# High-glacial (LGP, LGM, MIS 3-2) ice cover in the middle Marsyandi Nadi and the Damodar-Himal down to the junction of the Nar Khola and the Marsyandi Khola (N of Annapurna Himalaya)

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**Abstract**

Going on from the glacier-historical researches of 1977 in the upper Marsyandi Khola (Nadi) (Kuhle 1980, 1982, 1983) further down-valley field campaigns have been carried out in the years 2000, 2004 and 2007. The aim was to investigate the past glaciation of the middle Marsyandi Nadi from the Sabje Khola (Sapse Lungpa) up to the junction of the Nar (Naur) Khola (Nadi) and to reconstruct the synchronous glaciation of the Damodar Himal.
A connected ice stream network has been recorded that below the valley chamber of Kotogau (2500 m asl) was drained by the Marsyandi parent glacier. The maximum glacier thickness that has been reached amounted to c. 2200 - 2100 m. Accordingly, a transfluence into the upper Kanla Khola has taken place. Thus, apart from the confluence with the Nar trunk glacier - where nearly the same ice thickness has been attained - a further local glacier confluence has existed between the Marsyandi glacier of the Annapurna group and the Damodar Himalaya and because of that a contact with the glaciation of Tibet.
During the four Late Glacial advances (Ghasa-, Taglung-, Dhampu- and Sirkung Stage = I, II, III, IV; Tab. 1), according to a gradual uplift of the ELA (snowline), pedestal ground moraines have been built-up exceeding 200 m. Flowing down on these successively growing pedestal ground moraines with rising height, the glaciers - because of the more and more diminishing advances - have been increasingly isolated from the rock bottom of the valleys. Only during the Late Glacial Dhampu Stage (III), when the snowline depression (Δ ELA) amounted to less than 800-900 m (Tab. 1), the main glacier of the Damodar ice-stream-network, the Nar Khola glacier, no longer has reached the Marsyandi glacier.
The reconstructed High Glacial (LGP, LGM, Stage 0, MIS 2-3) ice-stream-network is one part of the whole Marsyandi ice stream network (Fig. 1) that has received further inflow from the Manaslu Himal and with its outlet glacier tongue flowed down up to c. 450 m asl (28°07'20''N/84°26'E) (Kuhle 1997: 125-127; 2009; 2011).

**Zusammenfassung**

Talabwärts anknüpfend an die gletschergeschichtlichen Forschungen von 1977 im oberen Marsyandi Khola (Nadi) (Kuhle 1980, 1982, 1983) wurden in den Jahren 2000, 2004 und 2007 weitere Geländekampagnen durchgeführt. Sie hatten zum Ziel, die vorzeitliche Vergletscherung des mittleren Marsyandi Nadi vom Sabje Khola (Sapse Lungpa) bis zur Einmündung des Nar (Naur) Khola (Nadi) zu untersuchen sowie die synchrone Vergletscherung des Damodar Himalaja zu rekonstruieren.
Es ist ein zusammenhängendes Eisstromnetz erfasst worden, welches unterhalb der Talkammer von Kotogau (2500 m ü. M.) durch den Marsyandi Nadi Hauptgletscher drainiert worden ist. Die maximal erreichte Gletschermächtigkeit betrug ca. 2200 - 2100 m. Dadurch erfolgte eine Transfluenz in das obere Kanla Khola. Neben der Konfluenz mit dem Nar Khola Stammgletscher, - wo etwa die gleiche Eismächtigkeit erreicht worden ist – bestand somit eine weitere lokale Gletscherverbindung zwischen dem Marsyandi Gletscher aus der Annapurna Gruppe und dem Damodar Himalaja und damit Kontakt zur Tibetvereisung hin.
Während der 4 spätglazialen Vorstöße (Ghasa-, Taglung- Dhampu- und Sirkung Stadium = I, II, III, IV; Tab. 1) wurden mit schrittweise hinaufrückender ELA (Schneegrenze) bis über 200 m mächtige Podestgrundmoränen aufgebaut. Auf diesen sukzessive anwachsenden Podestmoränen, auf denen die Gletscher - in zunehmender Höhe liegend - abfließen, sind diese wegen der immer geringer werdenden Vorstöße zunehmend vom Felsboden der Täler isoliert worden. Erst während des spätglazialen Dhampu Stadiums (III), als die Schneegrenzdepression (Δ ELA) weniger als 800 - 900 m betragen hat (Tab. 1), hat der Hauptgletscher des Damodar-Eisstromnetzes, der Nar Gletscher, den Marsyandi Gletscher nicht mehr erreicht.
Das rekonstruierte hochglaziale (LGP, LGM, Stadium 0, MIS 2 - 3) Eisstromnetz ist ein Teil des gesamten Marsyandi Eisstromnetzes (Fig. 1), das weiteren Zustrom aus dem Manaslu Himal erhalten hat und mit seiner Auslaßgletscherzunge bis auf ca. 450 m ü. M. (28°07'20''N/84°26'E) hinabgeflossen ist (Kuhle 1997: 125 - 127; 2009; 2011).

**Key words:** Former glaciation, Himalaya, southern Tibet, paleoclimate, ice age, glacial geology, glacial geomorphology, Annapurna-Damodar Himal

## 1. Methods

The following analytical working techniques and methods have been carried out in the research area: Glaciogemorphological observations have been mapped in detail with the help of 36 signatures especially developed for this sort of relief (Kuhle 2005, Fig. 3 and Fig. 11). They are registered in a map (Fig. 13) that means in topographic profiles, i. e. in three dimensions. The indicator value of the intended geomorphological mapping of e. g. „glacial striae" (cf. Photo 5), „roches moutonnées and related features of glacial polishing" like "glacially streamlined hills" or „glacial flank polishing and abrasion" (Photo 11) lies in the fact that they can be interpreted as glacigenic erosional forms (see legend of Fig. 13). According to the height of their position in the relief, i. e. up the valley flanks or even on mountain ridges or „transfluence passes" between two valleys, they provide evidence of a glacier filling up to the corresponding glacier level. This applies also to „glacially triangular-shaped slopes (truncated spurs)" (Photos 1; 2). Here, segments of valley flanks between inflowing side valleys are concerned which have been polished back glacigenically. At the same time these are elements of the larger form „glacial trough". According to roughnesses above, as e. g. wall gorges and gullies and a „polish or abrasion line" (cf. Photo 11 ----) separating the smooth and the rough rock face, the glacier trimline is recognizable. Corresponding observations can be made with the help of a trough cross-profile. Where its concave course comes to an end in an upward direction, the minimum altitude of the glacial trimline is reached. „Glacial horns" belong to the same glacigenic forms of erosion as troughs. These are summits between two trough valleys which have received their significant steepness by glacigenic undercutting and back-polishing on two sides. They indicate a mountain relief filled by glacier ice very far upward and are thus evidence of past ice stream networks. In many places „rock crumblings on past flank polishings" as well as „rock avalanches" suggest past glacigenic forms, because they are gravitational mass movements on flanks that have been oversteepened by glacier polishing, i. e. „trough valley flanks" (Photo 10). The typically Postglacial reshap-

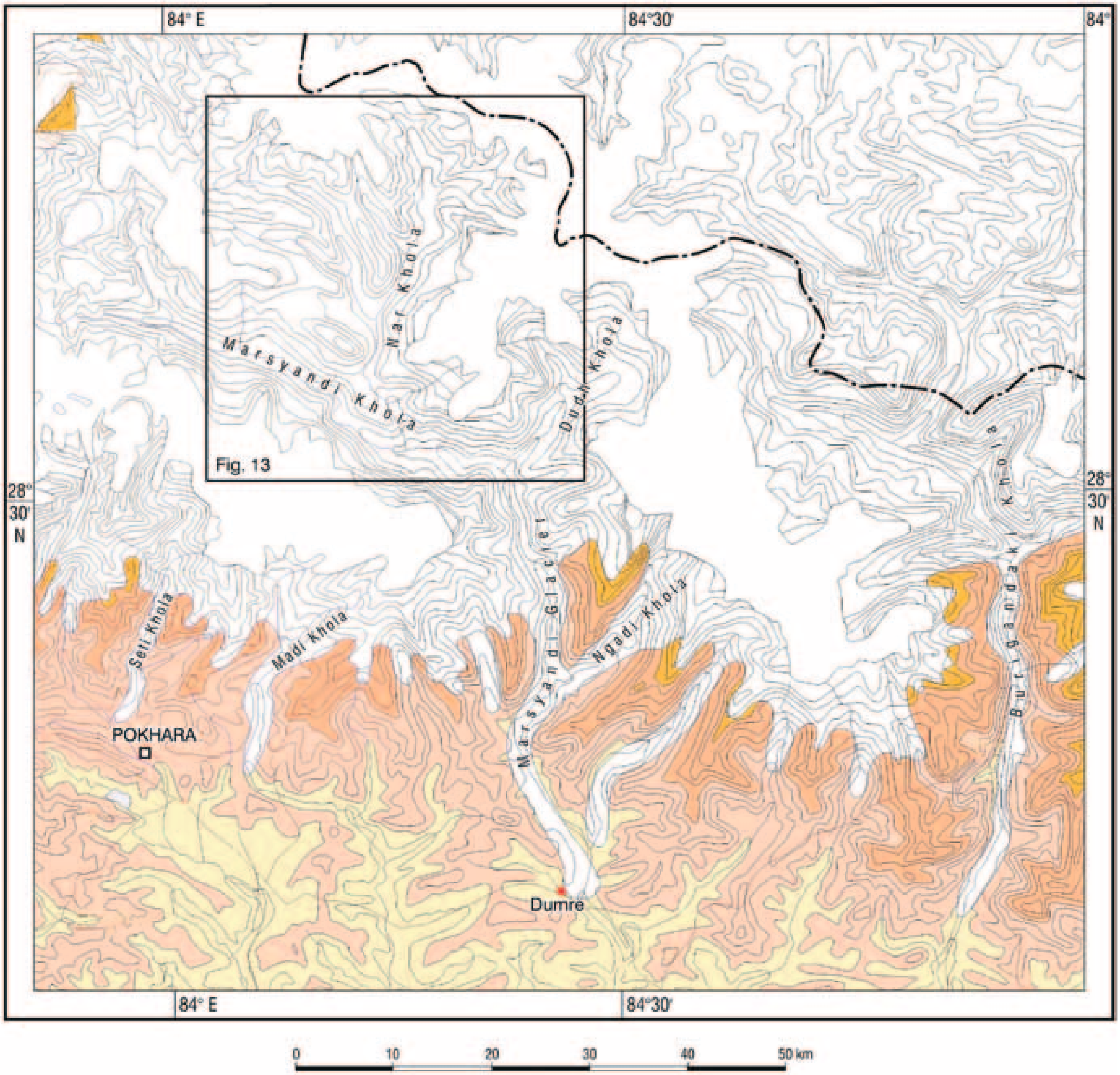



**Figure 1:** Glacier-map of the High Glacial (LGP, LGM, MIS 3-2, Stage 0 cf. Tab. 1) glacier cover in the Annapurna-, Chulu-, Damodar- and Manaslu Himalaya on the S-margin of Tibet. Scale 1:666,666. Basic topographic map: ONC (1978): H-9; 1: 1,000,000. The outline forms the boundary of the research area of the paper presented here. See Fig. 13.

ing of „glacial troughs“ by „fluvial undercutting of the valley flanks“ is a further factor which prepares „rock crumblings on past flank polishings“ (Photo 13; 14) and „rock avalanches“.

