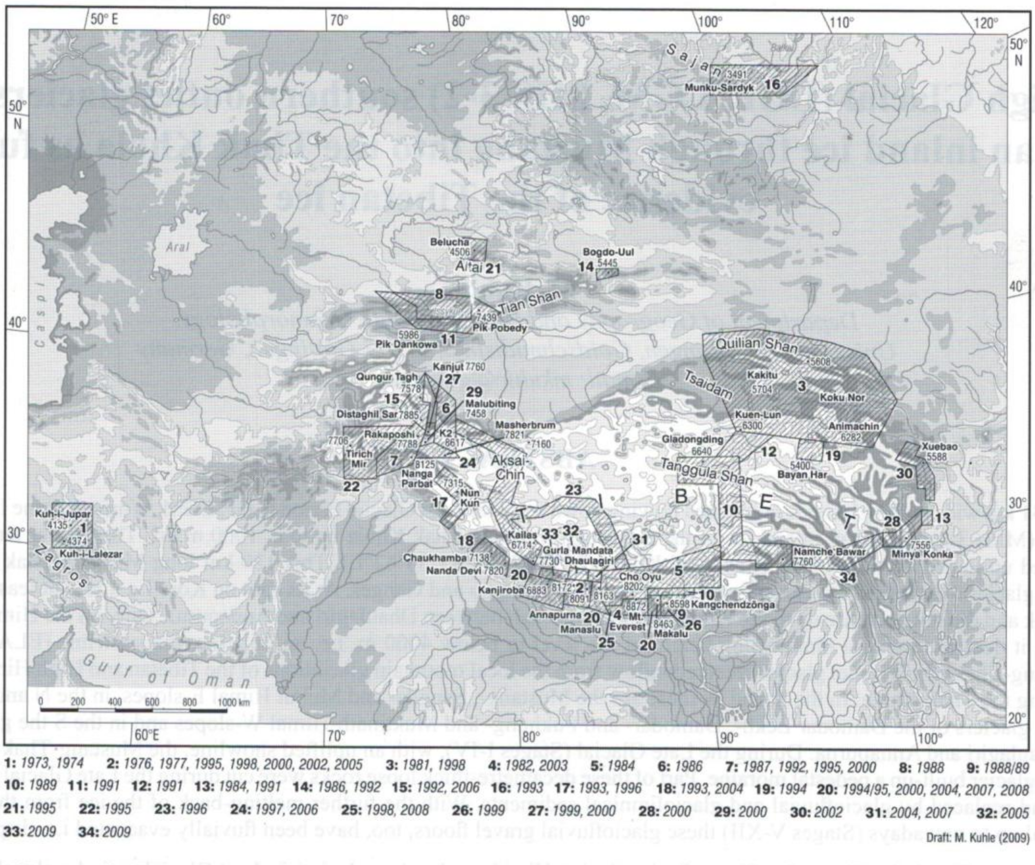


Fig. 1: Research areas in Tibet and surrounding mountains visited by the author. The study presented here introduces new observations on the Ice Age glacier cover from area Nos. 2 and 32.

METHODS

The geomorphological and Quaternary-geological methods used in the field and laboratory have been discussed in detail in the papers on empirical Ice Age research and the glaciation history of High Asia (Kuhle and Wang Wenjing 1988, Kuhle and Xu Daoming 1991, Kuhle 1994, 1997a, 1999a, 2001a, 2005a) published in the GeoJournal series "Tibet and High Asia - Results of Investigations into High Mountain Geomorphology, Paleo-Glaciology and Climatology of the Pleistocene (Ice Age Research)", "Glaciogeomorphology and Prehistoric Glaciation in the Karakorum and Himalaya" and "Glaciogeomorphology and former Glaciation in the Himalaya and Karakorum". Volumes I (1988), II (1991), III (1994), IV (1997a), V (1999a), VI (2001a) and VII (2005a). Accordingly, these scientifically common methods are only introduced in general: glaciogeomorphologic observations in the research area (Fig. 1 No. 32) have been mapped. Locations of typologically unambigous individual phenomena, i.e. glacier indicators, have been recorded with the help of 50 conventional signs (Figs. 2 and 3). The catalogue of signatures applied has been developed by the author especially for the base map 1:1 million (ONC H-9, 1978) and 1:50 000 (Nepal 1:50 000, 2000, Sheets No. 2983 12, 2984 09, 2983 16, 2984 13, 2883 04 and 03). The locations of sediment samples - from which only a selection could be taken in to consideration for this paper - have also been marked. All type localities are presented in Figs. 2 and 3. They concern areas in which the arrangement of the position of the indicators provides unambiguous evidence of the High Glacial glacier cover. References are given in the text, the photographs, Table s and figures. All indicators marked in the maps have been documented on the spot by photographs and photo-panoramas (Figs. 2 and 3) in a medium-sized format in colour or black/white. These photos are analogue photos, so that in contrast to digital photos - the content and validity of which can be changed without having any possibility of checking - the authenticity of the photos in the field is verifiable by negative films and prints.

For purposes of a detailed diagnosis and additional reassurance as to the occurrence of real ground moraine (lodgement till) in these high topographic positions testifying to past glacier trim-lines, representative samples have been taken in order to be analysed in the laboratory (Figs. 2 and 3). The analyse data of 40 moraine samples are for the most part presented in Fig. 4 a/b and - concerning the grain size analyses - by 5 representative samples (Fig. 5: 1-5). The rest can be demanded from the author's archives. The sediment analyses: Ct/Nt-determination (Elementar Analyser Leco CHN 1000), lime content determination (after Scheibler;

DIN 19684 Teil 5, 1977), grain-size analysis ('Kombinierte Sieb-u. Pipettanalyse' after Köhn (1928), DIN 19683 Blatt 2, 1973), determination of the sorting coefficient in the matrix spectrum (after the method of Engelhardt 1973) (Fig. 5: 1-5) and morphoscopic quartz grain analysis (after the method of Mahaney 1991) (Fig. 4 a/b) are able to underpin and complete the proof of a huge former glacigenic landscape. Glacially crushed or freshly weathered material cannot immediately be recognized by morphoscopic quartz grain analyses (Fig. 4), but by the petrographic analysis in the field, i.e. by the content of erratic material - in places also by the lime content of debris covers – it can be proved that glacially crushed and not freshly weathered material in situ is concerned. The confusion between glacially crushed material (fresh surfaces) with the material of rock avalanches and landslides can be unambiguously ruled out because of the admixture of fluvially polished (lustrous) SiO_2-grains of the medium sand fraction. What is true because of the admixture of erratic material anyway (see above). In addition, the course of the grain size accumulation curve of rock avlanches and landslides is significally different from that of glacigenic sediments; the same applies to the sorting coefficient (So).

The sorting coefficient So ($=\sqrt{Q3/Q1}$) compares the ratio of the grain sizes of the first quarter Q1 of the grain size distribution curve with that of the third quarter Q3 and provides an additional reliable proof mainly as to the differentiation of fluvial and morainic accumulations. If

Fig. 2: Quaternary-geological and glacio-geomorphological map of the Mustang-Thak Khola area including the Dhaulagiri-Himalaya-E- and Annapurna-Himal-W-slopes with localities of the analogue photographs (panoramas), the sedimentological samples and the valley cross-profiles during the maximum Ice Age glaciation. Basic topographic maps: Nepal 1:50 000: His Majesty's Government of Nepal, Survey Department in cooperation with the Government of Finland (2001): Sheet No.2983 12, and 16; 2883 03, 04, and 07. See Fig.3.

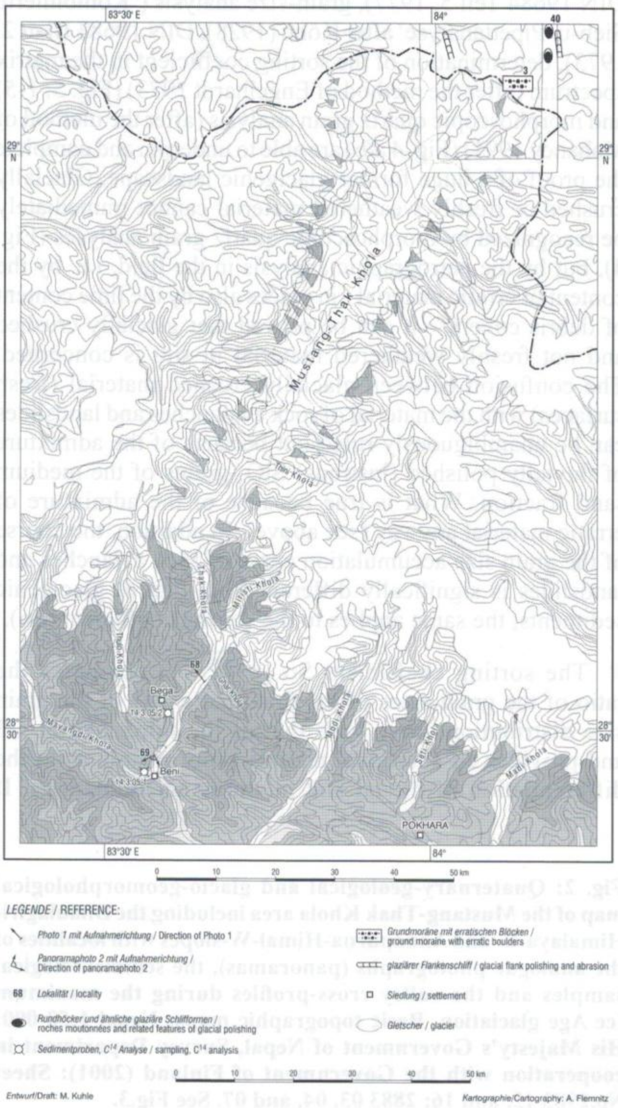


Fig. 3: Glacio-geomorphological map of the Mustang-Thak Khola with its ice cover (glaciers) during the LGM (Stage 0). Basic topographic map: ONC (1978): H-9; 1:1,000,000. See Fig. 2; cf. Fig. 6)

only one grain size appears in the sediment, than So = 1. The greater the coefficient, the stronger the intermixing of different grain sizes, which is typical of moraine matrix. Accordingly, the insignificant loss of ignition (LOI), the bi/trimodal and quadramodal grain size distribution, the lack of sorting and the very high percentage of glacially crushed quartz grains provide evidence of lodgement till (ground moraine) even up to very high positions in this steep valley relief. Owing to this, these analyses are further accumulation indicators of the former ice cover as well as of the glacier thickness and - in some places - even of the minimum altitudes of the glacier trim-line.

The geomorphological maps (Figs. 2 and 3) as to the glacier reconstruction of the last glacial period (Würmian, Isotope Stage 4 or 3 to 2, Stage 0 in Table 1 and in the Figs. 7-9) as well as the text of the paper consider the late glacial (Fig. 6), Holocene (neoglacial) and historical stages (Table 1) even though they are not the true subject of this investigation. The existence of these younger glacier indicators is important because they render the differentiation of 7 late glacial to neoglacial and 6 historical glacier stages possible, aligned between the lowest past (High Glacial of the last glacial period, LGP, LGM, Stage 0) and the lowest current glacier margins. They are marked by the numbers I-XII as being of late glacial to historical age (Table 1, Figs. 2, 6, 7 and 8). The number of 13 late glacial to historical glacier stages since the last glacial period corresponds with that of the number of glacier stages of the post-last glacial period diagnosed worldwide. So, these younger evidences of ice margin positions are important indications of the correctness of our dating of the lowest past ice margin positions as belonging to the last glacial period (LGP, Stage 0 = Isotope Stage 4 or 3-2).

Datings

Due to the aridity of the research area, no 14C-data could be obtained for the dating of moraines. As has been shown in other areas of the Himalaya, up to now only 14C-datings are glaciogeomorphologically safe, whilst the OSL (optically stimulated luminiscence)- and TCN (terrestrial cosmogenic nuclids) -datings carried out so far, because of the high sea level are 4- to 10-fold overestimated, i.e. they led to too old ages (Kuhle and Kuhle 2010). Thus, by means of ^{14}C-datings of moraines in the Khumbu Himal, a snowline (ELA)-depression up to 500 m has been evidenced during the Neoglacial period c. 2.1 and 4.2 ka ago; whilst the ELA-depressions according to OSL- and TCN-data amounted to c. 16-23 ka, i.e. they were overestimated by a factor 6.5. Therefore the CRONUS-Earth project still draws on specific 'Production Rate Calibration Sites', which rely on conventional radiocarbon dates, in order to improve current scaling models which are still not sufficiently reliable. Corresponding OSL- and TCN-overestimations are evidenced for S- and Central Tibet and the Karakoram (ibid.).

Probably the age of the TCN-data that so far have not been calibrated with regard to the high sea-level of High Asia, has been overestimated on the following grounds:

1. Obviously the correction factors underestimate the amount of cosmic rays that really hit the surfaces of very high altitudes.

2. Due to magnetic field excursions the amount of cosmic rays (CR) was additionally strengthened during the Late- and High Glacial. This must have had a special effect at a high altitude, so that the age overestimation exponentially increases with a growing moraine age.

This means, that the Late Glacial moraine stages can already be extremely overestimated as to their age and obviously differ from the Holocene stages in a clear age leap, whilst the glacio- geological finding does not cover this leap.