The wide-spread occurrence of these secondary features of erosion proves the development from a glacigenic relief of a trough valley of the last glacial period to an interglacial V-shaped valley relief. Owing to this, it is a secondary characteristic of the past glacial relief. “Gorge-like troughs” (see Fig. 13) are modifications of “glacial troughs” at a steep incline of the valley bottom. Here, the tractive forces within the glacier are predominant so that the ground scouring predominates over the flank polishing. “Subglacial gorges cut into the floor of a glacial trough” (Photo 14) are indicators of the course of trough valleys below the snow-line (ELA), because they have been additionally shaped by subglacial meltwater erosion. Along the deepest valley courses of the mountains surrounding Tibet like the Himalaya, they have been developed by High Glacial (LGP, LGM) activities and also - when the ELA increased - by Late Glacial activities along higher valley courses in the very high test- and investigation areas on the southern edge of Tibet as they have been visited. In several mountain areas the Late Glacial uplift of the snowline has led to the development of “cirques” (Fig. 13; Photo 10). Cause of this was that during the maximum of the last glacial period the snowline ran too low there, so that cirques have not been formed. Instead, an ice sheet or icestream network emerged, composed from valley glaciers. In positions high above fluvial talwegs or on rock slopes without a present-day fluvial catchment area „potholes“ can be a hard indicator of a past ice filling of the relief, supra- or subglacially canalizing the water needed for their development (Photos 5; 14).

Accumulative glacier indicators which may overlie the glacial-erosive features in different forms can be observed as “ground moraine with (pedestal ground moraine with escarpment and)

**Figure 2:** Morphometric quartz grain analysis of 51 representative samples of middle-sand from the middle Marsyandi Nadi (valley) with the Annapurna-, the Chulu- and the Damodar-Himalaya. Laboratory analysis (microscopy) – *Laboranalyse (Mikroskopie)*; sample localities see Fig 13 (cf. Figs 3 - 12). *Sampling M. Kuhle.*

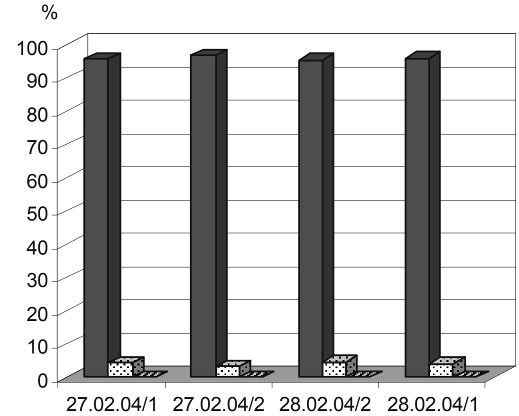
| sample No. / *Proben-nummer* | date / *Datum* | counted quartz grains of the medium sand / *ausgezählte Quarzkörner der Mittel-sandfraktion* | freshly weathered/ glacially crushed / *frisch verwittert/ glazigen gebrochen* [%] | lustrous (fluvially polished) / *fluvial poliert* [%] | dull (aeolian) / *äolisch mattiert* [%] | remarks / *Anmerkungen* |
|---|---|---|---|---|---|---|
| 1 | 27.02.04/1 | 279 | 95,7 | 4,3 | 0 | Heavily weathered, secondarily developed clay, compact grains with partially less rounded edges, only small portion of quartz / *stark verwittert, Tonmineralneubildung, kompakte Körner mit teilweise nur leicht gerundeten Ecken, eher geringer Quarzanteil* |
| 2 | 27.02.04/2 | 163 | 96,9 | 3,1 | 0 | Only small portion of quartz / geringer Quarzanteil |
| 3 | 28.02.04/2 | 183 | 95,6 | 4,4 | 0 | Small portion of quartz / *geringer Quarzanteil* |
| 4 | 28.02.04/1 | 151 | 96,0 | 4,0 | 0 | Small portion of quartz / *geringer Quarzanteil* |
| 5 | 05.03.04/1 | 203 | 99,0 | 1,0 | 0 | High portion of fine material; many secondarily developed clay minerals, high quartz portion / *viel feines Material, viele sekundär entwickelte Tonminerale, hoher Quarzanteil* |
| 6 | 29.02.04/1 | 243 | 98,8 | 1,2 | 0 | Secondarily developed clay minerals on quartz grains; strongly weathered / *Tonmineralneubildung auf Quarzkörnern mit starker Verwitterung* |
| 7 | 29.02.04/2 | 207 | 98,1 | 1,9 | 0 | Very small quartz portion / *sehr geringer Quarzanteil* |
| 8 | 01.03.04/1 | 190 | 98,4 | 1,6 | 0 | Small quartz portion similar to sample 7 / *geringer Quarzanteil wie vorige Probe* |
| 9 | 01.03.04/2 | 279 | 97,5 | 2,5 | 0 | Slight new development of clay minerals / *leichte Tonmineralneubildung* |
| 10 | 02.03.04/1 | 98 | 97,5 | 2,5 | 0 | Very small portion of middle sand / *sehr wenig Material* |
| 11 | 02.03.04/2 | 197 | 98,0 | 2,0 | 0 | Many secondarily developed clay minerals / *viel Tonmineralneubildung* |
| 12 | 02.03.04/3 | 166 | 98,8 | 1,2 | 0 | Secondarily developed clay; small portion of quartz / *Tonmineralneubildung, wenig Quarz* |
| 13 | 04.03.04/1 | 186 | 98,9 | 1,1 | 0 | Small portion of quartz; nearly not rounded / *geringer Quarzgehalt, kaum gerundet* |
| 14 | 06.03.04/1 | 211 | 97,2 | 2,8 | 0 | Content of organic material; grains are edged and not compact / *organisches Material enthalten; Körner kantig und nicht kompakt* |
| 15 | 04.03.00/1 | -- | -- | -- | -- | No quartz grains in the sample / *keine Quarzkörner in der Probe* |
| 16 | 05.03.00/1 | 16 | 93,75 | 6,25 | 0 | No significance because not enough quartz grains / *zu wenig Quarzkörner in der Probe* |
| 17 | 05.03.04/2 | 177 | 98,3 | 1,7 | 0 | Very sharply broken, compact quartz grains; high portion of quartz / *sehr scharf gebrochene, kompakte Quarzkörner bei hohem Quarzanteil* |
| 18 | 07.03.00/1 | -- | -- | -- | -- | No quartz grains in the sample / *keine Quarzkörner in der Probe* |
| 19 | 08.03.00/1 | -- | -- | -- | -- | No quartz grains in the sample / *keine Quarzkörner in der Probe* |

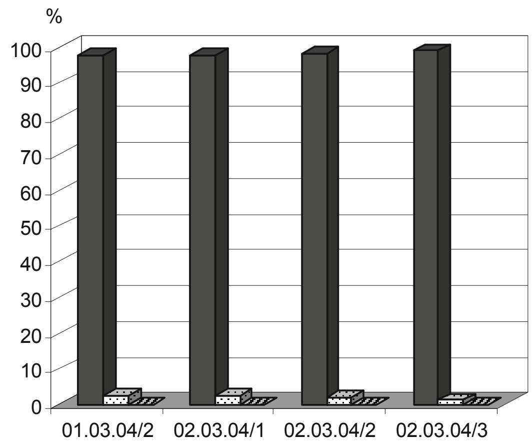
| sample No. / *Proben-nummer* | date / *Datum* | counted quartz grains of the medium sand / *ausgezählte Quarzkörner der Mittelsandfraktion* | freshly weathered/ glacially crushed / *frisch verwittert/ glazigen gebrochen* [%] | lustrous (fluvially polished) / *fluvial poliert* [%] | dull (aeolian) / *äolisch mattiert* [%] | remarks / *Anmerkungen* |
|---|---|---|---|---|---|---|
| 20 | 08.03.00/2 | 17 | 94,1 | 5,9 | 0 | Very low till; no significance (only 17 quartz grains) / *keine bis geringe Signifikanz* |
| 21 | 09.03.00/1 | 253 | 98,4 | 1,6 | 0 | Not many quartz grains, but high portion of mica / *wenig Quarzkörner, aber hoher Glimmeranteil* |
| 22 | 09.03.00/2 | 20 | 95 | 5 | 0 | No significance; quartz grains are not enough / *keine Signifikanz da zu wenig Quarzkörner* |
| 23 | 06.03.04/2 | 207 | 98,1 | 1,9 | 0 | Slight new development of clay minerals / *leichte Tonmineralneubildung* |
| 24 | 06.03.04/3 | 184 | 98,9 | 1,1 | 0 | Medium portion of quartz / *mittlerer Quarzanteil* |
| 25 | 06.03.04/4 | 240 | 99,6 | 0,4 | 0 | Slight new development of clay minerals / *leichte Tonmineralneubildung* |
| 26 | 06.03.04/5 | 235 | 99,1 | 0,9 | 0 | Medium quartz portion / *mittlerer Quarzanteil* |
| 27 | 09.03.00/3 | 16 | 100 | 0 | 0 | No significance (not enough quartz in the sample) / *keine Signifikanz; zu wenig Quarzkörner* |
| 28 | 09.09.07/1 | 19 | 94,7 | 5,3 | 0 | No significance, just 19 quartz grains in the sample; even no feldspars / *keine Signifikanz, da nur 19 Quarzkörner in der Probe, auch kein Feldspat* |
| 29 | 09.09.07/2 | 30 | 83,3 | 16,7 | 0 | No significance; just 15 quartz grains in the sample: even feldspars have been counted / *keine Signifikanz; nur 15 Quarzkörner in der Probe; auch kein Feldspat* |
| 30 | 08.09.07/1 | 242 | 94,2 | 5,4 | 0,4 | High portion of clear and milky quartz grains, which are sharply broken / *hoher Anteil an reinen und scharf gebrochenen Milchquarzkörnern* |
| 31 | 10.09.07/1 | 150 | 99,3 | 0,7 | 0 | The sample contains just a small portion of clear and milky quartz grains that are sharply broken / *Probe enthält nur einen kleinen Anteil von reinen- und Milchquarzkörnern, die scharf gebrochen sind* |
| 32 | 06.09.07/1 | 207 | 96,6 | 3,4 | 0 | All grains are quartz grains that mostly are clear and sharply broken / *alle Körner sind Quarzkörner, die meist rein und scharf gebrochen sind* |
| 33 | 17.09.07/1 | 212 | 98,1 | 1,9 | 0 | High portion of clear and milky quartz grains that are sharply broken / *hoher Anteil an reinen und Milchquarzkörnern, die scharf gebrochen sind* |
| 34 | 09.03.04/4 | 332 | 99,1 | 0,9 | 0 | High portion of quartz with sharply broken grains / *hoher Quarzanteil mit scharf gebrochenen Körnern* |
| 35 | 09.03.04/5 | 179 | 98,9 | 1,1 | 0 | Insignificant portion of quartz / *geringer Quarzanteil* |
| 36 | 09.03.04/2 | 326 | 97,9 | 2,1 | 0 | High portion of quartz; compact grains / *hoher Quarzanteil, kompakte Körner* |

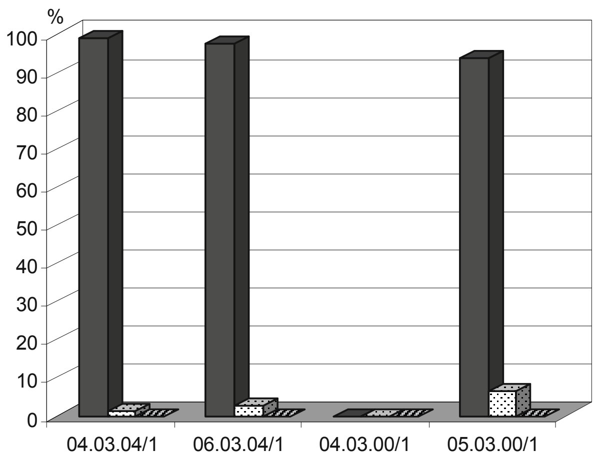
| sample No. / *Proben-nummer* | date / *Datum* | counted quartz grains of the medium sand / *ausgezählte Quarzkörner der Mittel-sandfraktion* | freshly weathered/ glacially crushed / *frisch verwittert/ glazigen gebrochen* [%] | lustrous (fluvially polished) / *fluvial poliert* [%] | dull (aeolian) / *äolisch mattiert* [%] | remarks / *Anmerkungen* |
|---|---|---|---|---|---|---|
| 37 | 04.09.07/1 | 336 | 95,2 | 4,8 | 0 | High portion of pure quartz grains that are sharply broken / *hoher Anteil an scharf gebrochenen, reinen Quarzkörnern* |
| 38 | 16.09.07/2 | 11 | 81,8 | 18,2 | 0 | No significance; nearly the whole sample consists of biotite grains / *keine Signifikanz; annähernd die gesamte Probe besteht aus Biotit-Körnern* |
| 39 | 16.09.07/1 | 173 | 81,5 | 18,5 | 0 | Small portion of clear and milky quartz grains; even feldspars were counted / *geringer Anteil von reinen- und Milchquarzkörnern; auch Feldspäte wurden mitgezählt* |
| 40 | 10.09.07/2 | 168 | 94,6 | 5,4 | 0 | Small portion of compact, but broken quartz grains / *geringer Anteil kompakter, aber gebrochener Quarzkörner* |
| 41 | 14.09.07/1 | 103 | 90,3 | 8,7 | 1,00 | Small portion of clear and milky quartz grains, which are mostly compact but broken / *geringer Anteil von reinen und Milchquarzkörnern, die meistens kompakt, aber gebrochen sind* |
| 42 | 15.09.07/1 | 55 | 85,5 | 14,5 | 0 | No significance, just a few quartz grains in the sample; even feldspars were counted / *keine Signifikanz, da nur wenige Quarzkörner in der Probe enthalten sind; auch die Feldspäte wurden mitgezählt* |
| 43 | 13.09.07/2 | 108 | 92,6 | 7,4 | 0 | Small portion of clear and milky quartz grains, which are mostly compact, but broken / *geringer Anteil reiner und Milchquarzkörner, die meistens kompakt, aber gebrochen sind* |
| 44 | 13.09.07/1 | 108 | 92,6 | 7,4 | 0 | Small portion of clear and milky quartz grains, which are mostly compact, but broken / *geringer Anteil reiner und Milchquarzkörner, meistens kompakt aber gebrochen* |
| 45 | 09.03.04/3 | 96 | 97,9 | 2,1 | 0 | Little material with many fine fraction and middle portion of quartz / *wenig Material mit viel Feinanteil und mittlerem Quarzanteil* |
| 46 | 09.03.04/1 | 253 | 98,8 | 1,2 | 0 | High portion of quartz; small compact grains, nearly not rounded / *hoher Quarzanteil, kleine kompakte Körner, kaum gerundet* |
| 47 | 10.03.04/1 | 234 | 98,7 | 1,3 | 0 | Very high portion of quartz with compact and long, less rounded grains / *sehr hoher Quarzanteil mit kompakten und länglichen, wenig gerundeten Körnern* |
| 48 | 10.03.04/2 | 261 | 97,7 | 2,3 | 0 | High portion of quartz / *hoher Quarzanteil* |
| 49 | 10.03.04/3 | 322 | 98,1 | 1,9 | 0 | High portion of quartz; different sizes / *hoher Quarzanteil; verschiedene Größen* |
| 50 | 25.02.04/1 | 282 | 95,7 | 4,3 | 0 | No secondarily developed clay; moderate portion of quartz / *keine Tonmineralneubildung, mittlerer Quarzgehalt* |

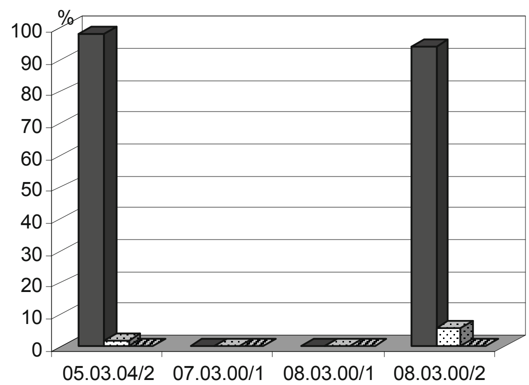
| sample No. / *Proben-nummer* | date / *Datum* | counted quartz grains of the medium sand / *ausgezählte Quarzkörner der Mittelsandfraktion* | freshly weathered/ glacially crushed / *frisch verwittert/ glazigen gebrochen* [%] | lustrous (fluvially polished) / *fluvial poliert* [%] | dull (aeolian) / *äolisch mattiert* [%] | remarks / *Anmerkungen* |
|---|---|---|---|---|---|---|
| 51 | 25.02.04/2 | 301 | 96,3 | 3,7 | 0 | No secondarily developed clay; medium-sized compact grains; less rounded / *keine Tonmineralneubildung, kompakte, mittelgroße Körner; kaum gerundet* |

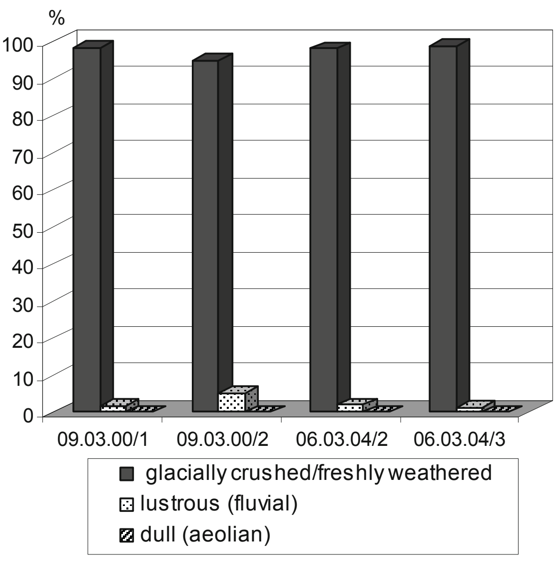
Sampling – Probenentnahme: M. Kuhle

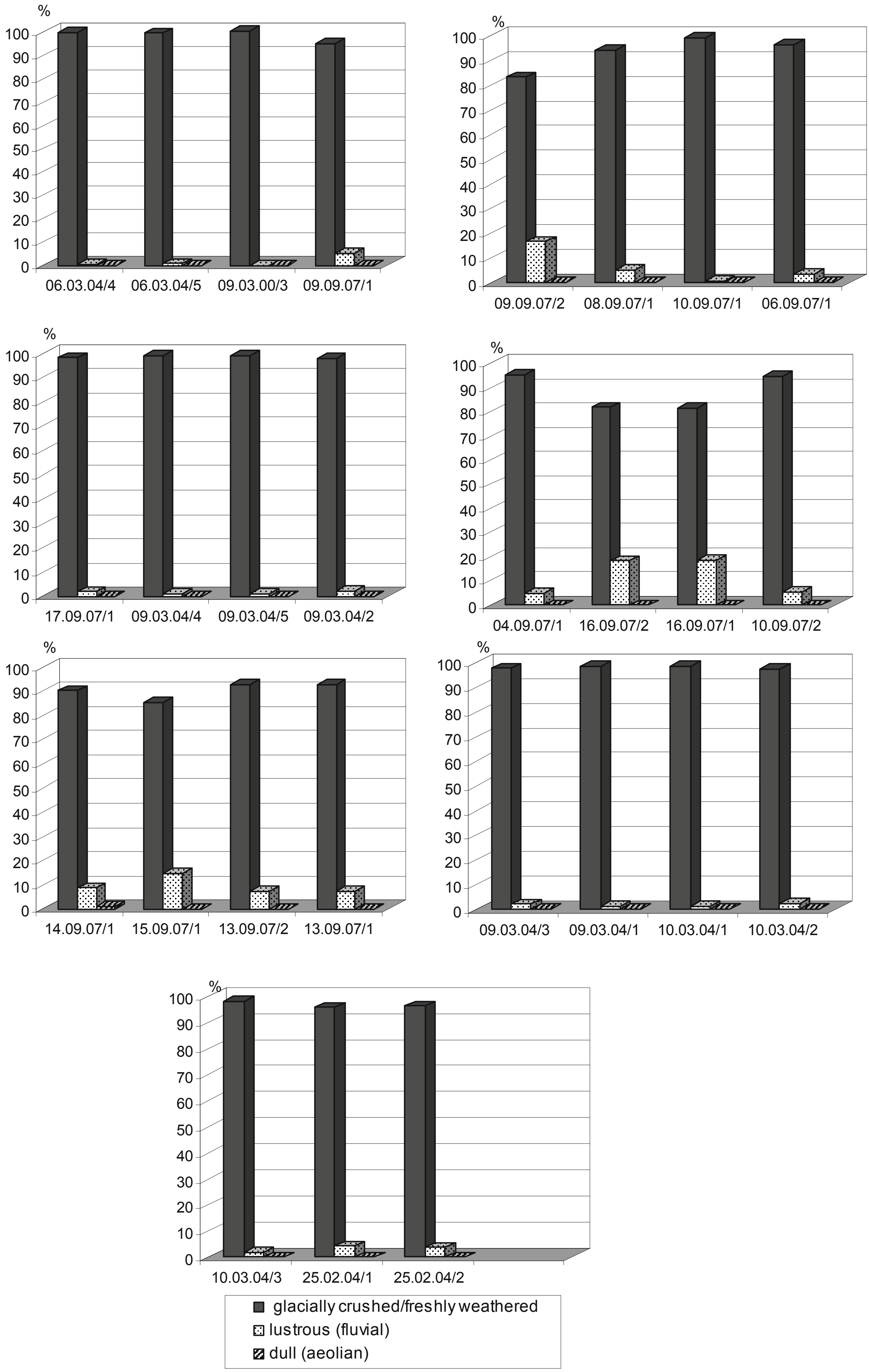
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14.09.07/1
15.09.07/1
13.09.07/2
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09.03.04/3
09.03.04/1
10.03.04/1
10.03.04/2
10.03.04/3
25.02.04/1
25.02.04/2
glacially crushed/freshly weathered
lustrous (fluvial)
dull (aeolian)