Sample No. / Proben nummer	Date / Datum	counted quartz grains of the medium sand / ausgezählte Quarzkörner der Mittelsand-fraktion	Freshly weathered/ glacially crushed / frisch verwittert/ glazigen gebrochen [%]	lustrous (fluvially polished) / fluvial poliert [%]	dull (aeolian) / äolisch mattiert [%]	remarks / Anmerkungen
1	14.03.05/1	298	99,0	1,0	0	Very high portion of different coloured quartz grains and biotite; quartz grains are clearly destroyed at the edges/ sehr hoher Anteil unterschiedlich gefärbter Quarzkörner und Biotit; die Quarzkörner weisen an den Ecken deutliche Bruchstellen auf
2	14.03.05/2	172	97,7	2,3	0	Most quartz grains are very small and they are not clearly lightning; many dark coloured biotite is in the sample/ die meisten Quarzkörner sind sehr klein und erscheinen trüb die Probe hat einen hohen Biotitanteil
3	15.03.05/1	294	95,9	4,1	0	Many compact quartz grains which are only broken at the edges/ viele kompakte Quarzkörner, die nur an den Ecken gebrochen sind
4	15.03.05/2	248	100	0	0	Many small sharp broken quartz grains and many feldspar in the sample/ hohe Anteile kleiner, scharf gebrochener Quarzkörner- sowie Feldspat in der Probe
5	15.03.05/3	312	99,4	0,6	0	High portion garnet and quartz in the sample/ große Anteile Granat und Quarz in der Probe
6	15.03.05/4	217	99,5	0,5	0	Many lighten glimmer and a high portion of garnet/ viel hell leuchtender Glimmer und ein hoher Anteil an Granat
7	16.03.05/1	225	97,8	2,2	0	Very homogenous sample of light quartz grains/ sehr homogene Probe aus hellen Quarzkörnern
8	16.03.05/2	301	99,3	0,7	0	Many compact quartz grains which are only broken at the edges/ viele kompakte Quarzkörner, die nur an den Ecken gebrochent sind
9	17.03.05/1	325	99,1	0,9	0	The quartz grains are angular and sharp shaped; there is much biotite in the sample/ die Quarzkörner sind scharfkantig und angular; in der Probe ist ein hoher Anteil Biotit
10	17.03.05/2	283	99,6	0,4	0	High portion of thin feldspar grains/ hoher Anteil dünner Feldspatkörner
11	18.03.05/1	308	99,4	0,6	0	Heterogenous sample (garnet, feldspar, biotite and different coloured quartz)/ heterogene Probe (Granat, Feldspat, Biotit und unterschiedlich gefärbte Quarze)
12	19.03.05/1	97	100	0	0	Only feldspar and calcite in the sample, no quartz grains; clear fedspar grains were counted/ nur Feldspat und Calcit in der Probe, keine Quarzkörner; die klaren Feldspatkörner wurden gezählt
13	19.03.05/2	231	99,6	0,4	0	Very homogenous sample of light quartz grains, which are compact and broken only at the edges/ sehr homogene Probe aus hellen Quarzkörnern, die kompakt- und nur an den Ecken gebrochen sind
14	20.03.05/1	42	95,2	4,8	0	Not many quartz grains in the sample, so the significance is not very high/ kaum Quarzkörner in der Probe, daher nur geringe Signifikanz
15	20.03.05/2	84	83,3	16,7	0	Only feldspar and calcit in the sample, no quartz grains; clear fedspar grains were counted/ nur Feldspat und Calcit in der Probe, keine Quarzkörner; die klaren Feldspatkörner wurden gezählt
16	21.03.05/1	70	94,3	4,3	1,4	Not many quartz grains in the sample, so the significance is not very high/ kaum Quarzkörner in der Probe, daher nur geringe Signifikanz
17	22.03.05/1	230	95,7	4,3	0	Quartz grains are in relation to the other grains very small and sharp shaped/ die Quarzkörner sind in Relation zu den anderen Körnern sehr klein und scharfkantig
18	23.03.05/1	109	98,2	1,6	0	Only feldspar and calcit in the sample, no quartz grains; clear fedspar grains were counted/ nur Feldspat und Calcit in der Probe, keine Quarzkörner; die klaren Feldspatkörner wurden gezählt
19	23.03.05/2	181	98,9	1,1	0	Many garnet and feldspar in the sample/ viel Granat und Feldspat in der Probe
20	24.03.05/1	91	95,6	4,4	0	The quartz grains are mostly compact and only broken at the edges/ die Quarzkörner sind überwiegend kompakt und bloß an den Ecken gebrochen
21	24.03.05/2	178	100	0	0	Most grains show iron- oxide crusts and a high portion of calcit/ die meisten Körner zeigen eine Eisenoxidkruste sowie einen hohen Anteil Calcit
22	25.03.05/1	223	98,2	1,8	0	Heterogenous sample with different coloured quartz grains/ heterogene Probe mit unterschiedlich gefärbten Quarzkörnern
23	25.03.05/2	147	99,3	0	0,7	Many glimmer in the sample (biotite and muscovite)/ viel Glimmer in der Probe (Biotit und Muskovit)
24	26.03.05/1	185	99,5	0,5	0	More milky looking quartz gains than clear grains, which are compact and broken at the edges/ mehr milchig aussehende Quarzkörner als klare Körner, deren Ecken gebrochen sind
25	27.03.05/1	267	98,1	1,9	0	Nearly only sharp broken clearly looking quartz grains in the sample/ beinahe nur scharf gebrochene und klare Quarzkörner in der Probe
26	27.03.05/2	311	99,4	0,6	0	Nearly only sharp broken clearly looking quartz grains in the sample/ beinahe nur scharf gebrochene und klare Quarzkörner in der Probe
27	28.03.05/1	168	98,2	1,8	0	Many different minerals in the sample; quartz grains are all clearly broken/ viele verschiedene Minerale in der Probe; die Quarzkörner sind alle deutlich gebrochen
28	29.03.05/1	271	98,5	1,5	0	Many different minerals in the sample; quartz grains are all clearly broken/ viele verschiedene Minerale in der Probe; die Quarzkörner sind alle deutlich gebrochen
29	29.03.05/2	200	96,0	4,0	0	Many quartz grains are round and compact and only broken at one or two places/ viele Quarzkörner sind rund und kompakt und nur an ein oder zwei Stellen gebrochen
30	30.03.05/1	212	96,2	3,8	0	Homogenous sample of many light quartz grains/ homogene Probe aus vielen hellen Quarzkörnern
31	30.03.05/2	97	97,9	2,1	0	Not many quartz grains in the sample; half of the quartz grains are red coloured, they were also counted/ wenig Quarzkörner in der Probe; die Hälfte der Quarzkörner sind rot, diese wurden ebenfalls mitgezählt
32	31.03.05/1	99	97	3	0	Not many quartz grains in the sample, half of the quartz grains are red coloured, they were also counted/ wenig Quarzkörner in der Probe, die Hälfte der Quarzkörner sind rot, diese wurden ebenfalls mitgezählt
33	01.04.05/1	89	95,5	4,5	0	Not many quartz grains in the sample, these grains are mostly milky or red coloured/ wenig Quarzkörner sind in der Probe, hiervon sind die meisten milchig oder rot eingefärbt
34	01.04.05/2	135	98,5	1,5	0	Not many quartz grains in the sample, these grains are rounded and only broken at the edges/ in der Probe sind wenig Quarzkörner enthalten, diese Körner sind gerundet und nur an den Ecken gebrochen
35	03.04.05/1	192	97,4	2,6	0	Many sharp broken quartz grains in the heterogenous sample/ viele scharf gebrochene Quarzkörner in der ansonsten heterogenen Probe
36	03.04.05/2	--	--	--	--	Not enough sand in the sample/ nicht genügend Sand in der Probe
37	06.04.05/1	100	98	2	0	The sample consists of fine sand, because medium sand wasn' t in it, so the quartz grains are small, compact and only broken at the edges/ die Probe besteht aus Feinsand, da Mittelsand in ihr nicht vorhanden war, die Quarzkörner sind klein, kompakt und nur an den Kanten gebrochen
38	07.04.05/1	120	95	5	0	Not many quartz grains in the sample, these grains are rounded and only broken at the edges/ in der Probe sind wenig Quarzkörner enthalten, diese Körner sind gerundet und nur an den Ecken gebrochen
39	09.04.05/1	90	91,1	8,9	0	Not many quartz grains in the sample/ in der Probe sind wenig Quarzkörner enthalten
40	11.04.05/1	106	92,5	7,5	0	The sample consists of all sandfractions, because medium sand wasn' t enough in it; all counted quartz grains belong to the fine sand fraction and are compact and only broken at the edges/ die Probe besteht aus allen Sandfraktionen, da zu wenig Mittelsand in ihr vorhanden war; die gezählten Quarzkörner gehören alle der Feindsandfraktion an und sind kompakt und nur an den Kanten gebrochen

Fig. 4a: Morphometrie Thak- Khola 14.03.05/1- 11.04.05/1

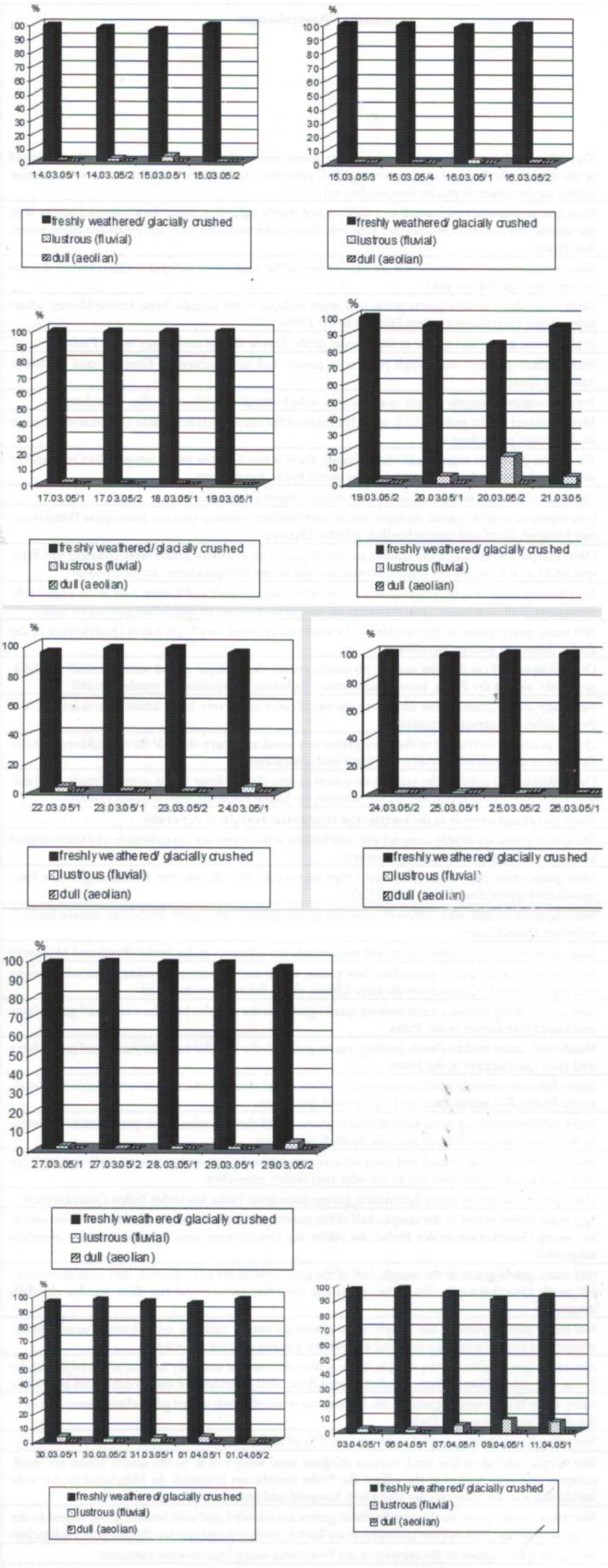


Fig. 4b: Morphometric quartz grain analysis of 40 representative samples from the Mustang-Thak Khola area including the Dhaulagiri-Himalaya-E- and Annapurna-Himal-W-slopes (cf. Figs. 3 and 5/1-5). Sampling: M. Kuhle

Actually there are already two independent proofs with regard to an "age leap" like this of the TCN-dating in High Asia. First there are the moraine complexes T1 and T2 in the lower Rongbuk valley on the Mount-Everest-North-slope dated by Owen et al. (2009). The sampling localities are situated in the same valley cross profile at a height of ~5140 m asl (T1) and ~5000 m asl (T2). T1 (Tingri moraine) is dated to >330 ka, whilst for T2 (Dzakar moraine) an age of >41 ka has been determined. The state of preservation of both accumulates does not cover this difference in age at all - both are described as being "highly weathered". (However, this cannot be assumed to be an indication of an especially high age, because in the upper Rongbuk valley the bedrock, which just recently has been cleared of the glacier, is already prepared for weathering because of its deep hydrothermal decay; cf. Heydemann and Kuhle, 1988). Here, the following is remarkable: despite the authors think that a weathering rate of 2.5 m/Ma is appropriate (Owen et al.2009, 1422) this erosion is not taken into account as to the calculation of the TCN age ("<...> we chose to express our TCN ages without correction for erosion because we cannot predict the uncertainty with any confidence", ibid., 1422)!. This means, however, that the actual TCN-age data have still to be corrected towards above and in the case of T2 must lie at ~45 ka, in case of T1, however, at >400 ka(!). The sample RON 48 of moraine complex T1 concerns boulder measurements of 100x80x35 cm. Without age-correction this boulder is dated to ~361 ka (ibid. Table 4, 1425). Even with a minimum correction this boulder had to be dated to >400 ka and, accordingly, shows an amount of erosion of ~1 m. Thus, with a recent volume of 0.28 m³ the original boulder must have had a volume of ~19 m³. Owing to this, the recent boulder would only consist of 1.4% of the original material - that means, the TCN-dating refers to this small remnant! Moreover it is remarkable, that the moraine boulders from T2 as to their dating are only 1/10 the age and thus have undergone only 1/10 of the erosion of the T1-complex; but in spite of that, the boulders show comparable cubatures (e.g. RON 44: 100x50x50 cm/ ~40 ka; RON 43: 110x80x30 cm/ ~32 ka; RON 42: 115x50x40 cm/ ~35 ka). Here, a further point is remarkable: on the same valley slope up-valley and at the same altitudinal interval, Kuhle has determined with the help of ray range finders (Geodimeter) installed over a period of 40 days at a 30°-moraine slope, current solifluction rates of 4-8 cm/a (Kuhle and Jacobsen 1988: 598). This proves an extreme reworking of the moraines. Considering these values, an in situ exposition age of a moraine boulder of >400 ka, at least should set some one thinking.

The second hint originates from the Skardu basin (Central Karakorum). Here Seong et al. (2008) dated the so-called Mungo glacial stage to ~16 ka. This stage reached or traversed in the position of the end of the glacier tongue a "Riegelberg" or "riegels" (Karpochi Rock), the moraine cover of which provides an average age of 125 ka (samples between 70 ka and 170 ka) and as "Skardu glacial stage" is classified as belonging to the last but one glaciation (Riss or older). In this case, too, the extreme age difference is not covered by the glaciogeological finding. In the meantime

Kuhle's classification of the "Karpochi Rock-Moraine" as being from the Late Glacial (Kuhle 2001c, 2008) has been confirmed by Hewitt (2009a, b).

On the other hand there are also TCN-datings in High Asia which confirm Kuhle's Quaternary-geological and glaciogeomorphological reconstruction of the glaciation. But this could be by chance. So, Seong et al. (2009) carried out TCN- datings of end moraines in the E-Pamir - which the author (Kuhle 1997b) has classified as belonging to the Late Glacial (Stage II-IV) - as being c. 17 ka and somewhat younger. This confirms the age determination of Kuhle. However, unfortunately Seong et al. did not refer to the author's maps and descriptions of the moraines concerned, though they have confirmed them at altitudes between c. 3550- to 3200 m. In addition, the author has evidenced in detail further, clearly lower past ice margins in the E-Pamir at an altitude below 2000 (1800-1850) m, i.e. 1350-1750 m lower. He has glaciogeomorphologically classified them as belonging to the LGM (Kuhle 1997b). However, they were not recognized nor discussed by Seong et al..

It has to be summarized that up to now there exists no physically sTable calibration of TCN-data with reference measurements for High Asia. Accordingly, for the time being, they have to be given up. OSL-data, too, are not applicable because of the incomplete bleaching of glaciofluvial sediments.

Chronology by means of snowline depressions (Ela-depressions)

Accordingly, up to now the methodologically most reliable chronology is only possible by lowest ice margin positions, but not by absolute datings which, with the exception of occasional ^{14}C-datings, are so far not practicable. Because the lowest ice margin positions as a function of the local heights of the glacier catchment areas are subject to very strong fluctuations, the respective height of the snowline (ELA = equilibrium line altitude) has to be calculated. Owing to this the orographic, i.e. real, ELA becomes locally, i.e. in dependence on the exposition, the criterion of the prehistoric glacier chronology. Actually this means that the lowest ice margin of a prehistoric glacier, i.e. its ELA, that is the lowest

Table 1: Glacier stages of the mountains in High Asia, i.e. in and surrounding Tibet (Himalaya, Karakorum, E-Zagros and Hindukush, E-Pamir, Tien Shan with Kirgisen Shan and Bogdo Uul, Quilian Shan, Kuenlun with Animachin, Nganclong Kangri, Tanggula Shan, Bayan Har, Gangdise Shan, Nyainquentanglha, Namche Bawar, Minya Gonka) from the pre-Last High Glacial (pre-LGM) to the present-day glacier margins and corresponding sanders (glaciofluvial gravel fields and gravel field terraces) with their approximate age (after Kuhle 1974-2005).

glacier stage	gravel field (Sander)	approximated age (YBP)	ELA-depression (m)
- I = Riß (pre-last High Glacial maximum)	No. 6	150 000 - 120 000	c. 1400
0 = Würm (last High Glacial maximum)	No. 5	60 000 - 18 000	c. 1300
I - IV = Late Glacial	No. 4 - No. 1	17 000 - 13 000 or 10 000	c. 1100 - 700
I = Ghasa-Stage II = Taglung-Stage III = Dhampu-Stage IV = Sirkung-Stage	No. 4 No. 3 No. 2 No. 1	17000 - 15 000 - 14250 - 13 500 - 15000 - 14 250 13500-13 000 (older than 12 870)	c. 1100 c. 1000 c. 800 -900 c. 700
V -VII = Neo-Glacial	No. -0 - No. -2	5500 - 1 700 (older than 1 610)	c. 300- 80
V = Nauri-Stage VI = older Dhaulagiri-Stage VII = middle Dhaulagiri-Stage	No. -0 No. -1 No. -2	5500 - 4 000 (4 165) 2000 - 4 000 (2 050) 2000 - 1700 (older than 1 610)	c. 300-150 c. 100- 200 c. 80- 150
VII-XI = historical glacier stages	No. -3 - No. -6	1700 - 0 (= 1950)	c. 80- 20
VII = younger Dhaulagiri-Stage VIII = Stage VIII IX = Stage IX X = Stage X XI = Stage XI	No. -3 No. -4 No. -5 No. -6 No. -7	1700 - 400 (440 resp. older than 355) 400 - 300 (320) 300 - 180 (older than 155) 180 - 30 (before 1950) 30 - 0 (= 1950)	c. 60 -80 c. 50 c. 40 c. 30-40 c. 20
XII = Stage XII = recent resp. present glacier stages	No. -8	+0 - +30 (1950 - 1980)	c. 10 - 20

Draft: M. Kuhle

empirically established snowline, belongs to the LGP and is c. 60-18 Ka of age. The next higher, lowest ice margin of the glacier proved by moraines, belongs to the first Late Glacial glacier advance 17-15 Ka ago; the once more next-higher ice margin belongs to the second Late Glacial glacier advance 15-14.25 Ka ago and so on. In this way in High Asia and also in the Dhaulagiri- and Annapurna Himalaya 4 to 6 Late Glacial, 3 Neoglacial (Holocene) and at least 6 historical glacier stages can be differentiated (Kuhle 1982, 1983, 2005b). The orographical-expositional, i.e. local, snowlines provide a further, still more abstract comparative standard, because from them the climatic snowline is derivable. Due to its supraregional comparability it makes a large-scale (i.e. supraregional) chronology possible (Table 1).

Area of investigation

During two 4-month expeditions in 1976 and 1977 (Kuhle 1980, 1982, 1983) the author has evidenced an Ice Age glaciation in the Dhaulagiri- and Annapurna Himalaya (Fig. 1 No 2) that was clearly more important than had been suggested befor for the Himalaya (cf. v. Wissmann 1959). As an area of reference the Dhaulagiri- and Annapurna Himal were especially appropriate for these observations, because the author could visit both, the Tibetan N-slope and the transverse valleys as well as the S-slope. Afterwards, in 2005, the author carried out a 5-week research expedition from the Dhaulagiri- and Annapurna Himalaya to the N through the upper Thak Khola up to Mustang and S-Tibet into the area of the Kore La (Fig. 1 No 32). The results that could be attained are introduced here.

For the reconstruction of the maximum Ice Age glacier filling and cover of this mountain area of S-Tibet through Mustang as far as into the Thak Khola the determination of the then ice thicknesses and ice trim-lines in the valleys are absolutely necessary.

THE HIGHEST FORMER TRIM-LINES AND GLACIER THICKNESSES OF THE MUSTANG-THAK KHOLA OUTLET GLACIER ON THE BORDER OF S-TIBET (TSANGPO VALLEY AND KORE LA) AND IN THE UPPER VALLEY CHAMBER BETWEEN KORE LA AND THE POSITIONS OF THE LOMATHANG- AND MARAN SETTLEMENTS

The 4660 (or 4594 or 4610) m-high Kore La (pass) (Figs. 7, 8 and Fig. 3: No. 3) is situated between the Tsangpo valley in Tibet and the Mustang-Thak Khola (valley). It is the watershed between the catchment areas of Tsangpo (Fig. 7 next to the second ∩ from the right) and Ganges (⇩). Located only c. 90 m higher than the Tsangpo thalweg at c. 4570 m asl, it runs 30 km N of it. This lowest watershad forming the Kore La is 5.5 km wide. Its large-scale course from W to E, and also from N to S, is nearly level (Fig. 7 No. 3). The approximately even face north, west and east of the Kore La (on the left, right and above No. 3) has been shaped in loose rock material (■ on the right of No. 3). To the S, however, the remnants of the originally level area are heavily dissected (⇓). Here we find a loamy-sandy-pebbly matrix into which large, erratic granite boulders in size of several metres are embedded. They are isolated from each other and show an edged, round-edged and facetted form. This is ground moraine with a thickness from 20 up to more than 100 m that lies on soft, middle Tertiary to Pleistocene sandstones of the "Takmar series" (according to Hagen 1968 Plate VI Fig. 1). Large-scale ground moraine surfaces are morphogenetically connected N of the watershed, in the Kore La N-valley, that runs down to the Tsangpo in a northward direction. They have covered the valley flanks across the flat valley bottom up to far over 500 m (Fig. 1 the three white ■ on the right). Here they are situated in thicknesses of some tens of metres on glacially round-polished rock knobs, -hills and mountain ridges. They consist of the dark-brown to black bedrock phyllites of S-Tibet (the four ∩ on the right; Fig. 9 No. 40). Round-polished forms of rock that correspond in height with the ground moraine cover can be found W (∩ on the very left) and E (Fig. 9 first ∩ right hand side of No.3) of the depression of the Kore La (pass). In places the overflowing ice and its glacier bottom has left exaration rills in the ground moraine surface (Fig. 7 ↑). The originally flat formation of the ground moraine in the area of the ice transfluence at the Kore La is typical of "cold- based ice" with permafrost underneath. It is also wide-spread in the High Glacial (Wisconsin) permafrost regions of W-Canada. The sharp dissection of the ground moraine plate on the S-side of the watershed (Fig. 7 ⇓) is a result of backward erosion, which in the future will capture the Tsangpo and drain it off into the Ganges. The force of the backward erosion is a function of the great relief energy of the S-margin of Tibet, which together with the Mustang Thak Khola has brought about here an antecedent transverse valley through the Himalaya. The branching linear erosion of the small side valleys and thalwegs in the Mustang Tak Khola, i.e. in the catchment area of the Kali Gandaki (-river), has cut and modified the ground moraine landscape of the entire valley bottom (Fig. 9 ↓) since the High- to Late Glacial deglaciation of the LGP (Stage 0-IV, see Table 1). This is the cause of the fact that at the Kore La a strong geomorphological change is evident. However, it concerns only the postglacial reshaping of a glacigenic forming, which due to the transfluence of an important S-Tibetan outlet glacier formerly has stretched homogenously and without any breakages across this pass. At many places samples from remnants of the ground moraine surface (Fig. 7 ⬇ and ■ black), i.e. of a ground moraine pedestal (Fig. 9 ¡) have been taken immediately next to erratic boulders (Fig. 7 ⬆; 9 ⇩; 8 ↑↓). – Ground moraine pedestal, pedestal ground moraine or pedestal moraine describe a decametre-thick or even up to several hundred metre-thick ground moraine, that the glacial to late-glacial glacier has built-up below its ground and on which it flowed down as far as into the Late Glacial.

Fig. 5/1 is a sample for that, taken at the Lhari Dzong (Fig. 9 ⇩; 8 x) near to erratic granite boulders. It shows the typical sedimentological characteristics of moraine: a matrix with a bimodal course of the grain size cumulative curve and a secondary maximum in the clay, the relatively high 13% portion of which is a further special indicator of moraine in this steep mountain relief, which otherwise is marked by very intensive fluvial flushing processes. The sorting coefficient of 4.13 is too high as regards fluvial transport mechanisms so that these cannot be taken in to consideration. The morphoscopic analyse is also proof of moraine with a predominance of ground moraine, because 98.1% of the 267 miscroscopically analysed quartz grains are glacially crushed (Fig. 4a/b No.25). Weathering in situ of the bedrock has to be ruled out, because loose material some tens of metres in thickness is concerned here, so that the sampling locality is isolated from the bedrock. Furthermore, the long-distance transport of the fine material matrix is evidenced by the erratic boulders among which it is situated. This also excludes a fresh weathering of the bedrock. Sample 27.03.05/2 from an adjacent locality shows corresponding characteristics (see Fig. 2; 3960 m asl (29°11'36"N/83°57'22"E). It is also situated c. 200 m above the next thalweg and has been taken from a diamictic layer of loose material tens of metres thick. The sorting coefficient of only 2.42 points to a local subglacial-fluvioglacial washing-out of the ground moraine pedestal. Its very small scale is indicated by the SiO2-grains of the medium sand fraction of this fine material matrix from which 99.4% are glacially crushed (Fig. 4a/b No.26). Sample 28.03.05/1 (locality: Fig. 9) on the very right, Fig. 2; 4660 m asl 29°10'20"N/83°53'10"E) provides evidence of ground moraine material in the area of the High Glacial pedestal ground moraine on the orographic right valley flank of the Mustang-Thak Khola at a comparably very great height, i.e. 1160 m above the current Kali Gandaki thalweg. An important indicator as to moraine matrix is the clay portion of 16 % in this slope position that was especially exposed to periglacial and fluvial morphodynamics since the deglaciation; but the 98.2% portion of glacially crushed quartz grains (Fig. 4 a/b, No.27) are also proof of the morainic sediment character. The numerous different minerals that belong to the matrix suggest a subglacial mixture of the material of distant- and local moraine. A matrix sample, the geomorphological position of which is similar to that one on the surface of the High- to early Late glacial terrace of pedestal ground, moraine has been taken 1.2 km further to the NE, i.e. somewhat further to the middle of the main valley and thus c. 85 m lower (Fig. 9 ■ left below ⇩; sample 29.3.05/1 locality: Fig. 2; 4575 m asl 29°10'47"N/83°53'40"E) 98.5% of the SiO2-grains of the medium sand fraction are glacially crushed here (Fig. a/b No.28). 29.03.05/2 (locality: Fig. 2; 4835 m asl 29°10'45"N/83°52'50"E) concerns a sample taken at the same main valley flank but c. 260 m higher up, i.e. nearer to the current glacial environment. Accordingly, the local moraine material there is end moraine material of a local E-exposed neoglacial hanging glacier, which has to be classified as belonging to the Nauri Stage V (Nauri-Stage Table 1). Due to the increased admixture of completely or at least partly glaciofluvial shaped quartz grains, the end moraine character can be recognized in contrast to the High Glacial ground moraine to which it is adjusted in the underlying bed (Fig. 4a/b No.29). 30.03.05/1 (Fig. 9 between ■ below 11 and ■ below 21 Fig. 2; 4310 m asl 29°09'20"N/83°54'16"E) represents a further example from the orographic right valley flank area of the High to Late Glacial Mustang-Thak Khola ground moraine pedestal. Here, the ground moraine pedestal covered by the High Glacial main valley glacier, which at the same time was the S-Tibetan outlet glacier, has undergone a reshaping due to Late Glacial hanging glacier dynamics of the right valley flank. One of the numerous parallel-arranged tongue basins of the Late Glacial hanging glaciers has been scoured out of the High Glacial ground moraine pedestal. The very high clay portion of 11.5%, the So of 4.53 and the morphometry of the quartz grains (Fig. 4a/b No.30), which in relation to the topographically-determined intensive washing-off at an exposed slope position 800 m above the current thalweg of the Kali Gandaki main valley river is very high, prove a position above the then snowline (ELA) even at the time of these Late Glacial tongue basins. Below the ELA a fluvioglacial washing-out and modification of the matrix ought to be expected. On the surface of the reshaped body of pedestal moraine granite boulders have been glaciofluvially deposited, i.e. concentrated by the flushing of moraine matrix during the deglaciation. A last representative sedimentological proof of well-preserved extensive remnants of ground moraine covers or -pedestals in a terrace-form situated very high up, provides sample 30.03.05/2 (Fig. 5/2). The sampling locality is on the valley cross-profile of the Maran settlement, c. 500 m above the thalweg of the Kali Gandaki (Fig. 2). The very clayey (15%) matrix was found between nests of boulders and separate, very large, partly erratic granite boulders (Mustang granite?); it shows again all the characteristics of moraine (Fig. 4a/b No.31). The very high sorting coefficient of 6.87 is typical of ground moraine. Exposures prove the very important thickness of this ground moraine complex. As in other localities geomorphodynamic slides have been observed here. They are typical of massive sediments of ground moraine covers, too. This applies the more, because strictly speaking here, in the precipitation shadow of the High Himalaya, the semiarid climate is unfavourable to slide dynamics.

Above the ground moraine pedestals (Figs. 7-9) that attract attention because of the large glacigenic sediments of drift far above 100 m in thickness, with a clayey matrix and - in the coarser fractions - glacigenically crushed grains (see above), ground moraine covers thinning out towards above (Fig. 9 the two ■ on the very right) continue between 4300 and 4900 m asl.. A sample from these has also been taken by the author for purposes of comparison at e.g. 4540 m asl (Locality: 29°06'N/83°51'50"E Fig. 2: 31.03.05/1). The analyses regularly show minor clay portions (here 9%) on the thin covers. However, the bimodal course of the grain-size histograms remains and also a relatively high sorting coefficient (here So = 4.1). 97% of the microscopically examined SiO2-grains again are sharp-edged, i.e. glacially crushed or freshly weathered (Fig. 4a/b, No.32). Due to the lack of erratics this was not to be excluded at this locality. As to the topography it is evident that a Late Glacial reshaping by hanging glaciers and flank ice must have taken place here, which ocurred glacigenically, but at a right angle to the High Glacial direction of the valley glacier, i.e. slope-downwards.

Up to date temporarily nival and perennially periglacial denudation is effective at this localities, which is proved by solifluidal slope terraces.

After the ground moraines have been evidenced sedimentologically and geomorphologically mainly along the orographic right Mustang-Thak Khola valley side (W of the Kali Gandaki), those on the orographic left, eastern valley side will now be introduced. They have been traced back down-valley and approached and marked in their topographical connection and thus the genetic arrangement of their positions in the Fig. 9 (■ above between No.1 and 12) and in Fig. 2.

As on the orographic right (see above), so also on the orographic left Mustang-Thak Khola valley flank glacigenic reshapings of the High Glacial (Stage 0, LGP or LGM, Würm; Table 1) ground moraine landscape by Late Glacial (Stages II-IV) up to Neoglacial (Stage V) glacier tongue basins joining from the orographic left, i.e. from the side valley glaciers from the E, have been evidenced (Fig. 2: 0-II, 0-III, III-IV, II, III). This reshaping took place nearly at a right angle to the High Glacial Mustang-Thak Khola outlet glacier stream flowing down from ca. N to S.

Above the pedestal ground moraines that in many places are more than 100 m thick (see Fig. 7 ■ black, Fig. 8 and 9: ■), the ground moraines on the orographic right side, as well as on the left, do thin out and rest against the rocky valley flanks (Fig. 7 ■ on the very left and right; Fig. 9 the two ■ on the very right). In some places this occurs in the form of a trough valley (e.g. Fig. 9 ■ below No.13). These are further local indicators of the preservation of primary forms of ground moraines.

In the valley cross-profiles of the Mustang-Thak Khola with an extension of 20-35 kilometres, classic glacigenic sections of trough cross-profiles in the bedrock naturally are only visible above the mantlings with ground moraines, i.e. above the valley bottom and the lower slopes. Accordingly, only there are they definitely verifiable (Fig. 7 ∩ on the very left and ∩ black, 9 ◓◠ and ∩). In some cases the pure line of the cross-profile is also preserved on sharpened rock ribs. Fig. 9 (∩ on the very right), however, shows a glacigenically back-polished mountain spur in a considerable slope-parallel extent of several hundreds of metres that forms a glacigenically triangular-shaped slope (Fig. 7 ∩ on the very left).

Generally these are faces of valley flanks which at the same time are named polish board. In many places they show rock smoothings or at least rock abrasion roundings (Fig. 7 ∩ on the very left; 9 ◠ and ∩ on the right). They mediate up to the polish- and abrasion line that, due to the abrupt change into strong roughening of the rock surfaces, makes the uppermost High Glacial (Stage 0) glacier trim-line recognizable and reconstructable (Fig. 9: 0 ---- and --->).

The trough valley cross-profiles of the tributary valleys hanging c. 1500-1800 above the main valley bottom and its thalweg, the Kali Gandaki, have been very well developed during the High- and Late Glacial (Stage 0-IV, cf. Table 1) (Fig. 2: ∪: east and south-east of Peak 16, north-north-west (NNW) of Peak 33, between Peak 32 and 33, S of Peak 32 and 33, E of Peak 29, WSW of Peak 17). They are preserved up to the confluence step into the main valley. Examples are also provided by the Ghyun Khola and the Dhuya Khola (Fig. 2: ∪ south and further south of Peak 16). The confluence step itself has been partially cut more than 100 m-deep as far as into the bedrock (Fig. 2: "subglacial-glacigenic ravine or -gorge": on many places between Peak 16 and 33, SE and SSE of Peak 16, E and SE of Peak 33, S and SW of Peak 28, ESE of Peak 29). These thalwegs have already been laid out subglacially by meltwaters at a time when the ELA had already been uplifted to at least 5000 m asl. This condition was only fulfilled during the late Late Glacial from Stage IV (Sirkung Stage, Table 1) on (see Kuhle 1982, Bd.1 Table VI.: 157/158). In some places subglacial incisions like these are preserved as glacial gorges (Fig. 2 "subglacial-glacigenic ravine or -gorge": SSE of Peak 16; NNE of Peak 33).

The three-dimensional control of the height of the abrasion- i.e. polish line in the longitudinal valley course of the Mustang-Thak Khola from the Kore La down to the S is a methodologically important empirical indication. Selective, i.e. small-scale errors may be caused due to differences of the rock and thus roughening at otherwise similar conditions of weathering. At a decline of this border line between smoothing and roughening running parallel on both valley flanks with the only possible direction of slope of a past glacier surface - this small-scale errors can be excluded - because this border line is confirmed to be a polish line on a large scale.

This polish line, i.e. the level of the High Glacial Mustang-Thak Khola glacier, runs nearly parallel on both valley sides from S-Tibet, i.e. from N of the Kore La (Table 2 No.3) from 6300-6000 m asl (Fig. 7 ----, 9: 0 ---- on the left and on the left side of 0 ---- in the center) - recognizable by polish- and abrasion lines lower than 6000 m and higher than 5300 m (Fig. 9: on the right side of 0 ---- (in the center) and between No. 39 and 12) - up to c. 5300 m asl to the valley cross-profile near the Maran settlement (Fig. 9:---- below No.7-11). The extent of the abrasion- i.e. polish line from NNE to SSW is 26-29 km long; over this distance the ice level has dropped by 700-1000 m. The lowering of this surface of the outlet glacier - that has been found out with the help of the polish line - is c. 300 m greater than that of the surface of the ground moraine slab on which the glacier bottom was superimposed. The difference in height of the ice surfaces of the cross-profile at the Kore La (Table 2 No. 3) of c. 6000 m, up to the Mustang-Thak Khola cross-profile near the Maran settlement with a height of the glacier surface of 5300 m asl, was 700 m. Compared with this, the height of the ground moraine slab in the lowest area of the transfluence pass (Fig. 7 No. 3) and the downward area of the valley bottom has dropped from c. 4650 to 4250 m (Fig.