erratic boulders" and "ground moraine with big non-erratic boulders". The higher their position above the valley bottom, the greater the former ice thickness. The same applies to big blocks (boulders) (erratic or not erratic). In addition, their edged, facetted or rounded form has been taken into consideration as an indicator of the way and the distance of their transport. Typical of high mountain systems like the Himalaya and Karakorum and their wealth of debris is the preservation of decametres to over 100 m-thick "pedestal ground moraine with escarpment" (cf. Fig 13; Photos 1; 4; 6; 13). They are the result of many thick layers of ground moraine, one on top of the other, which have been deposited step by step during the melting process. "Earthpyramids" (Photos 3; 7) are characteristic residual forms of lodgement till (ground moraine). They are evidence of recent fluvial dissection of former glacigenic accumulations. At the same time they make understandable that the preservation of these past forms must be incomplete. This applies also to "moraine slide", debris flow cone and alluvial fan or outwash fan and "glacier mouth gravel floor and alluvial terraces in contact with moraines" (Fig. 13), because they concern re-deposited moraine material which originally lay higher up the valley flanks. "Kames"and "paraglacial" or lateroglacial deposits are accumulations which are intercalated into lateral moraines. In the investigation areas they have been developed during the Post-High Glacial (LGP) decay of ice. "Alluvial terraces in contact with moraines" are forms of glacifluvial dissection of older sanders caused by further regression of the glacier mouth. These sander faces, i.e. outwash accumulations, form the Postglacial trough valley bottoms in several mountain areas (glacial trough with gravel-bottom) so that box-profiles do result. The Postglacial "rock avalanches" (see above) deposit their accumulations on the gravel floor of valleys as well as on moraine accumulations (Photo 4 ↙).

Representative samples have been taken in the test areas in the field (cf. Fig. 2; Fig. 13). They have been used for laboratory analyses in order to provide a detailed diagnosis and to show the actual occurrence of lodgement till in those topographical positions which suggest former glacier trimlines at high altitudes, the development of glaciofluvial terraces, alluvial fans, debris flows or rock avalanches and other types of accumulation. The sediment analyses (Fig. 3 - 12): the loss of ignition (LOI), lime content determination (Scheibler; DIN 19684 Teil 5, 1977), grain size analysis („Kombinierte Sieb- und Pipett-analyse" Köhn 1928, DIN 19683 Blatt 2, 1973), determination of the sorting coefficient in the matrix spectrum (Engelhardt 1973) and morphoscopic quartz grain analysis in the medium sand fraction (Mahaney 1995) may support and complete a proof of the fluvial and periglacial development in the test area since the deglaciation c. 15.0 - 1.7 Ka ago (Tab. 1) and the complete glacier cover before that time (LGM = Last Glacial Maximum; LGP = Last Glacial Period = Stage 0). The also intended morphoscopic quartz grain analysis does'nt make it immediately possible to recognize the material as „glacially crushed or freshly weathered" (Fig. 2). But the petrographical analysis in the field, i.e. the content of erratic material and partly also the lime content of the debris cover indicate that the material is glacially crushed and not freshly weathered in situ. The sorting coefficient So (Engelhardt 1973) provides further evidence as to the differentiation of fluvial, periglacial and morainic accumulations or the occurrence of debris flows. If only one grain size exists in the sediment, then So is = 1. The greater the coefficient, the more intensively mixed are the different grain sizes. This is for instance the characteristic feature of moraine matrix.

Accordingly, e.g. the minor LOI, the bi/trimodal grain size distribution and the lack in sorting, as well as the very high percentage of glacially crushed quartz grains provide evidence of lodgement till even up to very high positions in this steep valley relief. Thus, these analyses could be further accumulation indicators of the former ice cover and glacier thickness and - in some places - even of the minimum altitudes of the trimline. Analyses like these also enable the diagnosis of sediment types to be done that have only been developed primarily since the deglaciation or by redeposition, i.e. not glacigenically.

"Pedestal ground moraines" (Photo 6), "terminal moraines of valley glaciers" and "lateral moraine, terminal moraine (former ice margin)" (Fig. 13) are accumulative indicators of the ablation areas. In the investigation area, which the joint glacier terminal of the ice stream network had left during the maximum glaciation of the last glacial period (LGP, Stage 0), they are mainly evidence of Late Glacial (Stage I-IV, Tab. 1) glacier margins or even of Neoglacial glacier stages far below the highest trimlines which had already decreased. These younger Post-LGP glacier stages are main points of the detailed field research that has been carried out and was focused on the geomorphological development in correspondence with the deglaciation since the LGM or LGP.

Secure evidence of the High- and Late Glacial glacier history could be provided by the glacial-physically unambigous arrangement of the positions of geomorphological findings in detail inclusive of localities where sediment samples have been taken. The unambiguousness of the statements will be proved by a test hierarchy already in hand (Kuhle 1990). This is the usually applied glacio-gemorphological method - up to now it has not been replaced by another one - with which all glacier-historical results have been obtained so far (cf. v. Klebelsberg 1948, Flint 1971, Kuhle 1991). The three-dimensional arrangement of the indicators leads to the reconstruction of the glaciated area and in addition to that of the local ice thickness. Aim of the investigations is to find a spatial proof-system based on the arrangement of the positions, so that the photographs complete the glaciogeomorphological map (Fig. 13) especially with regard to the indication of past glacier thicknesses. Apart from that, the ice thickness provides local references as to the horizontal extension of the glacier cover (Fig. 1). Some indicators marked in the geomorphological map will be documented on the spot by photo-panoramas in a medium-sized format.

## 2. The highest former trim-lines and glacier thicknesses of the middle Marsyandi Nadi (Khola) glacier of the valley chambers between Bhraka and the inflows of the Sabje Khola (Sapse Lungpa) and Julu Khola up to the inflow of the Nar Khola down-valley (Figs. 1 and 13)

### 2.1. The valley chamber between Bhraka and Nawal (Fig. 13)

Photo 1 establishes the connection to the geomorphological and Quaternary-geological analysis of the upper Marsyandi Nadi (Khola) and the reconstruction of its glacial glaciation that has already been published (Kuhle 1980, 1982: 34-39; Abb.

44-65, 184, 1983: 279-306). The valley bottom of the upper Marsyandi Khola investigated there is filled up by High- (Stage 0) to Late Glacial (Stage I-IV, Tab. 1) remnants of pedestal ground moraine that develop terraces (Photo 1 ■). By means of his cross-profile of the Marsyandi Khola close to the Braga (Bhraka) settlement, Hagen (1968: 60-63, 67) has provided the first description of ground moraines on the valley bottom up to c. 200 m above the current talweg. He placed this "ancient ice age ground moraine" into the pre-last High Glacial, because it has been covered by an "interglacial landslide", the "landslide of Braga". By analogy with that one of Flims in the Alps, this landslide (rock avalanche) coming from the orographic left valley flank, even surged against the orographic right one. The author agrees with this description and analysis, i.e. he confirms it (cf. Fig. 2 No. 1; Fig. 13: 27.2.04/1). However, he does not confirm the age dating. Here, he assumes a compressed model to be sounder and classifies "the ancient ice age ground moraine" of Hagen (ibid.) as belonging to the LGP. So, the "landslide of Braga" either belongs to an earlier Würmian phase interrupted by warming up - that is between Würm I and II (i.e. MIS 3 and 2) - or has taken place during the post-LGM. In the first case the landslide (rock avalanche) would have been overthrust by the Marsyandi K. glacier during the LGM (Stage 0, cf. Tab. 1) and in the second case by one or several Late Glacial advances of Stages I to IV. The author (Kuhle) assumes the first, simpler case (between MIS 3 and 2) to be most probable. In addition, the author likes to call to mind, that part of that rock avalanche has been transported away by the Marsyandi glacier, i.e. dislocated as a rock avalanche moraine. This alternative possibility can be taken from the sediment character (cf. Fig. 3) and in addition cannot be ruled out, because according to the author's opinion the landslide-deposit diagonally across the valley bottom cannot be evidenced generally (see below).

The author's comments mentioned above (Kuhle 1982, 1983) that - in contrast to the earlier ones of Hagen (1968) - have been focused on the reconstruction of the glacial glaciation, have traced back the Quaternary- and glacial-geological as well as -geomorphological glaciation far higher, i.e. c. 1700 m higher up than only the lowest 200 m of the valley cross-profile. This procedure, that intends to investigate the maximum ice infilling of the valley receptacles, goes on as follows: further up the two valley flanks of the Marsyandi Khola, up to at least 4260 m asl (Fig. 13: 28.2.04/2), i.e. at least up to 850 m beyond the Marsyandi Khola talweg, remnants of ground moraine covers are verifiable on the slope. The sedimentary analyses (Fig. 4) confirm the ground moraine character by a - with regard to the slope position- high content of clay, a trimodal grain size cumulative curve, a relatively high sorting coefficient (So 4.42) and (see Fig. 2 No. 3) 95% glacially crushed $SiO^2$-grains of the medium sand fraction. The remaining approx. 5% fluvially polished $SiO^2$-grains completely rule out the possibility that these might be slopes of congelifracts or similar local accumulations instead of ground moraines. On the orographic right valley flank, on the Annapurna III superstructure (Photo 1 No. 9) between the current hanging glaciers, remnants of glacigenically back-polished (Fig. 13), triangular-shaped mountain spurs (Photo 1 ◓ black; Photo 2 ◓ black; Fig. 13) are preserved up to an abrasion limit (polish line) at c. 5400 m asl (Photo 1 ____ ; Photo 2 ---- white on the right).

The c. 400 m high pedestal ground moraine terrace (Photo 1 ■ and 0-IV) continuing down-valley, shows e.g. on its surface - apart from 96% crushed $SiO^2$-grains - also 4 % fluvially polished quartz grains (Fig. 13: 28.2.04/1; Fig. 2 No. 4). The grain size cumulative curves are bimodal, the So is 5.33 and the clay has been reduced to only c. 4.5% due to Late Glacial subglacial meltwater erosion. However, not only this fine material matrix proves the moraine-character of the sediment; also the polymictic large boulders contained show, that the surface of this loose material has not been heaped up by a rock avalanche. The lime content of 13.9 % also corresponds with that one in the down-slope ground moraine up to 4260 m asl above, where the author has found out 11.4 % (see Fig. 4).