9 from No. 3 down to the valley ground below No.11), i.e. by only c. 400 m to the S.

THE LATE GLACIAL LATERAL- AND GROUND MORAINES AND THE GLACIOFLUVIAL TERRACES OF THE UPPER MUSTANG-THAK KHOLA AND THEIR CONTINUATION INTO THE MIDDLE MUSTANG-THAK KHOLA

Since the start of the deglaciation at the end of the High Glacial and early Late Glacial (Stage 0 (= LGP) up to Ghasa Stage I, Table 1; see Kuhle 1982), the main valley chamber (the term "valley chamber" describes a topographically defined valley section within the longitudinal course of a valley as e.g. that one between the Tukuche (Tukche) and Kalapani settlements in the middle Thak Khola) of the Mustang-Thak Khola that is under discussion here, has become an ablation landscape, i.e. it was more and more released from the ice. This process was interrupted by Late Glacial glacier advances. However, they reached less and less far down the Mustang-Thak Khola. The last advance that reached the main valley thalweg in the area of the current Lomathan settlement took place during the last Late Glacial Stage, the Sirkung Stage (IV, Table 1). It is uncertain whether the glaciation has still taken place from the Tibetan inland ice across the Kore La (Table 2 No. 3) or whether at this time of the Late Glacial this High Glacial transfluence pass was already free of ice because of the uplift of the snowline (ELA). So, in case this outlet glacier of the Tibetan inland ice should no longer have existed, these must have been late Late Glacial glaciers from the catchment areas far above 6000 m that were connected to the two valley flanks of the Mustang-Thak Khola (e.g. Fig. 7 III-IV), and which on the valley bottom of the Mustang-Thak Khola have joined to one parent glacier. The reworking of the High Glacial ground moraine pedestal by late Late Glacial hanging glaciers from the area of the main valley flank are proved by tongue basins that everywhere are inset into those two valley flanks (see Fig. 2: all positions of IV, cf. Table 1). This reworking was not only the result of the advance of the Late Glacial to Neoglacial (Fig. 2: all positions of V and 'VII-V, cf. Table 1) glacier tongues, but also of their sanders. These were mainly glacier mouth gravel floors, filled into the ground moraine landscape which, due to the post-High Glacial deglaciation, had been released from the ice (Fig. 2 "glacier mouth gravel floor and alluvial terraces in contact with moraines", e.g. no.-0) and partly dissected by fluvial backward incisions (Figs. 7 and 9: □ white). In the course of the progressive back-melting of the Late Glacial (Stage I-IV) and then Holocene (Neoglacial Stage V-'VII) glacier tongues, the glacier mouth sanders (glacier mouth gravel floors) of which have been accumulated during the advance (advance gravel = Vorstoßschotter), these gravel floors have been cut by the regular-concavely hanging-through thalweg of the glacier stream. The terraces which at the same time have been developed and which in some places today still show over 100 m-high steps (e.g. Figs. 7 and 9: □ white), frequently reach down with their terrace steps up to the primarily developed High Glacial ground moraine. The highest terraces are located between the junction of the Cha Lungpa (valley) and the Tanbe settlement (Fig. 2: location between Panoramaphoto 58 and 59). In some places several glaciofluvial terrace levels are preserved, i.e. a terrace with many steps (Fig. 9 □ below No.7). Their levels maximally represent four Late Glacial (Stage I-IV) and three Neoglacial (Stage V-'VII) glacier stages (Table 1: No.4 to 1 and -0 to -2) in their catchment areas, i.e. the levels of the glaciofluvial gravel fields are classified as belonging to a certain ice margin position and glacial series ("glaziale Serie" after Penck and Brückner 1901-1909) as a sander down-valley of the glacier tongues and end moraines. The highest terrace levels are thereby the oldest Late Glacial ones, i.e. the lowest levels preserved in some places are only of historical age (Table 1: No.-3 to -7). The gravel field (or sander) No.-8 (Fig. 2: no.-3- -8) is the contemporaneously accumulated gravel floor in the Mustang-Thak Khola with the Kali Gandaki river and its tributary valleys. Accordingly, this gravel field represents the at present active gravel floors of the current glacier termini of the uppermost hydrological catchment areas, which with their meltwaters are connected to the Kali Gandaki. However, since the current glacier termini come to an end very high (about c. 2000 m) above the modern gravel floor of the main valley, steep escarpments and gorges are intercalated into the courses of tributaries and streams. They blur the differentiation of the younger gravel fields. Correspondingly the younger, i.e. historical gravel fields - which the author has therefore called "indirect sanders" (Kuhle 1982, 1983) - meet at just one level in the Mustang-Thak Khola valley bottom (Fig. 2: no.-3- -8).

In some places large debris flow fans of dislocated ground moraine instead of flatter glacier mouth gravel floors have developed below the Late Glacial or Neoglacial glacier termini (Fig. 7 □ black). This has regularly happened where the late Late Glacial to Neoglacial glacier mouths were located, i.e. where they were "hanging" in the steep slope areas or junctions of tributary hanging valleys of the Mustang-Thak Khola valley flanks. Mostly only the fan sediments close to the surface have been formed by debris flow activities (Fig. 7 □ black; see also Fig. 4a/b sample No.15: with regard to the terrace surface this morphoscopic analysis shows a relatively high portion of 16.7% of fluvially polished SiO2-grains so that glaciofluvial influence has to be assumed), whilst they regularly show a core of pedestal ground moraine (Fig. 7 ■ IV below □ black).

THE HIGHEST FORMER TRIM-LINES AND GLACIER THICKNESSES OF THE MUSTANG-THAK KHOLA IN THE VALLEY CHAMBER BETWEEN THE POSITIONS OF THE MARAN- AND CHAILE SETTLEMENTS

Somewhat N of the Dhakmar settlement an over 1 km extended intact, relatively flat, i.e. slightly hilly or terrace-shaped remnant of a ground moraine surface continues on the orographic right side in the middle Mustang-Thak Khola about 4030-4200 m asl as far as to the Muila Bhanjyan (a small pass) (Fig. 2: location sample 1.4.05/1). Samples have been taken from its material that show geomorphological as well as all the sedimentological characteristics of ground moraine (Fig. 5/3; Fig. 4a/b No.33). On the surface of the ground moraine, as well as in its everywhere tens of metres up to more than 200 m-thick sedimentation body erratic granite boulders are situated (Fig. 2). At this height about a fully 4000 m asl the bottom of the High- to early-Late Glacial (Stage 0-I or II) Mustang-Thak Khola outlet glacier was lying, i.e. moved in a flowing or sliding way across the ground moraine.

The southern continuation of this ground moraine pedestal has been interrupted by a younger Late Glacial glacier tongue in the area of the Dhakmar settlement, that the Dhakmar Khola - a pure moraine valley - has worked into the over 200 m-thick ground moraine (Locality: 3660 m asl 29°04'21"N/83°53'01"E, Fig. 2: 25.03.05/2). The bottom of this Late Glacial tributary glacier valley has been reshaped, i.e. dislocated by debris flow activities since the deglaciation (Fig. 4a/b No.23). The southern continuation of the ground moraine pedestal has unambiguously been evidenced with the help of a further remnant of a ground moraine pedestal between the Dhakmar- and Ghami Khola close to the Ghami La (pass) (Locality: Fig. 2: 01.04.05/2; Fig. 5/4). Moreover, Figure 4 (No.34) indicates that close to the surface of the ground moraine pedestal about c. 3640 m asl, subglacial meltwater has participated in the sedimentation; this is characteristic of "warm-based" glaciers. 1.5% of the SiO2-grains are fluvially polished; a significant portion of the grains which at 98% are glacially crushed, have first been fluvially rounded and then crushed. This is an indication of a glacier cover at a time when the ELA was already lifted up to a height clearly above 3640 m. The valley bottom of the Ghami Khola has also been developed in the excavation area of a Late Glacial (Stage III) hanging glacier flowing down from the orographic right Mustang Thak Khola valley flank (Fig. 2: Locality: IV in the W of Panoramaphoto 34). Before its downcutting it has been shaped by the gravel floor i.e. sander of the ice margin position of Stage IV.

Also on the orographic left flank of the Dhakmar- and Ghami Khola (Fig. 2: Locality of Panoramaphoto 33/36) - the two valley flanks merge in the junction area of the Dhakmar- and Ghami Khola - the up to several hundred metres thick (see above) material of the ground moraine pedestal continues to the S. It lies on reddish bedrock sandstones. At the Chingel Bhanjyan it culminates in ridges and hilltops shaped by postglacial fluvial erosion (29°03'45"N/83°54'10"E) Chingel Bhanjyan (pass, mountain- i.e. hill saddle)). In the centre of this ground moraine pedestal glaciotectonic disturbances are exposed, i.e. glacigenic compressions as they are characteristic of ground moraines with permafrost (Fig. 2: Locality of Photo 33). But also the samples (Fig. 2: 26.03.05/1, 29°03'45"N/83°54'10"E) taken from these highest accumulation surfaces prove its ground moraine character especially due to the 99.5%-portion of glacigenically crushed SiO_2-grains in the fine matrix (Fig. 4a/b No.24) that is interspersed with large erratic granite boulders (Mustang granite? after Hagen 1968 plate VII Fig. 2).

After the melting of the LGM (Stage 0)-Mustang-Thak Khola outlet glacier, the Late Glacial Ghami Khola glacier (probably Stage III, cf. Table 1) that has flowed down from S-Tibet towards ESE, i.e. straight across up to diagonally to the LGM-outlet glacier, has left behind a trough-shaped glacier valley in the High Glacial pedestal moraine body (location on Fig. 2: NE of Panoramaphoto 29). At this time the ELA has already run so high (c. 4300-4500 m; cf. Kuhle 1982, 1983) that in the lateral valleys of this Late Glacial glacier tongue meltwater has eroded the older pedestal ground moraines and dislocated and resedimentated as glaciofluvial lateral sanders (location on Fig. 2: Panoramaphoto 35). The N-parallel Charan Khola shows the same glaciogeomorphological characteristics as the Ghami Khola (location on Fig. 2: Panoramaphoto 14): here, too, a diagonally down-flowing orographic right glacier tongue of a tributary valley has been worked into the High Glacial ground moraine pedestal so that along the two glacier margins glaciofluvial washing-outs of ground moraine (Fig. 2 "glacier mouth gravel floor and alluvial terraces in contact with moraines" near Panoramaphoto 14) have developed. After the deglaciation the moraine pedestal in the Ghami Khola which has come into being during the late Late Glacial has also been slightly glaciofluvially reshaped for a short time (Fig. 2 "glacier mouth gravel floor and alluvial terraces in contact with moraines" near Panoramaphotos 35, 29) (during Stage IV) and fluvially cut backwards since the ending late Late Glacial (post Stage IV) and the early Holocene.

Between the Ghami Khola and the S-parallel Tama Khola again a S-connected complex of pedestal ground moraine is situated that is far more than 100 m thick. It culminates in the good 4000 m-high Nyi La (pass) (Fig. 2 "pedestal ground moraine" and "ground moraine" around Panoramaphotos 38; 39). In many places the postglacial dissection and formation of small valleys caused by backward erosion from the direction of the Kali Gandaki main valley thalweg, exposes the ground moraine sediment with its typical fine material matrix that shows all sedimentological (Fig. 2 sample 25.03.05/1 4020 m asl, 29°02'03"N/83°51'25"E Nyi La) and morphoscopical characteristics (Fig. 4a/b No.22) and also with isolated erratic granite boulders integrated in it. Despite the fluvial reshaping, the surface level of the pedestal moraine between 4000 and 4150 m asl remains recognizable up to the present time. The fluvio-glacial washing-out below the glacier that has taken place during the Late Glacial (c. Stage III), as well as the glacio-fluvial washing-out of the fine material matrix since the deglaciation has led to the concentration and in some places also sorting of sizes of those coarse, far-travelled granite boulders. Beyond the Tama Khola the very important ground moraine pedestal continues to the S with the same thickness and an equal surface level. At its eroded N-breakage sample 24.3.05/2 (Fig. 2; 4100 m asl 29°00'25"N/83°49'50"E) has been taken; with the exception of the sorting coefficient (So = 2.24) that points to fluvial transport, here too, all the other sedimentological and morphoscopical characteristics (Fig. 4a/b No.21) prove the ground moraine substrate. At the same time the SiO_2-grains, from which even 100% are glacially crushed, clearly provide evidence of a fluvial transport of only some metres to tens of metres but not more at this locality.

The Tama Khola discussed here (location on Fig. 2: N of Panoramaphoto 39) as well as the again S-parallel Yamta Khola (S of Panoramaphoto 41) have been eroded by the late Late Glacial (Stage IV) hanging glacier tongues - flowing down from the orographic right Mustang Thak Khola main valley flank - and its meltwaters into the LGP (Stage 0; Table 1) ground moraine pedestal.

The maximum Last Glacial (Stage 0) glacier trimline of the orographic right main valley flank reconstructed according to the abrasion line above the truncated spurs, i.e. glacially triangle-shaped slopes, runs between N of the Dhankmar settlement up to the Yamta Khola (Fig. 2: from 1.4.05/1 to 24.3.05/2) from c. 5300 down to 5000 m asl.

Again c. 2 km further S of the orographic right course of the tributary valley of the Yamta Khola, the Jhuwa Khola is running parallel as well as a further thalweg of a side valley (Fig. 2: 24.3.05/1). Both the thalwegs erode backward into a further, again more southerly section of the LGP (Stage 0-I) ground moraine pedestal described here. Here too, the postglacial fluvial cutting verifies a thickness of the ground moraine of more than 100 m. At the Beg La close to the Chunsi settlement a sampling near to the surface (Fig. 2: 24.3.05/1, 3930 m asl 28°58'55"N/83°48'52") confirms the geomorphological result of the ground moraine pedestal with a trimodal course of the grain size cumulative curve, a relatively large clay portion and a good 95% of glacially crushed SiO_2-grains of the medium sand fraction (Fig. 4a/b No.20). Here between 900 and 1200 m asl above the Kali Gandaki - that is to say the Mustang-Thak Khola thalweg in the middle of the main valley - the thickness of the ground moraine pedestal diminishes. Its down-slope surface incline, left behind by the High- to Late Glacial glacier bottom, increases and with decreasing thickness of the ground moraine the tapering-off ground moraine pedestal nestles against the valley flank at an acute angle (Fig. 2: W of Photo 45). Corresponding geomorphological circumstances exist along the S-parallel Bhena Khola hanging valley. Above the up-slope tapering-off ground moraine overlay, the High Glacial glacier level is verified by the highest polish line between 4800 and 4900 m asl (Fig. 2: "glacial flank polishing and abrasion" W of Photos 45, 46, 48).

The highest sedimentological evidence of ground moraine is provided here by sample 23.3.05/2 (Fig. 2; 28°58'30"N/83°48'20"E), taken at 4190 m; the grain size analyses show a fluvial and solifluidal modification, whilst the morphoscopy with 98.9% broken quartz grains makes a glacial genesis of the matrix probable (Fig. 4a/b No.19). The two small orographic right side valleys - upper Bhena Khola and adjacent thalweg (Fig. 2: Photo 45, 46) - cited here in connection (the Jhuwa Khola is not included because it drains further S), coalesce in a larger hanging side valley, the main valley Bhena Khola (Fig. 2: Photo 48). During the pre-LGP (Late Tertiary to Middle Pleistocene) this side valley has been eroded into the slightly tilted, reddish-brown sandstone bedrocks and conglomerates of the "Thakmar series" (according to Hagen 1968 i.e. plate VII Fig. 3); in the LGP it has been filled by the ground moraine of the Mustang Thak Khola outlet glacier. Now, since the last deglaciation, this pedestal ground moraine is again - in this case fluvially - excavated. Figure 2 ("pedestal ground moraine with escarpment" SE of Photo 48) shows the ground moraine cover described on the bedrock "Thakmar series".

A further 1.6 km (i.e. 2 km) from the Bhena settlement to the SSW, down the main valley, again two right tributary valley thalwegs cut through the High- to Late Glacial ground moraine pedestal - those of the Jhuwa- and the Samarkyun Khola. Above this root of the pedestal moraine on the right flank of the Mustang-Thak Khola valley, W above the Samar settlement (see Fig. 2: Photo 47) the LGP-polish line and thus the level of this S-Tibetan outlet glacier has also run between 4700 and 4800 m asl (Fig. 2: "glacial flank polishing and abrasion" W of Photo 47). Again 2.5 km to the S the Ghyakar Khola is situated with a large tongue-basin-like excavation area that has been taken up by a late Late Glacial orographic right tributary glacier tongue (Stage IV, Table 1). Earlier, during Stage 0-III, here too, a more than 100 m-thick pedestal moraine cover has existed, accumulated by the Mustang-Thak Khola main valley-, i.e. oulet glacier (Fig. 2: "pedestal ground moraine with escarpment" and "ground moraine..." NE and SW of Panoramaphoto 49). It was overlying the horizontal yellow-brown bedrock sandstones of the "Thakmar series" (Hagen 1968, i.e. plate VI Fig. 1). With regard to the sedimentology, the ground moraine character is also confirmed (sample 23.03.05/1, Fig. 2, 3640 m asl 28°56'30"N/83°48'44"E): 1. by means of the bimodal accumulative curve, 2. because of the 8% clay portion and 3. due to a high sorting coefficient (So = 5.21). The erratic facetted and round-edged granite boulders (palaeozoic Mustang granite) with longitudinal axes exceeding 1 m, that "swim" in the matrix isolated from each other, prove that the 98.2% crushed SiO2-grains of the morphoscopically analysed matrix are really "glacially crushed" (Fig. 4a/b No.18). This is unambiguously erratic matrix that cannot have been developed in situ. Accordingly, the possibility that these are freshly weathered quartz grains has to be ruled out.

Along the lowest valley chamber, the right flank of the Ghyakar Khola (location: Fig. 2 Panoramaphoto 49, 50) made up of remnants of pedestal ground moraine, is dispersed by backward linear erosion into small valleys and source basins. Since the deglaciation the valley bottom has also been reshaped by the accumulation of a debris flow fan (location: Fig. 2 Panoramaphoto 49) of dislocated ground moraine. In the meantime, however, this debris flow fan is no longer active, but is fossilized by incision. This very steep incision into the loose rocks of the debris flow fan and the still existing primary ground moraine that continues in the underlying bed and also down-valley, runs through - according to the process of backward erosion - up to the thalweg of the Mustang-Thak Khola, i.e. to the Kali Gandaki river (location: Fig. 2 Panoramaphoto 55). Today this junction solely consists of the High- to Post-Glacial sediments described, which above 100 m are vertically exposed. The largest exposure of that pedestal ground moraine exists on the N-side of a remnant of a ground moraine pedestal preserved up to the former approximately primary surface (Fig. 2 "pedestal ground moraine" WSW of Panoramaphoto 52).

The exposure allows the immediate macroscopic look at the ground moraine character of the accumulations. In the direct confluence of the Ghyakar Khola and the Kali Gandaki sorted gravel bands intercalated into the ground moraine excavation area, are exposed on which the Chaile settlement is situated and which can be interpreted as being "glaciofluvial". On the orographic right, i.e. on the side of the Chaile settlement, as well as on the left side of the Kali Gandaki (Mustang-Thak Khola) the High- to Late Glacial remnants of a ground moraine pedestal are situated. They correspond with regard to their level and in many places are far more than 100 m thick (Fig. 2 "ground moraine" E of Panoramaphoto 53 and "pedestal ground moraine" S of Panoramaphoto 54). They lie on the flat reddish-brown bedrock sandstones and conglomerates of the "middle Tertiary Thakmar series" (Hagen 1968 plate VII Fig. 2) and their rock ledges and cornices. The sedimentological condition of the fine material matrix confirms the morainic character that becomes recognizable by the bimodal course of the grain size accumulation curve (Fig. 2: sample 22.03.05/1: 2960 m asl 28°55'33"N/83°49'52"E c. 1 km SE of the Chaile settlement), the clay portion which is relatively high with regard to the mountain relief and the 95% high supremacy of glacially crushed SiO2-grains (Fig. 4 a/b No.17) in combination with polymictic and among them erratic granite boulders. The relatively insignificant sorting coefficient of So = 3 and the portion of 4.3% fluvially polished SiO2-grains prove a modification of the condition of the ground moraine which, due to the subglacial meltwater activity, is easily understandable.

The current gravel floor of the Kali Gandaki in which the glaciofluvial gravel floors of the last 2000 years, that is the historical recessional stage, join at one level (Fig. 2: between no.-3 - -8 S of Panoramaphoto 53 and 59), consists of the fluvially condensed, High to Late Glacial material of those important pedestal ground moraines, from which the matrix has nearly been washed out. Due to the supply with moraine material by debris flow fans and lateral erosion this process of fluvial redeposition and condensation still takes place (Fig. 2).

Immediately E below the Chaile settlement the Kali Gandaki a several tens of metres-deep glacial gorge (locality Fig. 2: "subglacial-glacigenic ravine or gorge" N of Panoramaphoto 53) runs in. Its vertical to overhanging faces in the Tertiary sandstones and conglomerates of the Thakmar series have been made up by the typical subglacial cavitation corrasion of the meltwater flowing under great pressure in an ice tunnel. This is a subglacial key form. In a reverse conclusion the glacial genesis of this gorge is confirmed by the Kali Gandaki flowing on a current gravel floor that covers the bedrock in a significant thickness. That means, that the modern mountain river accumulates gravels but does not cut into the rock underground - as this must have happened during the past development of the glacial gorge.

THE DEPOSIT OF MORAINES AND THE HIGHEST FORMER TRIM-LINES AND GLACIER THICKNESSES OF THE MUSTANG-THAK KHOLA IN THE VALLEY CHAMBER BETWEEN THE POSITIONS OF THE CHAILE- AND THINI SETTLEMENTS

W of the Chhomnan settlement the ground moraine (Fig. 2: "ground moraine" W and NE of Panoramaphoto 56) overlays as well as the bedrock in the underlying bed, the reddish-brown, flatly deposited sandstone bedrocks and conglomerates of the "middle Tertiary Thakmar series" (Hagen 1968 plate VII Fig. 3), are exposed up to a height of c. 400 m. Along the ac- and bc-clefts followed on by the front of outcropping rock faces, vertical subglacial meltwater organs are formed, which correspond to very deep potholes, i.e. have been developed from them (locality Fig. 2: W from the Panoramaphoto 54-58). The still remaining pillar-like covering of ground moraine that is only just preserved on the faces of the sandstone bedrocks and conglomerates is remarkable. It must be interpreted as an indicator of dating and originates from a past complete, several hundreds of metres-thick ground moraine filling of the Mustang-Thak Khola caused by that High- to Late Glacial pedestal moraine basement on which the corresponding S-Tibetan outlet glacier has flowed down. The dating indicator is given, due to the fact that this clay-containing loose sediment, which is easily to erode and can even be washed down by rainwater, has been preserved in a steep form, i.e. without crumbling away. So, without any compulsion this classifies the preceding ground moraine filling as belonging to the Last Glacial, i.e. the LGP (LGM=Stage 0) to Late Glacial (Table 1).

In a similarly good condition are the geomorphological indicators down the main valley W of the Chhusan settlement (Fig. 2 W of Photo 57). Subglacial potholes, i.e. organs structure the outcropping rock faces as well as the remnants of moraine preserved in an unsTable position, which not only form broad, relatively sTable pillars, but even form the still more fragile earth pyramids (Fig. 2 earthpyramids W of Panoramaphoto 59).

Separated by a debris flow fan (Fig. 2: NE of Panoramaphoto 58) originating from the orographic left tributary valley, the Narsin Khola, which consists of dislocated ground moraine of the Ice Age ground moraine pedestal, is situated the downward valley chamber of the Mustang-Thak Khola. Down-valley it is again fringed by a - now orographic right - debris flow fan (Fig. 2: W of Panoramaphoto 58). Its origin is the Chhincho Khola and it is also built up from dislocated ground moraine. The most highly situated mantle face of the Chhincho Khola debris flow fan preserved in remnants, has been fossilified long ago (since Stage IV? s. Table 1) due to incision. To the author it seems probable that the built-up of this oldest fan mantle face - and thus of the greatest portion of material - has taken place immediately after the deglaciation of this main valley cross-profile. This was the late Late Glacial to early Holocene initial phase during which the - here everywhere more than 100 m-thick - body of the pedestal ground moraine (Fig. 2: W of Panoramaphoto 59) was for the first time exosed to the postglacial fluvial morphodynamics. Correspondingly violent redeposition by debris flows must have been connected with this. The gorge stretch of the Chhincho Khola has been laid down as a subglacial gorge in the late LGP (Fig. 2: NW of Panoramaphoto 58). The down-valley connected valley chamber shows corresponding Late Glacial to Holocene remnants of a debris flow fan which today are dissected, i.e. undercut (Fig. 2: S of Panoramaphoto 59). In some places also rock roundings (Fig. 2: "features of glacial polishing" and "abrasion" W and S of Panoramaphoto 59) are preserved deriving from the High- to Late Glacial glacier ground polishing. In a vertical proximity to the valley bottom, remnants of gravel floors in the form of gravel ledges, i.e. terrace remnants are preserved in many places (Fig. 2: "glacier mouth gravel floor" S of Panoramaphoto 59). In addition rock falls (rock avalanches) have been interpreted as postglacial crumblings (Fig. 2: NW and NE of Panoramaphoto 59) of past glacigenic undercuttings and flank abrasions.

The really huge dimensions of the mantling with ground moraine in this middle section of the Mustang-Thak Khola between Chaile and Kagbeni up to far above the Kali Gandaki thalweg can be approximately estimated according to the Figure 2 ("pedestal ground moraine…", "ground moraine with and without erratic boulders" W and E of the profile between "Panoramaphoto" 53 and "Sampling locality" 3.4.05/1). At the same time the fluvial cutting into these ground moraine pedestals and the accompanying development of debris flow fans is clearly visible. As a result of the fluvial sharpening of the relief Holocene to current slides have also been observed in these glacigenic loose rocks (Fig. 2 "moraine slide" W and E of the profile between "Panoramaphoto" 53 and "Sampling locality" 3.4.05/1). The condition of the moraines, as well as their redeposition which in many places has geomorphologically been evidenced, is shown by sample 3.4.05/1 (Fig. 2, 2870 m asl 28°53'35"N/83°48'26"E): the at least 97% portion of crushed SiO2-grains of the medium sand fraction in combination with large erratic (Mustang?) granite boulders, the bimodal course of the cumulative curve of the grain sizes and the clay portion confirm the morainic genesis, whilst the sorting coefficient of So=2.37 and the 2.6% fluvially polished SiO2-grains speak in favour of a secondary fluvial rearrangement of the moraine matrix (Fig. 4a/b No.35): the loss of ignition LOI = 0.8% also points to a secondary redeposition considering the sampling depth of c. 50 m.

Between the sampling locality in the valley chamber of the Tanbe settlement mentioned above and the down-valley junction of the Ghilunpa Khola (Fig. 2: W of "Sampling locality" 3.4.05/1) or Cha Lungpa (as it is called by the inhabitants of the Sangda settlement living in this valley) findings have already been published by the author (Kuhle 1982, 1983). Here, five glacier gravel floor terraces have been described above the Kali Gandaki thalweg (Kuhle 1982: 68; Abb.27 background; Abb.26; Abb.25 segment 1-3 middleground; Abb.29 on the left below Nr.89; Abb.184; 1983:184). These are terrace forms of glaciofluvial origin that only surficially consist of gravels. By far the greatest portion of their material and their core is made up from pedestal ground moraine with a matrix of fine material washed out in some places. Accordingly, these are Late Glacial levels of glacier mouth gravel floors worked into the continuous ground moraine pedestal of the Mustang-Thak Khola. Above this, i.e. up to a level of 545 m above the Kali Gandaki thalweg, that is at 3445 m asl, in the left flank of the Cha Lungpa exit, a no longer modified, primary remnant of ground moraine (Kuhle 1982 Abb.27 exactly below No.52' and ') is located which the author (1983: 184) has classified as level 6. At that time he had placed this moraine level in the Riss Glacial (pre-last High Glacial Maximum, pre-LGM or pre-LGP, Stage -I Table 1) (ibid. 184/185; Kuhle 1982: 68). Due to additional knowledge of the field of the upper Mustang-Thak Khola - attained by the author in the meantime (in 1976/77 this valley was not yet accessible) - with its very extended ground moraine landscape of a S-Tibetan outlet glacier during the LGP (Stage 0), the author corrects his then chronological classification of the highest moraines at level 6. He now classifies these highest moraine remnants as also belonging to the Maximum Würm-Glacial (LGM, Stage 0 in Table 1, MIS 3-2) as a further part of the Cha Lungpa-Mustang-Thak Khola ground moraine pedestal. This is consistent with a further remnant of a ground moraine pedestal, still located within the Cha Lungpa on the orographic right valley side (ibid. Abb.13, segment 5 Nr.0), which the author already classified correctly at that time, namely as belonging to the LGM (Stage 0) (ibid. 68). Not the genesis, but the then chronological classification of the rest of the terrace steps shifts logically, i.e. with its oldest, highest level 5, from the LGM (Stage 0) into the oldest Late Glacial Stage, namely into the Ghasa Stage I (see Table 1). Consequently, all further levels 4-2 have to be classified as being from the Late Glacial Stages II-IV (Table 1). Photo 60 summarizes the glaciation situation of the LGM (Stage 0) in the confluence area of the Cha Lungpa (i.e. Ghilunpa Khola in Fig. 2) by means of the communicating, i.e. corresponding glacier levels: (——0 on the right below No.32) is the ice level of the Cha Lungpa tributary glacier and (—— and 0——) that of the Mustang-Thak Khola main valley- and outlet glacier from the Kore La (No.3) up to Thini (below No.30), to which that of the orographic right Cha Lungpa tributary glacier has been adjusted. (II) and (III) are the end moraines of the Late Glacial Taglung- and Dhampu Stage (see Table 1) of the Jhon- i.e. Jhong Khola glacier. These ice margin positions have also been diagnosed by the author for the first time and described in detail (Kuhle 1980, 1982, 1983), but they have been classified as being from two older Last Ice Age (LGP) glacier stages, namely II (in Photo 60) belongs to the LGM (Stage 0 in Kuhle 1982, Abb.38 Nr.0; cf. Abb.184) and III (in Photo 60) to the early-Late Glacial pre-Ghasa stagnations (Kuhle 1982, Abb.38 ˜1,2; Abb.184). Accordingly, the corrected ages II and III are younger, namely middle instead of older Late Glacial to High Glacial (LGM).

The lowest sediment sample 21.3.05/1 (Fig. 2; 2875 m asl 28°49'55"N/83°47'10"E), has been taken at an insignificant sea-level, 0.5 km S of the Kagbeni settlement close to the valley bottom. It shows all characteristics of ground moraine: 14% clay, a trimodal course of the grain size accumulation curve in the matrix, i.e. a quadro-modal course if one adds the large erratic boulders in the portion of coarse material (cf. Dreimanis and Vagners, 1971), a high sorting coefficient (So=5.89) and more than 94% glacially crushed SiO2-grains in the analysed medium sand fraction (Fig. 4a/b No.16). This confirms the above formulated interpretation of a complete High Glacial glaciation of the valley chamber of the Mustang-Thak Khola between the Cha Lungpa- (Ghilunpa Khola- (Fig. 2: W of "Sampling locality" 3.4.05/1) junction and down-valley from Kagbeni in the direction of the Thini settlement and to the Himalaya break-through (Fig. 2: "Sampling locality" 15.3.05/1-4). The sediment sample 6.4.05/1 (Fig. 2; 06.04.05/1: 3400 m asl 28°49'N/83°50'10"E) taken in the Jhon Khola near to the Kunjok settlement, is the unambiguous confirmation of the existence of a Jhon Khola glacier (Fig. 4a/b No.37). The So and also the LOI 1.2 m below the current sediment surface point to a small-scale glaciofluvial rearrangement of the material as it can be observed in lateral glacier valleys. How active the Holocene morphodynamics is, which reshapes the Late Glacial glacigenic accumulation landscape, becomes obvious up the Jhon Khola E of the Jharkot settlement at about 3600 m asl. Here, a moraine boulder in size that of a hut has turned about 190-200° since c. 30-50 years (Fig. 2: locality of Photo 61). This Late Glacial ground moraine area, which for the last time was covered by glaciers during Stages III-IV, has been identified as being a large-scale slide area (Kuhle 1982 Abb.38 and 184). The cause of the sliding segments of moraines and typical saturation flows ("Schieferfliessungen") are the schists outcropping in the underlying bed of the lower to middle Paleocene Saligram series (after Hagen 1968 plate VI Fig. 2). Due to his findings of typical goniatite fossils the author was able to prove the portion of schist scree in the ground moraine.

The geomorphological indicators of the past glaciation of the Jhon (Jhong-) Khola and its Late Glacial, Neoglacial and Historical stages have already been published in all detail (Kuhle 1980, 1982, 1983) and in the meantime have also been confirmed (Wagner 2007). Therefore they need not be repeated here. That is the reason why in the following only evidences of the highest LGM-glacier level are shown, because they can be explained by the inflow of the S-Tibetan outlet glacier - the Mustang-Thak Khola main valley glacier - from Tibet, where vast areas above the snow line (ELA), i.e. glacier nourishing areas, have existed.

The Jhon Khola is mantled by remains of ground moraine covers up to a height of c. 4200 m asl (Fig. 2: W of Panoramaphoto 60); among them are remnants of ground moraine pedestals in excess of 100 m. Also the 4100 m-high Chehang La (Fig. 2 transfluence pass No.34, Table 2) is covered by these ground moraines. They are proof of a local glacier transfluence from the Jhon Khola to the N or - more probable - from the Narsin Khola (Fig. 2: north of No.34) to the S into the Jhon Khola.