Sample 27.2.2004/1 (Fig. 13), taken c. 240 m above the talweg from the concerning, c. 400 m high pedestal ground moraine terrace that continues down-valley, confirms the ground moraine character e.g. by a high sorting coefficient of So = 7.74 and c. 96 % glacigenically crushed (Fig. 2 No. 1) and 4.3 % fluvially polished $SiO^2$-grains. The high lime content of c. 66 % speaks for local moraine material from the NE-adjacent Julu Khola leading down from the calcareous Julugan- and Kanla Himal. - Sample 27.2.2004/2 (Fig. 3) has been taken from the hanging loose rock that corresponds to the material called „interglacial landslide" by Hagen (1968: 60 Fig. 44). However, due to the condition of its matrix, the recent author (Kuhle) classifies it as being a rock avalanche moraine (see above). The clay content of still 6.5 %, the relatively high So = 5.51 and the portion of 96.9 % glacially crushed as well as 3.1 % fluvially polished (Fig. 2 No. 2) material argue against a pure landslide, but in favour of a glacigenic reshaping. Finally, the with regard to this locality obviously minor lime portion of only 12.5 % pleads for it. This is especially insignificant, because the whole N-rising source slope of the landslide consists of outcropping edges of calcareous rock from the Devonian to Triassic limestones and dolomites (cf. Hagen 1968: 60/61, 65/66). With a lime content of only 12.5 % probably an intermixing, typical of ground moraine, has to be assumed. Down-valley the Tonje Khola joins the Marsyandi Nadi main valley from the orographic left side, so that the pedestal ground moraine terrace (see above) of the main valley is fluvially cut and deeply exposed. Apart from the granulometric and morphoscopic characteristics of the fine material matrix, like the bimodal course of the cumulative curve, a clay content of 9 % (sample No. 5.3.2004/1: Fig. 13) and 99 % glacially crushed $SiO^2$-grains (Fig. 2 No. 5), the content of metre-sized, polymictic, edged and rounded boulders provide indications of a typical ground moraine character as well as the local, characteristic admixture of rock avalanche- and landslide material. In the tributary valley itself samples have been taken from further moraine sediments, belonging - if not to the LGP - then definitely to the Late Glacial (Stage I-IV, Tab. 1) (Fig. 13: 29.2.04/1 and /2). The clay content of 5.5 - 12 % as well as a sorting coefficient of So = 5.11 to 6.29, a bi- to trimodal course of the grain size cumulative curve (Fig. 5) and 98 to 99 % of crushed $SiO^2$-grains (Fig. 2 No. 6 and 7) prove the glacigenic character of their matrix. Whilst the lime content of the two moraine samples amounts to 0 %, the lime content of 42.5 % is very high in this pedestal ground moraine terrace in the exit of this side valley (Fig. 13). This result, too, speaks in favour of the glacigenic dislocation of the

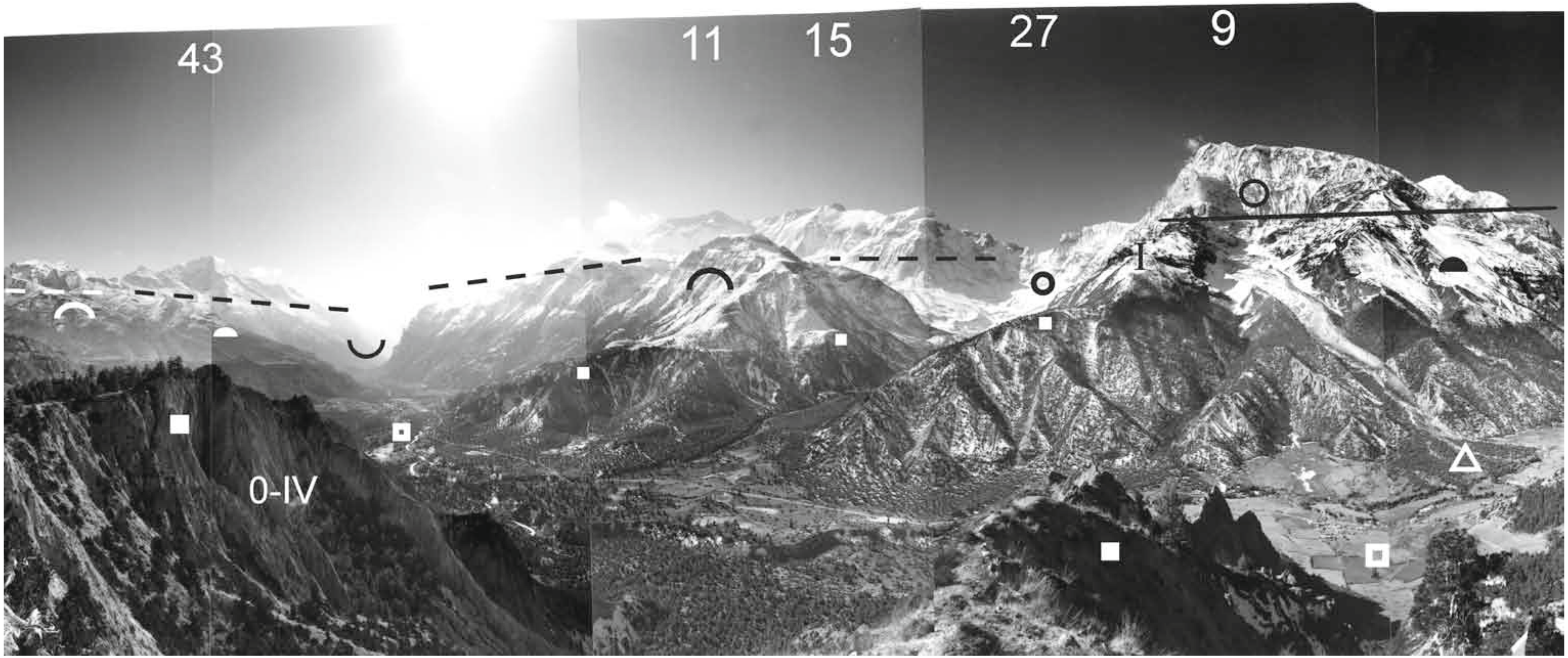


**Photo 1***:* C. 130°-panorama at c. 3810 m asl (28°39'06"N/84°03'40"E; map: 1:50 000, No.2884 05; Fig. 13 Panorama Photo 1) from the orographic left valley side of the upper Marsyandi Khola from the High- to Late Glacial ground moraine pedestal (Stage 0-IV, Tab. 1) taken facing down-valley to the E (left margin, Pisan Peak No. 43) via facing S into the right tributary valley (Sapse Lungpa) with Seti Gap (No. 27, see Tab. 2), between Annapurna IV and III (No. 15 and 9, Tab. 2). (■) are glacigenic sediments with ground moraine character, among them terraces of pedestal ground moraine (0-IV); (☐) mark partly block-bearing glaciofluvial gravels of a late-Late Glacial (Stage IV) to Holocene (Stage V-'VII) age; (Δ) indicates a debris flow fan consisting of redeposited lateral- and end moraine material of the Neoglacial to Historical Annapurna-III-N-glacier (cf. Kuhle 1982, 1983); (I) is a remnant of moraine- and glacigenic bank development on the mountain spur at the exit of the Sapse Lungpa (see in detail: Kuhle 1982: Bd. II Abb. 59 I). (○) mark modern cirques; (◓) mark High Glacial polish bands and (∩) an orographic right flank polishing; (∪) signifies the trough valley cross-profile of the Marsyandi K. in the valley chamber of Chame; (---- and ____ ) is the highest verifiable glacier level (Stage 0 = LGP, i.e. LGM) between c. 5200 and 5600 m asl. Analogue photo M. Kuhle, 28/02/2004.

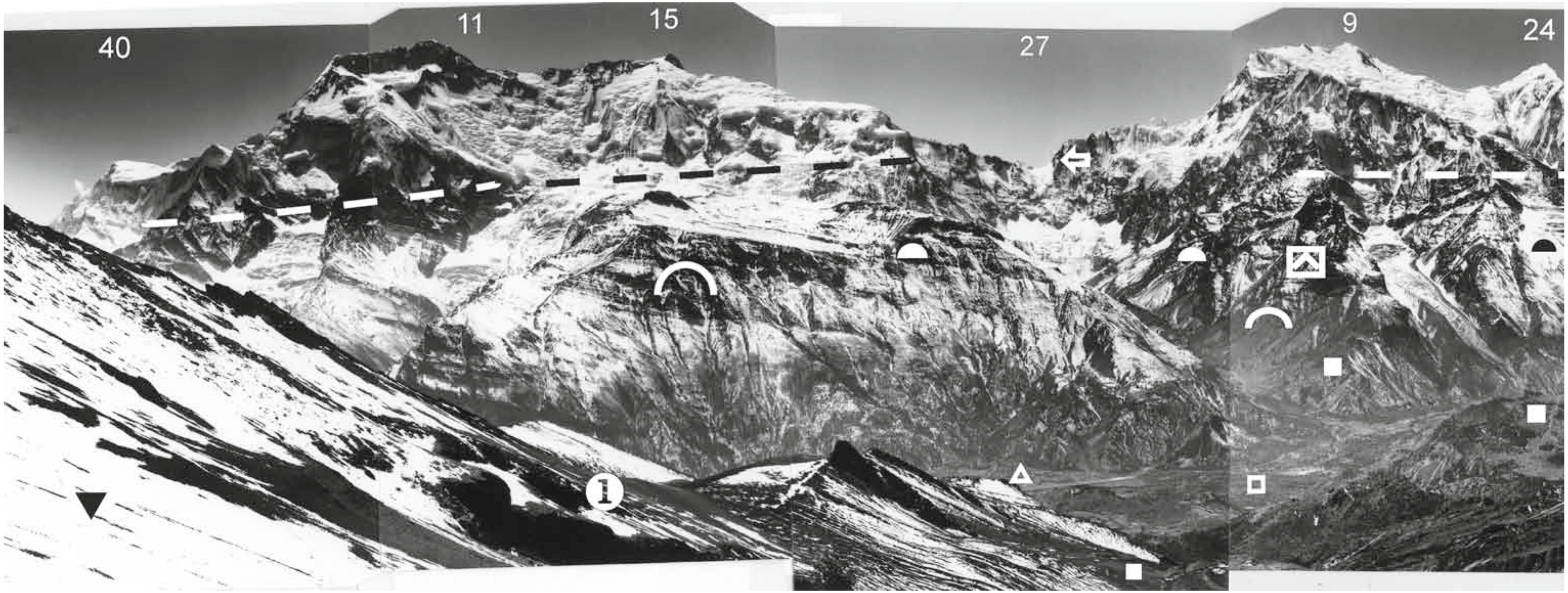


**Photo 2**: C. 100°-panorama taken at c. 5200 m asl (28°41'12''N/84°07'38''E; map: 1:50 000, No. 2884 05; Fig. 13 Panorama-Photo 2) from S below Kang La (Kanla Bhanjyan, 5365 m asl, Tab. 2 No. 76) from the Tonji Khola in the orographic left valley flank of the Marsyandi Nadi from up (on the right) to down the main valley (on the left) via the N-side of the Annapurna-group (cf. Tab. 2) with the 7937 m-high Annapurna II (No. 11), from Gangapurna (No. 24) up to Lamjung (No. 40). (■) mark glacigenic sediments with a ground moraine character, among them remnants of a pedestal ground moraine terrace (■ below No. 9 and 24), (□) signifies a Holocene (Stage V-'VII) glaciofluvial gravel floor, in part containing condensed moraine boulders, (Δ) is a debris flow fan of redeposited Late Glacial (Stage 0-IV, Tab. 1) ground moraine material, (∩) show glacigenic flank abrasions and rock roundings, (◓) are High- to Late Glacial (Stage 0-II) polish bands that have back-polished the mountain spurs, thus producing glacigenically triangular-shaped faces; (⊠) is a Post-Glacial crumbling; (----) indicates the maximum LGP- or probably LGM-glacier level of the Marsyandi parent glacier between c. 5200 and 5400 m asl, verifiable according to the polish line; (▼) are currently active debris slopes with an annual snow cover. Analogue photo M. Kuhle, 04/03/2004.

landslide of Braga deca-kilometres down the main valley (see above). Otherwise samples 29.2.04/1 (Fig. 5) and 29.2.04/2 that exactly originate from the supposed detachment zone of the landslide after Hagen (1968: Fig. 45), at least should have shown a certain content of lime, but not those 0%.