Above the thinning-out moraine covers, where the glacier lay above the ELA and mainly eroded, so that it has no longer left behind ground moraines - rock roundings and corresponding forms of flank polishing and -abrasion (Fig. 2: W of Peaks Nos.10 and 21) provide evidence of a connected LGM-glacier level between 4500 m up valley in the N and 4500-4400 m asl down valley in the S. These are the highest abrasion limits of the orographic left valley flank of this part of the Mustang-Thak Khola in the wider sense, i.e. the hanging glaciers that are still smaller than the small Jhon Khola side valley glacier into which they flow, participate in the development of this very high abrasion line by heightening it.

Fig. 2 (transfluence pass W of Peak No.10) indicates a further ice transfluence about 3770 m asl into the S-parallel Panda Khola. Also the 3971 m high glacial horn of the Puchhardada (Fig. 2 SE of 21.3.05/1) situated to the W, probably has been completely overflowed by the Mustang-Thak Khola outlet glacier during the LGM.

Also the more south-eastern, 3875-3950 m-high Panda La (SE of the hill Dhanladada) (Fig. 2 transfluence pass W of Peak No.20) has been overflowed by this connected ice of the main valley glacier. The author has already evidenced this earlier (Kuhle 1982: u.a. Abb.40 Nr.0; Abb.184: 0 beside Nr.88 u. Abb.38 Nr.88) by means of ground moraine findings classified as belonging to the LGM (Table 1 Stage 0).

Along the orographic right flank of the Mustang-Thak Khola main valley section discussed here, W opposite of the Jhon- and Panda Khola as well as the Thini Khola (also Longpoghyun Khola in Kuhle 1982) there runs the abrasion line between ca. 4600-4500 m down to ca. 4300 m asl. (Fig. 2: ESE of the profile from Peak Nos.28 to 36). This LGP- i.e. LGM-ice filling (Stage 0) of the main valley is proved, i.e. made probable by remnants of ground moraine (Fig. 2: "ground moraine" SE of Peaks Nos.28 and 31) and glacigenically triangular-shaped slopes, i.e. back-polished truncated mountain spurs (SE of Peak No.31). Only part of these findings of ground moraine has been described by Kuhle (1982) (ibid. among others Abb.184), that is to say those in the Tingri- and Panga Khola. During further field campaigns (the last was in 2005) remnants of a ground moraine pedestal have been observed in the side valley exits of the Jhon Khola in the NE, the Jomosom Chu in the SW and also in between in the Panda Khola, in a very great thickness - in some places they were several decametres-thick (Fig. 2: "pedestal ground moraine" far W of Peak No.21). In addition, the then findings are completed by mapping of a ground moraine ledge about 3650 m asl on the orographic left side of the valley exit of the Syan- (also Syang) Khola (Fig. 2: "ground moraine" SE of Peak No.31) (cf. Kuhle 1982, Abb.35 light accumulation on the upper margin of the picture, above Nr.3). This is above a classic polish board with very clear glacigenic flank abrasions. But also on the polish board itself remnants of a ground moraine cover are preserved, so e.g. at 3420 m, ca. 720 m above the Kali Gandaki (Thak Khola thalweg) (sample 7.4.05/1, cf. Fig. 2; 3420 m asl (28°47'55"N/83°42'53"E). The analysis of the fine material matrix shows a trimodal course of the grain size accumulation curve, a very high clay portion (15%) and a high sorting coefficient of So = 4.71. This unambiguously points to ground moraine. The diagnosis is confirmed by 95% glacially crushed SiO2-grains (Fig. 4a/b No.38). The observation that these are rounded grains with sharp edges that have been crushed later, points to fluvial sediment picked up by the glacier, as it can be met more and more below the snow line (ELA) (see below). As already described in detail (Kuhle 1982: among others Abb.36) the valley ground of the Syan Khola is filled by many decametres-thick ground moraine material that has to be addressed as Late- to Postglacially reshaped pedestal ground moraine. This reshaping is due to the Late Glacial to Neoglacial (Holocene) glaciation of Stages IV, V, VI and 'VII (ibid. Abb.36) (cf. Table 1) as well as to the still remaining fluvial backward erosion from the direction of the Thak Khola main valley thalweg (see ibid. Abb.35).

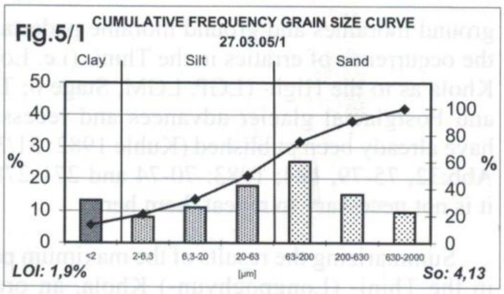
The remnants of pedestal ground moraine of the High Glacial (Stage 0, LGP, LGM: Table 1) Mustang-Thak Khola outlet glacier and its dendritically connected tributary glaciers which genetically are connected with that ground moraine filling of the Syan Khola, have been sedimentologically investigated at three exemplary localities: once in the immediate exit of the Syan Khola (Fig. 2: 20.3.05/2; Fig. 5/5, Fig. 4a/b No.15) and twice in the Thini- (or Longpoghyun-) Khola which opposite on the E-side joins the Thak Khola (Fig. 2: 9.4.05/1 (2890 m asl 28°45'55"N/83°43'45"E) and 11.4.05/1 (2942 m asl 28°45'49"N/83°42'32"E); Fig. 4a/b Nos.39 and 40). All three cases show a bimodal or even trimodal course of the grain size cumulative curves in the fine material matrix with clay portions of 8-13% as secondary or tertiary maximum that in addition to the 83.3 to 92.5% portion of glacially crushed SiO2-grains in the medium sand fraction and the sorting coefficients So = 4.56 to 7.26 unambiguously points to moraine matrix. That the morphoscopic analysis does not concern freshly weathered but glacially crushed SiO2-grains, is evidenced by the in part far-travelled, erratic skeleton portions which are embedded into the fine material matrix. That the portion of fluvially polished SiO2-grains of up to 16.7% against that of the moraine samples taken up in the main- i.e. tributary valleys is greater, can be inferred from the insignificant heights of the sampling locations in the valley bottom area of the Thak Khola (see Fig. 2) at only 2780 up to 2942 m asl. In these heights, ca. 1000-1200 m below the altitude of the LGP-snow line which the author has empirically established as belonging to Stage 0 at ca. 3980 (3981) m asl (Kuhle 1982: 150/151), the appearance of subglacial meltwater is already so important that in places, i.e. dependent on the locality, it can clearly be recognized even in the grain shapes of the primary deposits of ground moraine.

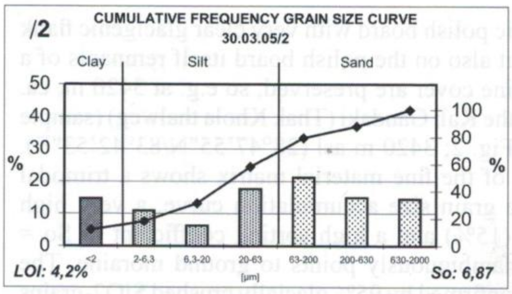
The glaciogemorphological detail-analyses of the ground moraines and ground moraine pedestals, as well as the occurrence of erratics in the Thini- (i.e. Longpoghyun-) Khola as to the High- (LGP, LGM, Stage 0; Table 1) Late- and Postglacial glacier advances and recessional stages, have already been published (Kuhle 1982: 31/32, 96-98 and Abb.32, 75-79, 184; 1983: 70-74 and 271-278). Therefore it is not necessary to repeat them here.

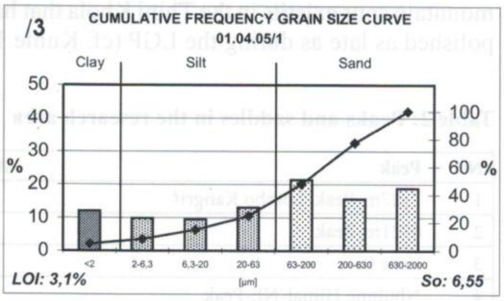
Summarizing the results of the maximum past glaciation in the Thini- (Longpoghyun-) Khola, an orographic left mountain spur existits in the Thini Khola that has been back-polished as late as during the LGP (cf. Kuhle 1982 Abb.75,

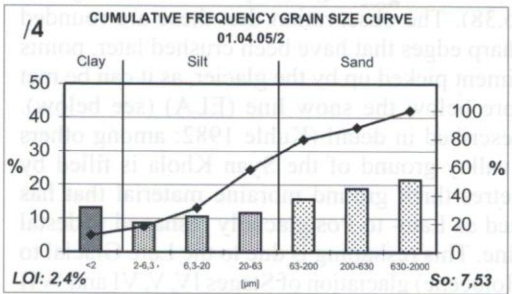
Table 2: Peaks and saddles in the research area

No.	Peak	Altitude (m asl)
1	7327m-Peak, Loinbo Kangri?	7327
2	6821m-Peak	6821
3	Kore La	4610 (4661)
4	Nhubine Himal-NE-Peak	6386
5	Kekyap-N-Peak	6162
6	Khumjung Himal-Mainpeak	6699
7	Jomosom Himal	6581
8	Putrung Himal	6466
9	Annapurna III	7548
10	Thorongtse (Yakwakan)	6481
11	Annapurna II	7937
12	Bhrikuti	6364 (6920)
13	6187m-Peak, Teri Himal	6187
14	Annapurna I	8091
15	Annapurna IV	7525
16	Manshail	6268
17	Nilgiri	7060
18	Thini Nup La (Tilicho La)	5099
19	Khangsar Kang (Roc Noir)	7484
20	Thorong La	5416
21	Deriatse (Khatunkan)	6636 (6484)
22	6065m-Peak	6065
23	Tilicho	7133
24	Gangapurna	7454
25	Phalkandada	6180
26	Dhaulagiri I	8172 (8167)
27	Seti Gap	5501
28	Dangartse	5704
29	Tukche Peak	6976
30	Dhaulagiri II	7751
31	Pughru Kang (Tashikang)	6386
32	Tach Garbo (Charchok Chuska Dada)	6150 (6074)
33	Sangda Himal (Yakkhawako Dada-NE-Peak)	6181 (6196)
34	Chehang La	4100
35	Yamkim Peak	5882
36	Thapa Peak (Marphatse, Dhampush Peak)	6012
37	Annapurna South	7218
38	Annapurna West	7646
39	Gaugiri	6111









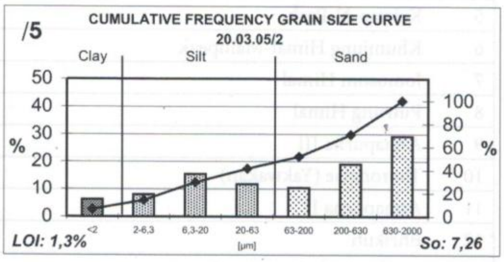


Fig. 5: 5/1 (Sample 27.03.05/1): Taken from the 3974 m-high hill on which Lhari Dzong (also Bhanka Dada) is situated, at 3935 m asl (29°11'36"N/83°57'22"E) on the orographic right flank of the upper Mustang-Thak-Khola c. 210 m above the current thalweg of the Nhichun Khola (3722 m), the immediately adjacent local tributary of the Kali Gandaki Nadi, from lodgement till with granite erratics (Mustang granite?); depth of taking in the exposure: 1 m. This ground moraine has been sedimentated during Stage 0 to IV (Tab.1). The primary maximum occurs with 26% in the fine sand. The secondary maximum with c. 13% clay determines the bimodal course of the cumulative curve which is typical of moraine matrix; the very high portion of clay alone is also typical of ground moraine. Sorting coefficient calculated according to Engelhardt (1973, p. 133) amounts to So = 4.13 (So= $\sqrt{Q_3/Q_1}$), the loss of ignition (LOI) amounts to 1.9%. Locality: Panoramaphoto 2; Fig.2: 27.03.05/1, see also Fig.4a/b sample No.25 (27.03.05/1).

/2 (Sample 30.03.05/2): Fine material matrix taken from 4050 m asl (29°06'48"N/83°53'15"E) from the slope of the orographic right valley flank of the upper Thak- i.e. Mustang Khola, 2 km W of Maran c. 500 m above the current thalweg of the Kali Gandaki Nadi. Taken from the surface of a pedestal ground moraine from an exposure 2 m below the sediment surface. The primary maximum occurs with 22% in the fine sand. The secondary maximum with c.15% clay determines the bimodal course of the cumulative curve; this is typical of moraine matrix. Already the relatively very high portion of clay itself is typical of ground moraine. Sorting coefficient amounts to So = 6.87, the loss of ignition (LOI) amounts to 4.2%. Locality: Fig.2: 30.03.05/2; see also Fig.4a/b, No.31.

/3 (Sample 01.04.05/1): Fine material matrix taken at 4035 m asl (29°05'59"N/83°53'55"E) in the orographic right valley flank of the upper Thak- i.e.Mustang Khola (c. 0.8 km N of Dhakmar), c. 500 m above the current thalweg of the Kali Gandaki Nadi. Taken from a digging from a depth of 0.5 m below the pedestal moraine surface. The primary maximum occurs with 22% in the fine sand. The secondary maximum with c.18% in the coarse sand and the third maximum with 12.5% clay determine the trimodal course of the cumulative curve which is typical of lodgement till matrix. The in relation to the steep topography very high portion of clay itself is also typical of ground moraine. Sorting coefficient amounts to So = 6.55, the loss of ignition (LOI) amounts to 3.1%. Locality: Fig.2: 1.4.05/1; see also Fig.4a/b, No.33.

/4 (Sample 01.04.05/2): Fine material matrix taken at 3640 m asl (29°03'45"N/83°52'55"E) from Ghami La from the orographic left valley side of the Ghami Khola, a right tributary valley of the upper Thak-i.e. Mustang Khola 0.5 km NE of the Ghami settlement c. 360 m above the current thalweg of the Kali Gandaki Nadi; taken from a digging 0.5m below the surface of the pedestal moraine. The primary maximum occurs with 22% in the coarse sand. The secondary maximum with c. 14% in the clay determines the bimodal course of the cumulative curve which is typical of lodgement till (ground moraine) matrix. The in relation to the steep topography very high portion of clay itself is also typical of ground moraine. Sorting coefficient amounts to So = 7.53, the loss of ignition (LOI) amounts to 2.4%. Locality: Fig.2: 01.04.05/2, see also Fig.4a/b, No.34.

/5 (Sample 20.03.05/2): Fine material matrix taken at 2780 m asl (28°46'55"N/83°43'17"E) from the orographic right valley flank of the Thak Khola transverse valley N of the Himalaya main crest, c. 0.5 km WSW of the Jomosom settlement; 60 m above the current Kali Gandaki river, taken from an exposure from a depth of 18 m below the sediment surface of a remnant of a ground moraine pedestal. The primary maximum occurs with 29% in the coarse sand. The secondary maximum with 16% in the medium silt determines a bimodal course of the cumulative curve typical of moraine matrix; also the clay portion (8%) points to moraine. Sorting coefficient amounts to So = 7.26, the loss of ignition (LOI) amounts to 1.3%. Locality: Fig.2: 20.03.05/2; see also Fig.4a/b, No.15. Sampling: M. Kuhle.

76). The corresponding, i.e. communicating ice level of the Mustang-Thak Khola parent glacier in the junction area of the Thini Khola tributary glacier had run about 4300 m asl (cf. Kuhle 1982 Abb.31).

THE REMNANTS OF THE GROUND MORAINE PEDESTAL IN THE THAK KHOLA BETWEEN THE JUNCTIONS OF THE THINI- (LONGPOGHYUN-) AND MYAGDI (MAYANGDI-)KHOLA (FIG. 2 FROM SAMPLING LOCALITY 11.4.05/1 MUSTANG-THAK KHOLA DOWN VALLEY AND FIG. 3 FROM THINI K. TO MAYANGDI K.), MAINLY IN THE VALLEY CHAMBER BETWEEN THE POSITIONS OF TUKUCHE- (TUKCHE-) AND BENI SETTLEMENTS, I.E. IN THE HIMALAYA BREACH BETWEEN ANNAPURNA AND DHAULAGIRI

In the Thak Khola section between the Thini settlement (Thinigau), i.e. the junction of Syan-(Syang-) and Thini-(Longpoghyun-) Khola and the Tukuche settlement remnants of ground moraine and ground moraine pedestals do occur that have already been described in detail (Kuhle 1982: 42-46, Abb.28, 32, 80, 81, 83, 84; 1983: 103-114). Owing to this, their quality is confirmed here just by an exemplary sediment analysis (Fig. 2: 20.3.05/1 (2600 m asl (28°42'53"N/83°39'17"E) Fig. 4a/b No.14). The portion of coarse erratic granite boulders and the bimodal course of the grain size cumulative curve in the fine material matrix by which they are isolated, as well as the high sorting coefficient of So = 5.92 and 95.2% glacially crushed quartz grains, unambiguously confirm the glacial genesis.

The following remarks complete the earlier, very detailed investigations from the Himalaya-break-through between Annapurna and Dhaulagiri (Kuhle 1982: 42-51, 80-89, 1983: 103-132, 225- 252). They provide empirical evidence of an uninterrupted continuation of the Ice Age (LGP) S-Tibetan Mustang-Thak Khola outlet glacier, arising from the Tibetan ice reconstructed by the author (Kuhle 1980-2010; cf. among others Hughes 1998).

A key locality for this is between the massifs of Dhaulagiri and Annapurna above the Titi settlement at ca. 3000 (3000-3030) m asl (Fig. 2 Locality: Panoramaphotos 62, 63). It is a rather extended, plane remnant of a pedestal ground moraine (Fig. 2 17.3.05/1/2:"pedestal ground moraine with and without erratic boulders") the preserved form of which has been classified by the author as being from the Late Glacial Stage of the "Second pre-Ghasa Stagnation" (Kuhle 1982 Bd.1: 153, Bd.II: Abb.86, 87, 184. However, the primary shaping of this ground moraine body took place during the LGM (Stage 0, Table 1) underneath the Mustang-Thak Khola outlet glacier, which here received ice inflow from the massifs of Dhaulagiri (Fig. 2 No.26) with Tukche Peak (No.29) and from Annapurna (No.14; Table 2) with Nilgiri (No.17; Table 2) rising kilometres-high above the ELA.

According to the sampling from this accumulation body only a gemorphologically evidenced glacial genesis is possible (Fig. 2: sample 17.3.05/1; 3000 m asl (28°39'20"N/83°39'10"E) Fig. 4a/b No.9 and 17.3.05/2; 3020 m asl (28°39'38"N/83°39'10"E) Fig. 4a/b No.10). The course of the grain size cumulative curve of both spot checks is a bimodal one; 99.6% and 99.4% of the SiO2-grains are glacially crushed. The with regard to moraine relatively insignificant sorting coefficients of So = 2.55 - 2.87 prove a fluvio-glacial reshaping of the sediments close to the surface. This is a confirmation of the author's opinion, according to which the ground moraine pedestal, built-up during the High Glacial, has been modified even up to the "Second pre-Ghasa Stagnation" (Kuhle 1982: 153) (see above). Perhaps the surficial modification continued even up to the oldest Late Glacial stage of advance, the Ghasa Stage I (see Table 1).

Besides the microsedimentological indicators of ground moraine, mainly the macrosedimentological ones in the shape of erratic granite blocks up to hut-size (Fig. 2 "pedestal ground moraine with erratic boulders" NE of Panoramaphoto 62), situated here 500 m above the Kali Gandaki and ca. 250-600 m away from every slope-like potential catchment area, are clearly pronounced.

A further remnant of a ground moraine pedestal is at ca. 3400 m asl (Fig. 2 Locality: Panoramaphoto 64), 400 m above that one already described (s.o. Fig. 2 Panoramaphoto 62). Probably it has been laid out syngenetically with the lower one - preserved as a much greater remnant of a ground moraine pedestal - during the LGM (Stage 0). The cause of the difference in height is a rock ridge between the two subglacial sediment complexes, which in part has been abraded and thus rounded by the glacier bottom. This hill has lifted the ice of the Thak Khola glacier so that the more highly situated face of pedestal ground moraine could be made up in its flow shadow.

The sedimentological analyses confirm the geomorphological approach to classify this ca. 100x200 m extended accumulation body as ground moraine (Fig. 2: sample 19.3.05/2; 3400 m asl (28°39'30"N/83°19'E)). The 11% clay portion and the bimodal course of the grain size cumulative curve, but also the 99.6% angularly broken SiO_2-grains of the medium sand fraction prove the crushing of the material by a hanging glacier (Fig. 4a/b No.13).

Again up the slope at a height in excess of 3600 m, 1200 m above the valley floor, further sediment samples have been taken on the orographic left flank of the Thak Khola (Fig. 2: sample 18.3.05/1, 3550 m asl (28°39'48"N/83°38'08"E), Fig. 4a/b No.11 and 19.03.05/1, 3605 m asl (28°39'40"N/83°38'20"E); Fig. 4a/b No.12). In both cases the course of the grain size cumulative curve is a bimodal one; also the sorting coefficient So = 3.2-3.3 and mainly the 99-100% portion of crushed quartz grains speak in favour of a moraine-like mantling of the slopes. The clay portion of ca. 3% points to a downslope reworking of the moraine mantling by post-glacial denudation.

During the LGM (Stage 0, Table 1) the pertinent level of the Mustang-Thak Khola parent glacier in the valley chambers described here, ran at a minimum height of 4300 m asl (Fig. 2 in the cross-profile of the valley between Peaks No.29 and No.37) on the hill flank of the Thulo Bugin; this proves an ice thickness of ca. 1300 m (cf. Kuhle 1982 Bd.2: Abb.87 ——). In the Tangdung (also Tantun-) Khola joining from the orographic left (Fig. 2: S of 17.3.05/1/2), up to 530 m-high terraces of pedestal ground moraine are preserved (cf. Kuhle 1982 Bd.2: Abb.90 II und I; 89) that have also been reshaped and modified during the Late Glacial and fluvially cut in the postglacial period. They continue the ground moraine pedestal in the immediate breach of the Himalaya main chain exactly between Dhaulagiri (Fig. 1 and Table 2 No.26) and Annapurna (Fig. 9 No.14) down to the S.

With regard to the arrangement of the positions there are further remnants of pedestal ground moraine which fit with these findings, situated 7-8 km down the Thak Khola, downwards of the Kabre- and above the Dana settlement. 27 years ago (Kuhle 1982 Bd.1: 46/47 Bd.2: Abb.96, 100, 184; 1983: 114-119) over 7 km-long ground moraine pedestals have already been described here on both valley sides, located between Kabre and the junction of the Seti Khola. They have rightly been classified as High Glacial glacigenic accumulations modified to lateral moraines in the Late Glacial. During his field researches in 2005 in this valley chamber the author's findings concentrated especially upon the ground moraine pedestals deposited by the Mustang-Thak Khola outlet glacier during the LGM (Stage 0) (Fig. 2 Locality Panoramaphoto 65).

On the orographic right side of the main thalweg the ground moraine pedestals concerned reach up to a height of 1900 m asl, i.e. up to 500 m above the Kali Gandaki (Locality: Fig. 2, 15.3.05/2 m asl (28°32'27"N/83°38'17"E) Fig. 4a/b No.4,). The horizontally greatest, planest extension is that of the terrace of the ground moraine pedestal, also situated in the area of the Thara hamlet at 1840 m asl, i.e. 440 m above the main valley thalweg (Fig. 2: sample 15.3.05/3, 1840 m asl (28°32'28"N/83°38'27"E), Fig. 4a/b No.5). A further plane remnant of ground moraine is at 1700 m - 300 m above the Kali Gandaki (Fig. 2, 15.3.05/4, 1700 m asl (28°32'35"N/83°38'43"E) Fig. 4a/b No.6). At the base of the lowest ground moraine complex, 60 m above the thalweg, a sampling has been taken, too (Fig. 2, 15.3.05/1, 1460 m asl (28°32'15"N/83°39'E) Fig. 4a/b No.3). Both the sediment analyses and the microscopic analyses point to moraine material: 95.9-100%, whereby the highest sample shows 100% glacially crushed SiO2-grains and the lowest sample only 95.9% glacially crushed and 4.1% lustrous (fluvially polished) SiO2-grains. This is in accordance with the increasing effect of the meltwater on the sedimentation of ground moraine. The two samples 15.3.05/3 and /4 taken at heights in between, lie with 99.4 and 99.5% glacially crushed grains also in between. The rest of the sedimentological parameters point to denudative slope-downwards dislocations and thus reworking. Besides the characteristics of the fine material matrix also the very large far-travelled gneiss boulders that occur separated in the fine material (Fig. 2 Locality of Photo 66) prove the morainic character of these pedestal-shaped loose sediments.

Fig. 6: Glacio-geomorphological map of the Mustang-Thak Khola with the ice cover (glaciers) during the Late Glacial period (Stage I). Basic topographic map: ONC (1978): H-9; 1:1,000,000. See Fig. 3

On the orographic left valley side at 1730 m asl, somewhat N of the Kopchepani settlement, 80 m above the Kali Gandaki in the area of the narrowest gorge-stretch of the Kabre gateway, a representative sediment sample has also been found (Fig. 2: 16.3.05/1 (28°34'55"N/83°38'35"E), Fig. 4a/b No.7). Here 97.8% of the quartz grains are glacially crushed. In the ground mass they are situated adjacent to far-travelled granite- and gneiss boulders the size of several metres. The composition of the grain sizes shows a bimodal course which, inclusive of the coarse boulders, is even trimodal and thus has the typical course of moraine. In geomorphological terms - because the surface of the ground moraine pedestal shows the form of a debris flow fan - as well as because of the insignificant sorting coefficient (So=2.88) the in places even repeated redeposition by debris flows is evident.

Similar conditions have been found again upward of the Thak Khola on the orographic right valley side near the Dhaiku settlement, where ground moraine material has been dislocated by a debris flow (Fig. 5: 16.03.05/2, 2200 m asl (28°37'05"N/83°38'25"E)). The 99.3% crushed SiO2-

grains of the medium sand fraction have been developed from fluvial-rounded grains crushed afterwards (Fig. 4a/b No.8). First, this proves that glacially crushed material is concerned but not material that has been freshly weathered out of the bedrock or in situ in the loose material; secondly it is evidence of fluvial material retaken by the Thak Khola glacier. This is also supported by the not too great sorting coefficient So = 2.78. Here, i.e. at least 1500 altitudinal metres below the corresponding past snowline (ELA) where a lot of subglacial meltwater must have risen, a process like this is easy to understand. In all probability subglacial, glaciofluvial material is concerned here, again taken up by the glacier bottom and transported glacigenically, then laid down as ground moraine and after the deglaciation taken up by a debris flow and displaced once more.

In the valley chamber of the Thak Khola discussed here, i.e. in the immediate Himalaya break-through and S of it, glacigenic flank polishings and backward-abraded mountain spurs are obvious (Fig. 2 "glacigenic flank polishings" E of Photo 66); in part there their destruction by postglacial to current crumblings ("rock crumblings" E of Photo 66) and the attachment, i.e. covering of the valley flanks by ground moraine (E of Photo 66) pedestals accumulated up to 500 m above the modern gravel floor that have filled the valley floor below the main valley glacier (W and SE of Photo 66) can also be seen. Further remnants of a ground moraine cover mantle the valley flanks up to an altitude of 2600 m (S of Photo 65). The Mustang-Thak Khola outlet glacier, i.e. the level of the Thak Khola parent glacier, that according to these moraines, glacigenic abrasions and polishings has been reconstructed, has run during Stage 0 (Würm, LGM) from ca. 3700 m in the Himalaya break-through up to 2600 m downwards of the Ghar Khola-junction (Fig. 3), i.e. 7-10 km down-valley of the Miristi Khola-junction (Fig. 3). This indicates ice thicknesses of ca. 1400-1000 m from the glacier surface down to the surfaces of the pedestal ground moraines. In the area of the Miristi Khola-junction, the surfaces of the pedestal moraines near the Thaku settlement, similar to those at the Tara hamlet, 1.15 km W above the Dana settlement, are situated at a level of ca. 1920-1940 m asl (Fig. 2 "pedestal ground moraine with escarpment" SE of Photo 65). Here, an orographic left tributary glacier, which had a very short connection to the highest catchment areas of the W-Annapurna group (up to 8091 m high, Table 2 No.14) has joined. Accordingly, its surface was very steep, so that an overthrust across the Thak Khola-parent glacier must have taken place there.

Ca. 5 km up-valley of the Dana settlement, in the area of the gorge-stretch of the Thak Khola between the Ghasa- and Kabre settlements, on the orographic left side N of the Pairothapla settlement, a perfectly preserved pothole has been found in the very hard outcropping gneiss (Fig. 2 locality: Photo 67). It has been kept free from slope debris by a monsoonal water thread. The development of this classic pothole cannot be explained by a current waterfall from a sufficiently large hanging side valley, nor by a selective

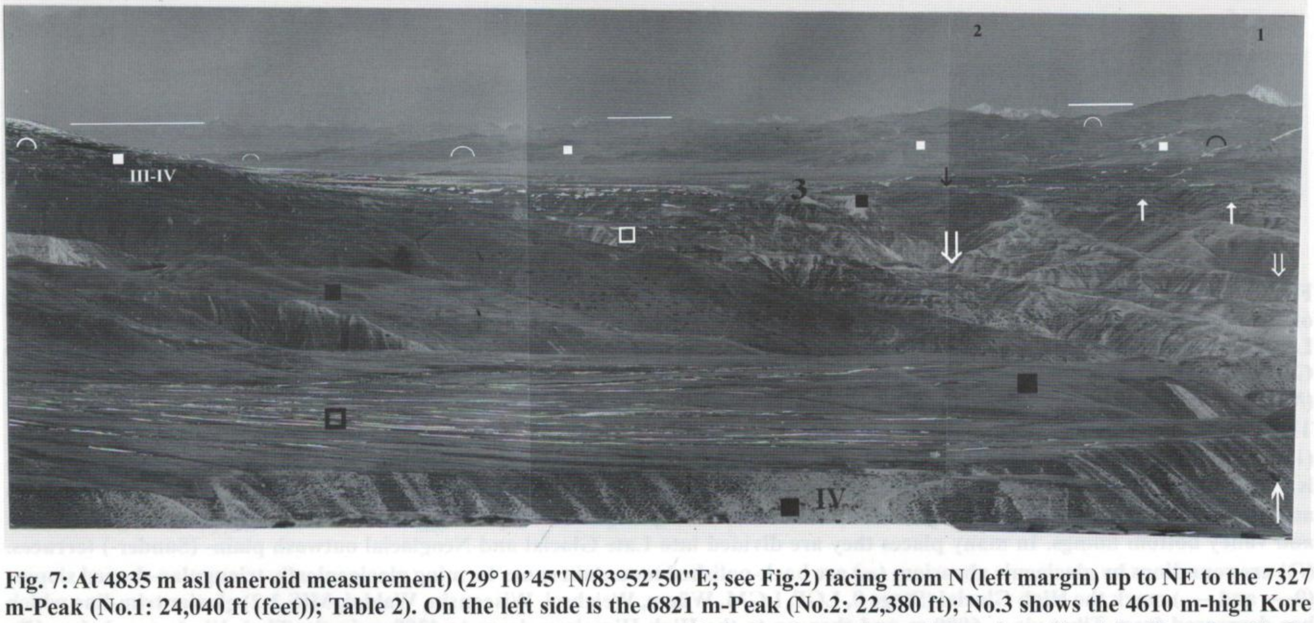


Fig. 7: At 4835 m asl (aneroid measurement) (29°10'45"N/83°52'50"E; see Fig.2) facing from N (left margin) up to NE to the 7327 m-Peak (No.1: 24,040 ft (feet)); Table 2). On the left side is the 6821 m-Peak (No.2: 22,380 ft); No.3 shows the 4610 m-high Kore La; (🡅) are glacigenic roundings and abrasion forms on metamorphic bedrocks on this and the other side of the Kore La (No.3); (■) show ground moraine covers preserved up to over 800 m above the Thak Khola- (⇓ on the left) and Tsangpo thalweg (below ____ on the left); the Tsangpo flows 95 m below the Kore La; (⇓) are young thalwegs of the backward erosion from the uppermost Thak Khola (Kali Gandaki) which since the Last Glacial deglaciation dissect and partly cut through the ground moraines (■); (↓) marks the primary ground moraine surface before this dissection; (↑) are exaration rills of the glacier bottom which flowed across the Kore La; (🡅) is an erratic granite boulder the size of a room; (■ III-IV and ■ IV) are remnants of ground moraine cover of the Late Glacial Stages III and IV; (□) mark glaciofluvially and fluvially modified ground moraine surfaces. (____) are Ice Age (LGP) glacier trim-lines about c. 6300 m asl. Analogue photo M. Kuhle, 29/03/2005.