All the morainic sediments (ground moraines) described of this valley chamber are bound to occur below the ice level of Ghasa Stage (I), i.e. the oldest Late Glacial Marsyandi parent- i.e. main-valley glacier. The author has proved this by his finding of moraine at 4420 m asl on the mountain spur at the junction of the Sapse Lungpa (Sabje Khola) (Kuhle 1982: 41 and 104; Bd. II Abb. 59 I). In Photo 1 the position of the mountain spur is marked by I (on the left below No. 9). The moraine finding gives evidence of the minimum height of the corresponding ELA about 4400 m asl. In case of a lower height of the snowline the moraine remnant would have been removed in this position. With an ELA about 4000 m asl (Kuhle 1982: 150-152) evidenced for the LGM (Last High Glacial Maximum = Stage 0, cf. Tab. 1), even Taglung Stage (II) would have been a possiblity for the deposition of this lateral- i.e. ground moraine at 4420 m. The accompanying, i.e. simultaneous ice level might have been situated at most some 100 m higher. Details with regard to further lateral- i.e. ground moraine accumulations in the exit of the Sapse Lungpa (Fig. 13) with implications as to the Late Glacial glacier- and ELA-level can be found in Kuhle 1983: 95/96 and 294/295.

In the Tonje Khola that as an orographic left side valley leads up from the Marsyandi Khola to the NNE to the Kanla Bhanjyan (Table 2 No. 76), a series of 6 samples has been taken from c. 4500 (4365 aneroid) m asl up to the 5315 (5374 aneroid) high pass (Fig. 13: 1.3.04/1/2; 2.3.04/1-/3; 4.3.04/1). These samples belong to the Late Glacial up to Historical moraine sequence. All matrixes show characteristic features of ground moraines as e.g. high sorting indices (up to So = 7) or/and bimodal or even trimodal courses of grain size cumulative curves and - in relation to the position in the steep relief - high clay portions (up to 9 %) and about 97-99 % freshly weathered / glacially crushed medium sand grains (Fig. 2 No. 8 - 13). With the exception of samples 1.3.04/1 (Photo 2 ❶) and 4.3.04/1 all samples are situated at localities where the geomorphology of the sampling place makes a moraine immediately diagnosable (see Photo 2 ■ totally below). However, beside the supremacy of crushed $SiO^2$ grains, there also occur several fluvially polished grains (Fig. 2 No. 8 and 13) in these two samples. This has to be reduced to meltwater discharge that in the corresponding high slope positions can only become understandable by glaciation. Especially with regard to sample 04.03.04/1 (Fig. 2 No. 13) a historical periglacial weathering in situ due to the exposed, very high notch position cannot be ruled out, i.e. can be assumed as being sure. To this as well as to a denudative redeposition by the current periglacial solifluction cover on the slope, the monomodal course of the grain size cumulative curve has to be reduced.
One may safely assume that during Stages I and II (s. Tab. 1) the Late Glacial Tonje K. glacier flowing down to the SSW, has reached the Marsyandi main valley glacier (samples 01/03/2004/1 and 2: Fig. 13). Probably this has still happened during Stage III. During the Late Glacial Stage IV the glacier developed a dumped end moraine (samples 2.3.2004/1 - /3: Fig. 13) down to c. 4200 m asl. At a current ELA about 5600 m asl (5615 m after Kuhle 1982: 168) this proves a then ELA about 4900 m asl, and accordingly an ELA-depression of c. 700 m during Stage IV (cf. Tab. 1). The lowest Neoglacial ice margin position (Stage V) reached with its end moraine down to c. 4600 (4620) m asl (Fig. 13) what corresponds to an ELA about 5100 m and an ELA-depression of c. 500 m. Currently permanent snowfields only exist into the summer in the uppermost valley head where the permafrost line is reached.

According to these exemplary stages of hanging glaciers and chronology in the Tonje K., in the region of the orographic left catchment areas, it has to be assumed that during the Late Glacial Stage IV (Sirkung Stage, see Tab. 1) the Marsyandi Nadi was still flowed through by the Marsyandi parent glacier. It has been nourished by all orographic right tributary glaciers of the Annapurna-group N- to NNE exposition (see Fig. 13). The current hanging glaciers concerned have catchment areas in excess of 7000 m asl (Fig. 13 No. 27-40; Photo 2 No. 24-40; Tab. 2) and come to an end about only 3600-3800 m asl, i.e. only 200-500 m above the main valley bottom. An ELA-depression about c. 400 m would already be enough for the development of a main valley glacier. During Stage IV there existed an ELA-depression of c. 700 m (see above). The analysis of these conditions of glacier extension and their chronology has been documented by the author by e.g. Photo 68 (in Kuhle 1982: Bd. II (Abb.-Teil)) for the Sapse Lungpa (Sabje Khola). In this orographic right side valley of the Marsyandi Nadi, in the immediate valley exit on the orographic left side, that moraine remnant of the oldest Late Glacial Stage I (see above Kuhle 1982: 41 and 104; Bd. II Abb. 59 I) is situated at 4420 m asl (ibid. Abb. 68 ✕I) high above the two valley bottoms. Below, the Neoglacial lateral moraine of Stage V can be found (ibid. Abb. 68: V far below No. 31). It proves that the Sapse Lungpa glacier has still reached the main valley. The older pedestal ground moraine of the Marsyandi Nadi-main

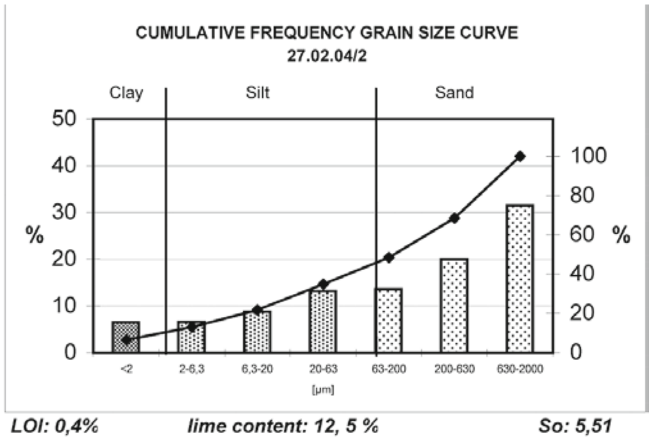


**Figure 3:** (grain size diagram 27/02/2004/2): Fine material matrix of light-yellow Late Glacial rock avalanche ground moraine (Stage IV) (Hagen 1968: 60 Fig. 44 describes the material as "interglacial landslide") between polymict boulders of dark-grey schists, silt stones and light quartzites, edged and partly triturated, at c. 3640 (3540 aneroid) m asl (28°39'17"N/84°04'29"E) from the orographic left valley flank of the upper Marsyandi Nadi (Khola) taken c. 250 m above the river. Exposure, sampling depth c. 160 m. The primary maximum occurs with a c. 32 % peak in the coarse sand; the clay content is c. 6.5 %; a secondary peak is just not developed anymore. The sorting coefficient calculated according to Engelhardt (1973, p. 133) is So = 5.51 (So = $\sqrt{Q3/Q1}$); lime content: 12.5 %. Locality: Fig. 13: 27.2.04/2 (10 m higher than 27.2.04/1) and Photo 1: 0-IV; see Fig. 2 No. 2. Sampling: M. Kuhle.

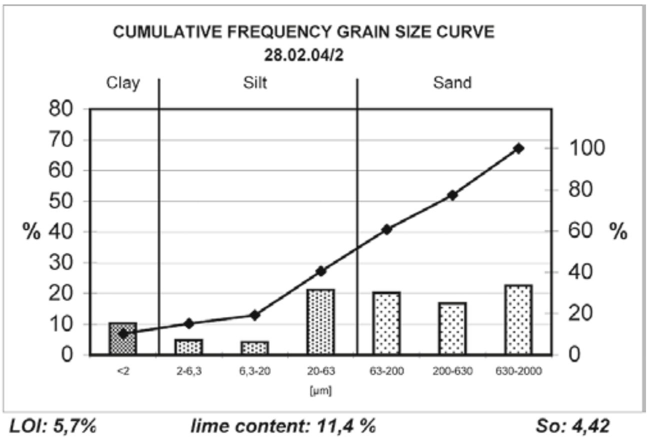


**Figure 4:** (grain size diagram 28/02/2004/2): Fine material matrix of ground moraine cover on a slope (Stage 0 - I to II, III or IV?) between polymictic boulders, taken at c. 4260 (4155 aneroid) m asl (28°39'54"N/84°03'18"E) on the orographic left valley flank of the upper Marsyandi Nadi (Khola) c. 850 m above the river. Digging, sampling depth c. 0.50 m. The primary maximum occurs with the c. 23 % peak in the coarse sand; a secondary peak is with c. 22 % in the coarse silt and a third with c. 11 % in the clay. The peaks determine a trimodal course of the grain size cumulative curve. The sorting coefficient calculated according to Engelhardt (1973, p. 133) is So = 4.42 *(So =* $\sqrt{Q3/Q1}$*);* lime content: 11.4 %. Locality: Fig. 13: 28.2.2004/2; see Fig. 2 No. 3. Sampling: M. Kuhle.