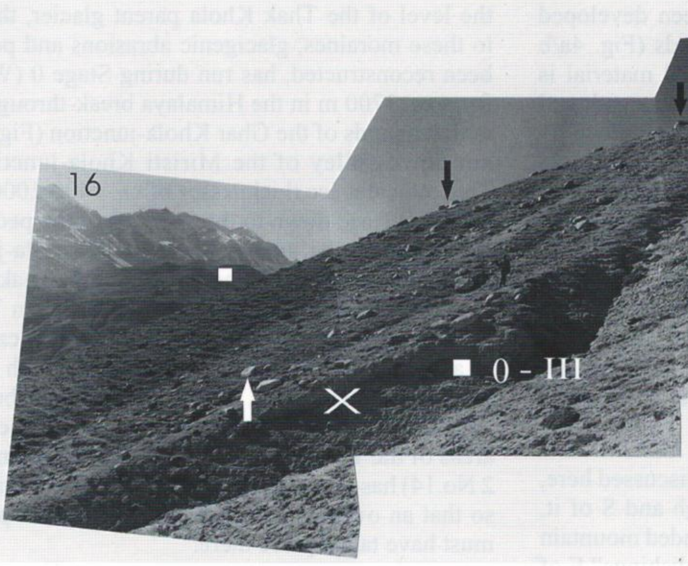


Fig. 8: The 3974 m-high hill on which Lhari Dzong (also Bhanka Dada; fortress of King Ami Pal) is situated, at 3930 m asl (map: 150 000, No.2983 16) (29°11'36"N/83°57'22"E, Fig.2) c. 13 km S of the Tsangpo-Ganges watershed near the Kore La, taken facing NW in the upper Thak- i.e. Mustang Khola above Tilekheji; Manshail (No.16, Table 2) is in the background. (■) is a High- to Late Glacial (Stage 0-III, see Tab.1) remnant of a ground moraine pedestal from which the hill with the fortress as a further remnant of a ground moraine pedestal (■0-III) has been cut out by backward fluvial (linear) erosion since the Late Glacial (Stage III) deglaciation (cf. Photo 8). (x) is a moraine exposure with sampling locality (sample No.27.03.05/1); (↑↓) are far-travelled erratic granite blocks of several varieties, up to over 1 m in size (see two persons for scale). They lie 100-250 altitude-metres above the surrounding thalwegs. The ground moraine consists of polymictic components of loose material: besides different granites also dark metamorphic sedimentary rocks (phyllites). Analogue photo M. Kuhle, 27/03/2005.

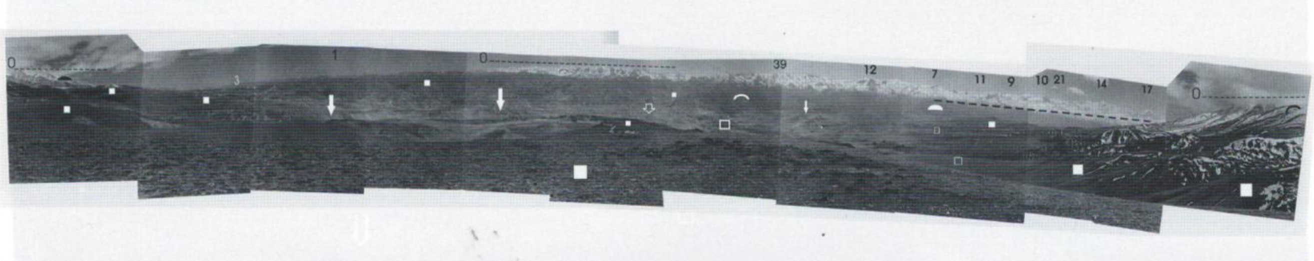


Fig. 9: Taken at 4576 m asl (map: 1:50 000, No.2983 16) (29°10'47"N/83°53'40"E, Fig. 2) from the orographic right valley flank of the uppermost Thak Khola facing NW (left margin) via facing N (No.3 Kore La) towards Tibet and the 7327 m-Peak (No.1 Loinbo Kangri?) and via the orographic left flank of the Thak Khola facing SE with the summits of the Damodar Lekh (No. 39 Gaugiri, 6111 m) and the Khumjung Himal (No.12 Bhrikuti and No.7 Jomosom Himal; see Tab. 2) and the Annapurna group (No.11, 14 is Annapurna I, 8091 m and No.17; Tab.2) in the S, up to facing SW (right margin) into the right flank of the upper Thak Khola, i.e. Mustang valley. (■) are metre- to decametre thick remnants of ground moraine, in part also pedestal moraine; (↓) are remnants of ground moraine pedestals disintegrated and removed by backward erosion through rills and small valleys; (⇓) is a ground moraine locality of this sort with large far-travelled erratic granite boulders in a high position without connection to an equidirectional slope and without possibility of another than glacigenic transport. (□) are fluvial, i.e. glaciofluvial gravel fields and valley bottom fillings. In many places they are divided into Late Glacial and Neoglacial outwash plain- (Sander-) terraces. (∩) are roundings by glacigenic abrasion; (⏶) are back-polished mountain spurs forming glacigenically triangular-shaped slopes; (0---- and ----) mark the High Glacial (Stage 0, LGP, LGM, Würm, Weichsel, Wisconsin, Waldai, MIS 3-2) glacier trim-line which has decreased from Tibet via c. 6000 m and then up to the High Himalaya down to 4300 m in the Thak Khola (---- below 17). Analogue photo M. Kuhle, 29/03/2005.

erosion by the Kali Gandaki. The thalweg of the Kali Gandaki river on this main valley cross-profile is ca. 150 m lower than the pothole and runs on a gravel floor. Only the subglacial cavitation corrasion of the confined meltwater discharging with a very high velocity through intraglacial ice tunnels is able to develop it. A further subglacial shaping of a pothole, which here will be introduced exemplarily, is situated ca. 15 km down-valley N of the Doba Khola junction, at only ca. 1120 m asl, on the orographic right valley flank of the Thak Khola (Fig. 3: locality: Photo 68). Here, too, the fluvial catchment area as to formations like these is lacking, so that solely the subglacial development by very rapid meltwater remains.

As far as possible in this chapter (5.) nothing will be repeated that has already been described and genetically explained in detail (Kuhle 1982 and 1983) with regard to the lower section of the Thak Khola between Thini-(Longpoghyun-) and Myagdi (Mayangdi-) Khola which was glaciated during the ice age. Only observations of the lowest valley section, that in 2005 has been investigated once again, will be confirmed and completed here. At the same time, i.e. due to the important accumulations of pedestal moraines that are very rich in material, it is intended to make the really new finding of this study understandable, namely, that the lower Thak Khola glacier is the tongue end of a ca. 120 km long outlet glacier, which from the S-margin of the Tibetan inland ice and through the Himalaya-main ridge has flowed down to a height of merely ca. 1000 m. For this purpose we turn our attention to the lowest 11 km of the Thak Khola that were glaciated during the Würmian ice age, i.e. the section between the junction of the Beg- and Mayangdi (or Myagdi-) Khola. 700 m down-valley of the Beg Khola junction a representative sediment analysis has been carried out on the orographic right valley flank of the Thak Khola (Fig. 3: 14.3.05/2, 1020 m asl (28°25'30"N/83°33'30"E) Fig. 4a/b No.2). 60 m above the Kali Gandaki an exposure has been dug into the slope debris, from the base of which a matrix with a bimodal grain size cumulation curve has been taken. The portion of 97.7% angularly broken Si02-grains of the medium sand fraction unambiguously speaks in favour of moraine. In combination with far-travelled coarse boulders in the fine material matrix they can be addressed as being glacially-crushed. In this valley cross-profile this ground moraine material has even been evidenced 490-630 m above the Kali Gandaki (Kuhle 1982 Bd.II Abb.102, 103). Part of it has tipped over and been displaced down the slope, so that it could be found in the analysed fine material matrix.

11 km further down the Thak Khola, a little more to the N, close to the junction of the Mayangdi (or Myagdi-) Khola, a change of the landscape is evident (Fig. 3: locality: Panoramaphoto 69): the valley becomes wider, i.e. the flanks are flatter and the accumulation terraces lie on merely low rock pedestals. Lastly, somewhat further down-valley in the area of the Beni settlement they even flank the Kali Gandaki and its gravel floor. 5 km up-valley (to the N) of the Mayangdi (or Myagdi-) Khola junction, the gorge-like narrow incision of the valley is formed by high, outcropping rock faces. Only far more than 100 m above the valley floor important deposits of ground moraine are situated on the denudation terraces developed on these rocks (Kuhle 1982 Bd.II Abb.104). Accordingly, these accumulation terraces, which are remnants of ground moraine pedestals, only then - i.e. in the area of the Mayangdi Khola- junction - overlie the real valley ground of the Thak Khola. Among others, the condition of the ground moraine can be evidenced here by an exemplary sampling of fine material matrix. The sediment shows the characteristics of redeposited moraine (Fig. 3: 14.3.05/1, 880 m asl (28°21'43"N/83°34'05"E) Fig. 4a/b No.1). Here, local rearrangements that have been caused fluvially or by debris flows, are concerned. They have occurred from rills in the body of the pedestal moraine. The moraine character is proved by the bimodal course of the grain size cumulative curve, the sorting coefficient So = 4.53 and 99% glacially crushed quartz grains.

These findings show, that the High Glacial (LGM, Würm, Stage 0, Table 1) glacier terminus has reached approx. up to the junction of the Mayangdi Khola (28°20'24"N 83°33'42"E, Fig. 3), perhaps even several kilometres further down-valley. In this area morainic and glaciofluvial occurrences are mixed. The last ones have mainly been observed in the form of high energy flows, which are typical of a position near to the glacier outlet and as a result of which even very large boulders can be displaced. At the termini of 120 km-long valley glaciers like these, naturally it is not possible anymore to locate exactly the final positions of the tongues. The reason for this are the narrowly channelized, highly energetic meltwater activities ca. 3000 m below the ELA (snow line).

RECONSTRUCTION OF THE HEIGHT OF THE LOWEST TERMINUS OF THE GLACIER TONGUE OF THE MUSTANG-THAK KHOLA OUTLET GLACIER S OF THE BREACH OF THE MAIN HIMALAYAN CHAIN

The current valley bottom of the Thak Khola is situated in the area of the junction of the Mayangdi Khola at 830 m asl (28°20'24"N 83°33'42"E, Fig. 3). However, as above shown, this is a valley bottom which the Kali Gandaki has set into the ground moraine pedestal by ca. 330 m, i.e. which has been eroded. Accordingly, the glacier terminus lay at ca. 1130-1190 (1160) m asl. But because the deposition of the preserved ground moraine pedestal has taken place during the very last phase of the accumulation of moraine, shortly before the back-melting, a somewhat lower position of the glacier terminus has to be assumed. As can regularly be observed, this must have come into being together with the most down-valley glacier advance. It has existed first of all, i.e. at the very beginning of the stagnation, during which the ground moraine pedestal has gradually been built up (Kuhle 1982: 46- 51, 1983: 123-128). As has already been published in 1982, due to these considerations we can assume a lowest terminus of the Thak-Khola valley glacier, i.e. of the Mustang-Thak-Khola outlet glacier, at ca. 1000 m asl (1010 m asl after Kuhle 1982 Bd.I: 152; Bd.II Abb.8).

TO THE FINDINGS OF A THAK-KHOLA DAMMED GLACIER LAKE AND ITS LATE GLACIAL CLASSIFICATION

At many places of the upper Mustang-Thak Khola, i.e. N of the Himalaya main crest, lake sediments have been observed (Kuhle 1982 Bd.I: 68-71, Bd.II Abb.26, 28, 29, 33, 34, 184; 1983: 188-193). They prove an at least 360 m deep and 46 km long dammed glacier lake extending from N to S, which thus has reached at least from the Chhairo settlement in the S up to the Tange Khola with the Tanbe settlement (Tangya, Tangye) in the N. The lake level lay at ca. 3110 m asl. According in the author's opinion, this lake has been dammed up by the LGM-Thak-Khola valley glacier and at that time (1982) was classified as being from Stage 0 (Würm Glacial, Table 1). Due to the new findings introduced here that reconstruct a S-Tibetan Mustang-Thak Khola outlet glacier, which during the LGM flowed down to 1000 m asl from the margin of the S-Tibetan inland ice, i.e. icestream network, across the Kore La (No.3) towards the S through the Himalaya break-trough (Fig. 9 see —— from left to right) up to the junction of the Mayangdi Khola, this ice-dammed lake did not exist until the Late Glacial. Figure 6 shows the glacier cover of the Late Glacial period (Stage I). Consequently a part of the ice free area in the upper Mustang-Thak Khola was covered by this ice-dammed lake.

The limnites sedimentated in the ice-dammed lake - into which numerous creeks of glacier meltwater have flowed - are exemplarily taken 180 m above the current Kali Gandaki river and ca. 110 m below the past lake level (Fig. 2: "glacio-limnic lake terraces" Sampling locality 3.4.05/2: c. 3000 m asl (28°50'25"N/83°47'20"E)). They show the typical glacier-induced characteristics of rhythmic, in this case seasonal stratification, i.e. varved clay. This corresponds with the clay portion of a good 25% and the sorting coefficient of So = 2.72 as well as the monomodal grain size characteristically with only one pronounced peak in the medium silt (33%).

SUMMARY OF THE RECONSTRUCTION OF THE ICE AGE (LGP, MIS 3-2) MUSTANG-THAK KHOLA GLACIER AS AN EXEMPLARY SOUTHERN OUTLET GLACIER FROM THE TIBETAN INLAND ICE THROUGH MUSTANG INTO THE THAK KHOLA THROUGH THE HIMALAYA MAIN CREST UP TO THE HIMALAYA S-SLOPE

The findings prove a further Ice Age (LGP, LGM, Würm, Weichsel, Wisconsin, Waldai, MIS 3-2, Stage 0) S-Tibetan outlet glacier flowing down to the S over the watershed between Tsangpo (upper Brahmaputra) and Ganges river system (Kali Gandaki), i.e. over the Kore La (Table 2 No.3). From the Kore La up to its terminus in the confluence area of the Mayangdi (Myagdi-) Khola and Thak Khola the Mustang-Thak Khola outlet glacier was 120 km long and came to an end at 1000 m asl. At the Kore La, where it flowed out of the S-Tibetan inland ice, the ice stream was 26-31 km wide. Corresponding, but much smaller, outlet glaciers at the S-margin of Tibet have existed during the Last Ice Age also in the Bote Chu, E of Shisha Pangma, in the Kyetrak-Nangpa-Bote Koshi valley W of Cho Oyu (Kuhle 1999b, 2001b, 2002, 2005b), in the Rongbuk valley W and E of Mt. Everest (Kuhle 1988b, 2005b), in the upper Arun valley E of Makalu (Kuhle 1991, 2005b) and in the transverse gorges in SE-Tibet between Tsangpo- and Yalong river-valley, in the Dadu-, Litang-, Jangtsekiang-, Langcang- (Mekong) and the Saluen- (Nu Jiang) river-valley (Kuhle 1998, 2001c, 2010). They drained the Tibetan ice through the main Himalaya chain down into its S-slope. The outlet glacier, the trim-line of which has decreased from S-Tibet from 6300 m (Fig. 7 and 9) via 6000 m and then up to the Himalaya down to 4300 m in the Thak Khola (Fig. 9) was, at its root on the watershed (Kore La), at least 1400 m thick. This thickness was approximately maintained to the antecedent Himalaya breach between Dhaulagiri and Annapurna. Only on the Himalaya S-side was its thickness reduced rapidly when the height of the level dropped below the snowline (ELA) that ran about 4000 m (Kuhle 1982, 1983). The outlet glacier received supply from the ice-stream-like local glaciations of the mountain massifs of the Inner (Tibetan Himalaya) and the High Himalaya which flanked both sides of the antecedent valley of the Mustang-Thak Khola. In the N and W the valley glaciers of the Mustang-, Sangda- and Mukut Himal E-slopes were concerned, in the N and E the valley glaciers of the Damodar Lekh-, Damodar- and Pukhung- and Muktinath-Himal W-slopes - which had developed their own ice stream networks - and in the S the glaciers of the Dhaulagiri- and Annapurna Himalaya (Kuhle 1982, Bd.I u. Bd.II: Abb.8). According to the increasing snowline (ELA) the Mustang-Thak Khola outlet glacier has built-up a ground moraine pedestal during the Late Glacial (Stages I-IV, Table 1). During the late Late Glacial (Stage IV) its over several decametres up to 400 m thick loose rocks have been cut and replaced in part by glaciofluvial and glaciolimnical sediments. Along with the further down-melting and receding of the ice that was separated into single glaciers, from the Late Glacial up to the Holocene Neoglacial (Stages V-'VII, Table 1) and during the historical time up to nowwadays (Stages VII-XII, Table 1) these glaciofluvial gravel floors, too, have been eroded and fluvially cleared, i.e. displaced. From the Late Glacial Ghasa Stage (I) as far as into the middle Late Glacial (Stage II or III) an at least 46 km-long and 360 m deep ice-dammed lake has existed, dammed-up by the glaciers of the mountains of the Himalaya main crest, which during the Late Glacial has shrunk progressively.

At some places of the region of the upper Mustang Thak Khola, glaciotectonic disturbances, as e.g. glacigenic compressions that show a real faulting character in the ground moraine, prove High Glacial permafrost below the outlet glacier (Locality: Fig. 2 Photo 33), i.e. a cold-based ice stream and thus cold-arid conditions. With an increasing snowline during the Late Glacial, according to morphoscopic evidences (Fig. 4 No.34) the subglacial meltwater has also influenced the sedimentation of ground moraine at a height over 3600 m asl. This is characteristic of "warm-based" glaciers.

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