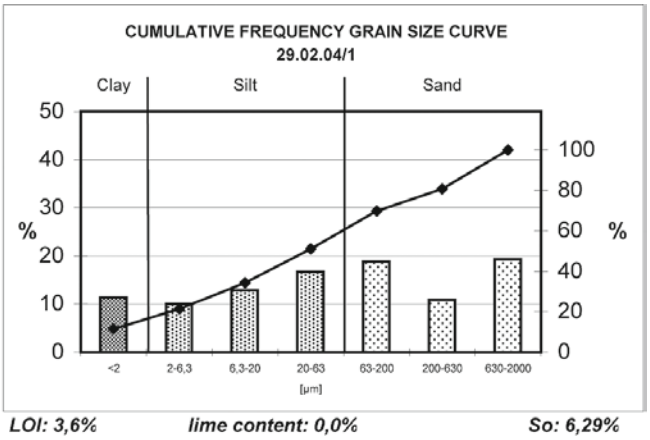


**Figure 5:** (grain size diagram 29/02/2004/1): Fine material matrix from a down-slope slipped Late Glacial (Stage I - IV?) ground moraine cover on the orographic right valley flank of the Tonji Khola leading from Kanla Bhanjyan to the S down to the Marsyandi Khola, N of the Bhardoche settlement, at c. 4080 (3940 aneroid) m asl (28°40'12"N/84°06'1"E) in the area of the orographic left valley flank of the upper Marsyandi Nadi (Khola) taken c. 700 m above the main valley talweg. Exposure, sampling depth c. 1.2 m. The primary maximum occurs with a c. 29 % peak in the coarse sand; a secondary peak is developed with c. 28 % in the fine sand and a third with c. 12 % in the clay. The peaks determine a trimodal course of the grain size cumulative curve. The sorting coefficient calculated according to Engelhardt (1973, p. 133) is So = 6.29 (So = $\sqrt{Q3/Q1}$); lime content: 0.0%. Locality: Fig. 13: 29/02/2004/1; see Fig. 2 No. 6. Sampling: M. Kuhle.

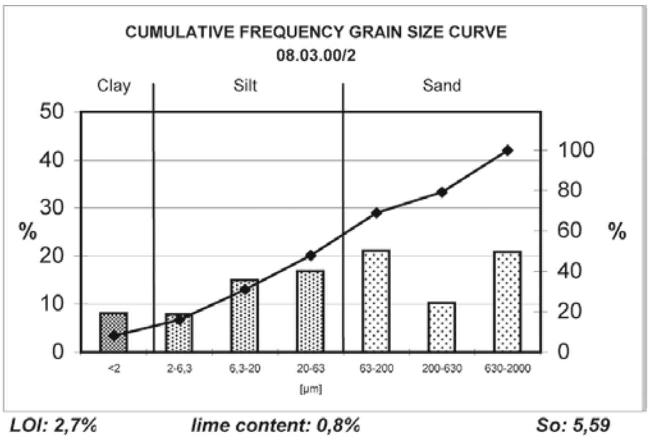


**Figure 6:** (grain size diagram 08/03/2000/2): Fine material matrix of a down-slope ground moraine cover at c. 4550 (4375 aneroid) m asl on the orographic left valley flank of the Marsyandi Khola (28°38'00"N/84°09'55"E) 1360 m above the talweg near to the Pisan settlement. Digging, sampling depth 0.3 m. The primary maximum occurs with 22 % in the fine sand, the secondary peak with c. 31 % in the coarse sand and the third peak with c. 8 % in the clay. They show a trimodal course of the grain size cumulative curve, characteristic of ground moraine. The sorting coefficient calculated according to Engelhardt (1973, p.133) is So = 5.59 (So = $\sqrt{Q3/Q1}$); the loss of ignition (LOI) amounts to 2.7 %; Locality: Fig. 13: 08/03/2000/2; see Fig. 2 No. 20; Photo 3 below of --- on the right. Sampling: M. Kuhle.

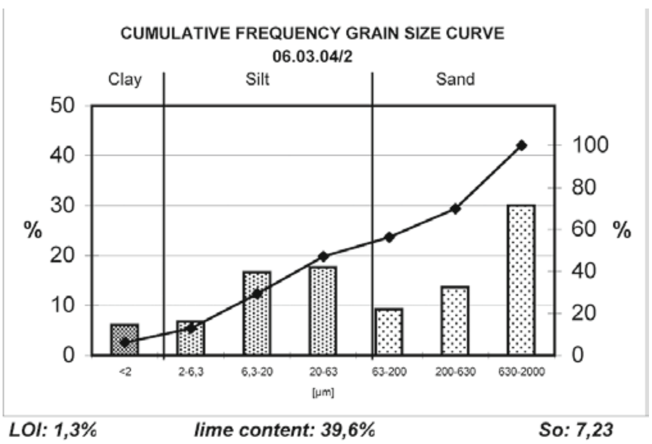


**Figure 7:** (grain size digram 06/03/2004/2): Fine material matrix between coarse boulders from a late Late Glacial inner slope of end moraine at c. 3190 (3115 aneroid) m asl on the orographic right valley side of the Marsyandi Khola (Nadi) (28°36'7"N/84°10'53"E) c. 0.3 km down-valley of the Dhikur Pokhari settlement, c. 50 m above the talweg; digging, sampling depth 0.3 m. The primary maximum occurs with a c. 30 % peak in the coarse sand, a secondary peak is with c. 17 % in the coarse silt. The peaks determine a bimodal course of the grain size cumulative curve. The clay content is c. 6 %. The sorting coefficient calculated according to Engelhardt (1973, p. 133) is So = 7.23 (So = $\sqrt{Q3/Q1}$); lime content 39.6 %. Locality: Fig. 13: 06/03/2004/2, Photo 1 below of È; see Fig. 2 No. 23; cf. Fig. 2 No. 22. Sampling: M. Kuhle.

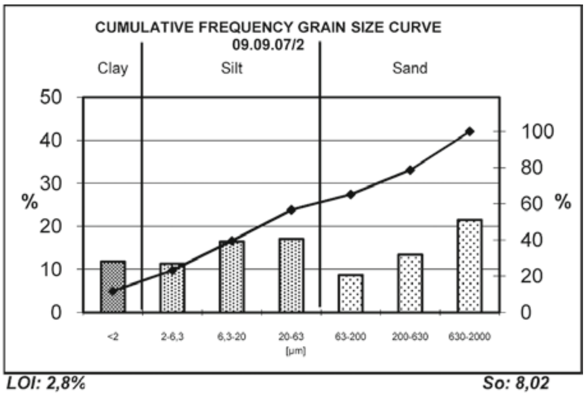


**Figure 8:** (grain size diagram 09/09/2007/2): Fine material matrix from a Late Glacial ground moraine pedestal (Stage II-IV, see Tab. 1), c. 4445 m asl (28°47'36"N/84°17'02"E) from the orographic left flank of the Layju Khola c. 2 km up- valley of the Phugau settlement. Digging, sampling depth c. 0.3 m. The primary maximum occurs with a c. 32 % peak in the coarse sand; a secondary peak has been developed with c. 17 % in the coarse silt and a tertiary peak with c. 12 % in the clay. The peaks determine a bimodal course of the grain size cumulative curve. The sorting coefficient calculated according to Engelhardt (1973, p. 133) is So = 8.02 (So = $\sqrt{Q3/Q1}$), the loss of ignition (LOI) amounts to 2.8 %. Locality: Fig. 13: 09/09/2007/2 and Photo 7 k; see Fig. 2 No. 29. Sampling: M. Kuhle.

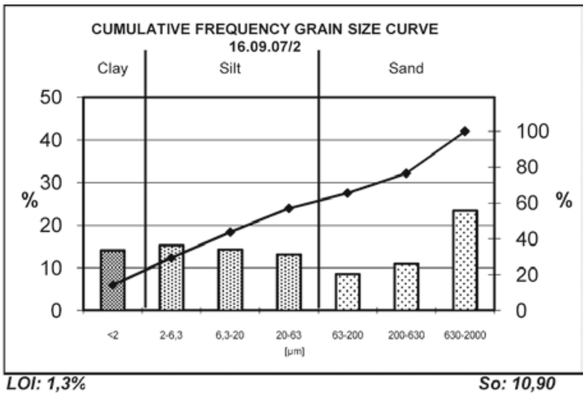


**Figure 9:** (grain size diagram 16/09/2007/2): Fine material matrix from Late Glacial ground moraine, built-up of schist-containing local moraine at c. 5300 (5400 aneroid measurement) m asl (28°42'07''N/84°07'07''E) in the immediate valley exit of the Kanla- (or Ghatte-) Khola taken on the glacigenic transfluence pass; digging, sampling depth c. 0.3 m. The maximum occurs with a c. 24 %-peak in the coarse sand, a secondary peak is developed with c. 15.5 % in the fine silt. Accordingly, there exists a bimodal course of the grain size cumulative curve. The content of clay amounts to c. 14.5 %. The sorting coefficient calculated according to Engelhardt (1973, p. 133) is So = 10.90 (So = $\sqrt{Q3/Q1}$), the loss of ignition (LOI) amounts to 1.3%. Locality: Fig. 13: 16/09/2007/2 and Photo 11 below of ; see Fig. 2 No. 38. Sampling: M. Kuhle.

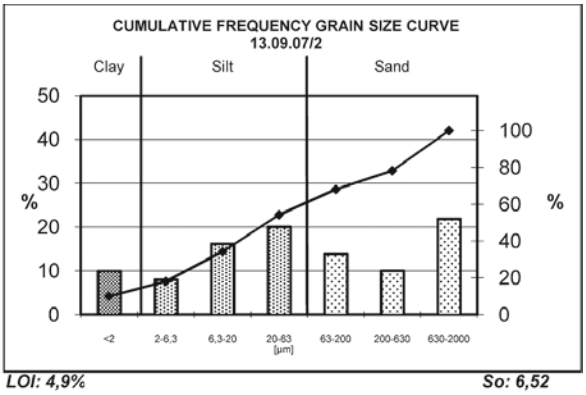


**Figure 10:** (grain size diagram 13/09/2007/2): Fine material matrix taken from a hilly ground moraine cover of the Late Glacial Stage IV (see Tab.1) on the orographic left side of the valley bottom of the Ghatte (or Kanla-) Khola c. 1.7 km W of the Nar settlement at c. 4370 m asl (28°40'47''N/84°11'08''E); digging, sampling depth c. 0.3 m. The maximum occurs with a c. 22 % peak in the coarse sand, the secondary maximum lies with c. 20.5 % in the coarse silt, the tertiary one with c. 10 % in the clay. The peaks are cause of a trimodal course of the grain size cumulative curve. The sorting coefficient calculated according to Engelhardt (1973, p. 133) is So = 6.52 (So = $\sqrt{Q3/Q1}$), the loss of ignition (LOI) amounts to 4.9 %. Locality: Fig. 13: 13/09/2007/2;see Fig. 2 No. 43. Sampling: M. Kuhle.

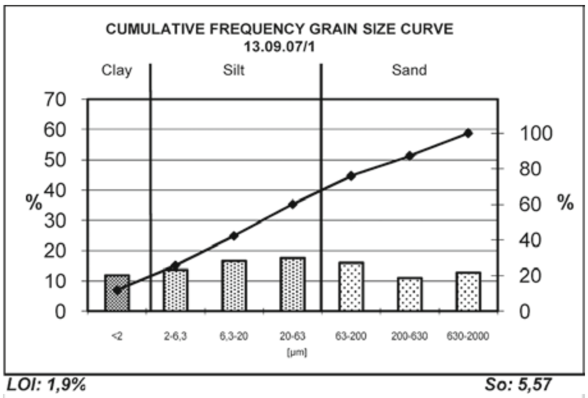


**Figure 11:** (grain size diagram 13/09/2007/1): Fine material matrix from hilly ground moraine cover taken in the confluence area of Lapse- and Ghatte (or Kanla-) Khola c. 1 km ENE of the Nar settlement at c. 4180 (4270 aneroid) m asl (28°40'58''N/84°12'41''E). Digging, sampling depth c. 0.4 m. The maximum occurs with a c. 18 % peak in the coarse silt, the secondary maximum lies with c. 13.5 % in the coarse sand. The peaks are cause of a bimodal course of the grain size cumulative curve. The clay content attains 12 %. The sorting coefficient calculated according to Engelhardt (1973, p. 133) is So = 5.57 (So = $\sqrt{Q3/Q1}$), the loss of ignition (LOI) amounts to 1.9%. Locality: Fig. 13: 13/09/2007/1; see Fig. 2 No. 44. Sampling: M. Kuhle.

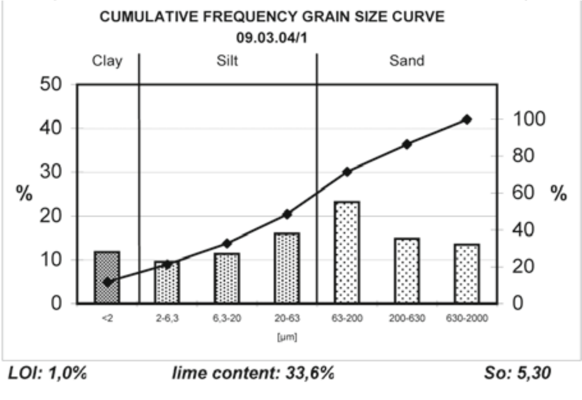


**Figure 12:** (grain size diagram 09/03/2004/1): Fine material matrix between large polymictic, edged and round-edged erratic boulders of decametre-thick pedestal ground moraine on the orographic left gorge slope of the Nar (Na or Naur) Khola at c. 3350 (3140 aneroid) m asl (28°38'50"N/84°13'11"E) c. 1.82 km S of the Meta (Metagau) settlement, taken c. 120 m above the talweg; exposure, sampling depth c. 10 m. The primary maximum occurs with a c. 24 % peak in the medium sand and a secondary peak is developed in the clay with c. 12.5 %. The peaks determine a bimodal course of the grain size cumulative curve. The sorting coefficient calculated according to Engelhardt (1973, p. 33) is So = 5.3 (So = $\sqrt{Q3/Q1}$); lime content 33.6 %. Locality: Fig. 13: 09/03/2004/1 and Photo 13 ¡ black on the right; see Fig. 2 No. 46. Sampling: M. Kuhle.

valley glacier, that accordingly has to be classified as belonging to the Late Glacial Stage IV, is marked immediately above (ibid. Abb. 68 IV above V and below Nr.31). This is the same pedestal ground moraine that in the paper in hand is shown in Photo 1 (0-IV) at close range (see also Photo 2) with the Sapse Lungpa inflow into the Marsyandi Nadi (below No. 27 - 9).

Accordingly, the High Glacial (LGM) flank abrasions and -polishes situated far above on the orographic right valley flank of the Marsyandi Nadi (Fig. 13), in the course of the Late Glacial have been reshaped at right angles by hanging - i.e. side glaciers that had flowed down deeper and deeper up to the junction of the Marsyandi parent glacier and became increasingly destroyed from below to above (Photo 1 and 2: below No. 9).

**2.2. The valley chamber between Nawal and Pisan (Fig. 13)**

Photo 1 establishes the connection of the Marsyandi valley chamber up-valley of the Nawal settlement - that has been treated before - with the one following down-valley (left half of the panorama and Photo 2), as far as to the Pisan settlement. First we continue with the eastern side valleys and at the same time parallel valleys of the Sabse K. (Sapse Lungpa). The still glaciated Chaichanwa Khola (Fig. 13) at the valley head shows a classic trough cross-profile. During the Neoglacial Stage V it was still glaciated up to a similar sea level as the Sabse K. (Fig. 13: 6.3.04/1). Its Neoglacial glacier - just like the synchronous Sabse K.-glacier - has reached the main valley, though this side valley junction arrived at the main valley bottom only 200 altitude-metres lower. This can be explained without any difficulty by the greater height of the glacier catchment area that reaches up to the 7937 m-high summit of Annapurna II. With the help of sample 6.3.2004/1 (Fig. 2 No. 14) the fine material matrix of the end moraine of the Chaichanwa glacier of Stage V - we are speaking about - has been analysed: the course of the grain size cumulative curve as well as the So and the 97 % crushed $SiO^2$ grains prove the morainic accumulation character. Due to its relatively low position above the current talweg (150 m) the talus of ground moraine from which a sample has been taken on the orographic left valley flank (sample 04/03/2000/1: Fig. 13; Fig. 2 No. 15) has still been reached by the orographic left ice margin during Stage V.

Noticeable higher above the talweg, sample 5.3.2000/1 (Fig. 13; Fig. 2 No. 16) has been taken in the area of the right flank of the valley on the mountain spur between Chaichanwa- and the E-adjacent Chauwi Khola, 260 m above the talweg of the Chaichanwa Khola and c. 550 m above the Marsyandi Khola-river. It gives evidence of a ground moraine cover that can be classified as belonging to the Late Glacial Stage IV (Tab. 1). Confirmation of the material is given by sample 3.3.2000/1 (Fig. 13), c. 0.6 km further to the E with the still higher So (= 6.42) and a trimodal grain size cumulative curve in the matrix between erratic gneiss boulders on outcropping limestone shale and marble. Only in the sample mentioned first, there exist some $SiO^2$-grains that mainly are broken (Fig. 2 No. 16). These grains, but also the small portions of fluvially-rounded grains at this position far away from a river, testify to a past glacier and its subglacial meltwater that, too, always exists below the snowline.

The valley chamber of Deuralidada (Photo 3) of the Marsyandi main valley shows decametre-thick ground moraines that belong to different generations and have been cut by the Marsyandi river (⇓). Basally the stratigraphically older High- to Early Late Glacial (Stage 0 - I, Tab. 1) ground moraine material (■) is located in the underlying bed, whilst the younger one is in the hanging layer, that has to be classified as belonging to the Late Glacial glacier stages. The last forms classic earth pyramids (II-IV). The condition of the matrix (sample 5.3.2004/2: Fig. 13; Fig. 2 No. 17) proves the morainic character with 98 % glacially crushed $SiO^2$-grains, a bimodal grain size cumulative curve and a large So of 5.59.

These thick morainic accumulations of the valley bottom continue down-valley: NNW opposite the junction of the Chaichanwa Khola, in the area of the orographic left inflows of the two talwegs or small hanging valleys Tagar- and Ghatte Khola into the Marsyandi Nadi, these two tributary streams have cut through decametre-thick pedestal ground moraines, which in addition have been eroded and exposed by the Marsyandi main valley talweg. The moraine pedestal, that in the side valley exits concerned has been surficially truncated after the deglaciation in the Postglacial (Holocene), has to be classified as belonging to the Late Glacial Stages II-IV (Tab. 1). Among others, the down-valley continuation of these thick ground moraines also occurs in the area of the Pisan settlement.

On the relatively steep orographic left valley slopes upward, glacigenic flank abrasions are partly preserved on back-polished mountain spurs up to a height of 5300 m asl on the SW-flank of

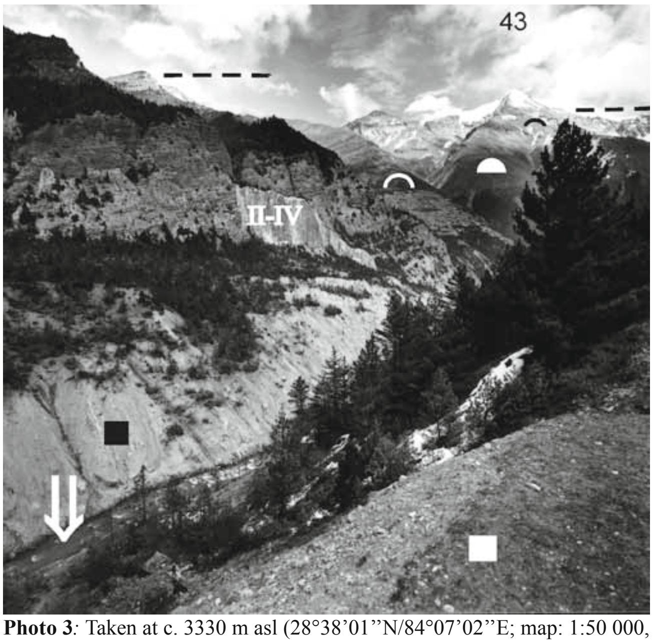


**Photo 3**: Taken at c. 3330 m asl (28°38'01''N/84°07'02''E; map: 1:50 000, No. 2884 05; Fig. 13, Photo 3) seen diagonally down-valley from the orographic right valley side of the Marsyandi Nadi where the Marsyandi Khola (⇓) has been cut c. 80 m-deep into the pedestal moraine (■) on the valley bottom. (0-IV) are remnants of the ground moraine pedestal reaching 100 m higher up, currently forming earth pyramids. They have been built up during the Late Glacial Stages II to IV (see Tab. 1). (◓) marks a glacigenically back-abraded mountain spur on the orographic left side of the Ghatte Khola. (∩) signify glacigenic flank abrasions and polishings up to 5300 m asl, (----) is the highest verifiable LGP (LGM?)- ice level of the Marsyandi-ice-stream-network. The Pisangtse (No. 43) has towered above this ice surface about c. 700 m and received the sharpened form of its summit due to glacigenic lateral abrasion (erosion) up to a height of c. 5400 m asl. Analogue photo M. Kuhle,05/03/2004.

Pisangtse (Tab. 2 No. 43) (Photo 3 ∩ and ◓). Mainly on the flatter areas of these slopes there are also ground moraine covers (Fig. 2 No. 18-20; Fig. 6): between 4450 and 4760 m asl 94 % glacially crushed $SiO^2$ grains (as far as quartz did exist in the medium sand fraction), bi- and trimodal courses of the grain size cumulative curves, up to 20 % clay and sorting coefficients of So = 5.59 and 7.6 have been met (Fig. 13: samples 7.3.2000/1; 8.3.2000/1/2).

The opposite NE-exposed Marsyandi valley flank (Photo 2) shows corresponding glacigenic abrasions and polishes (∩ left) on the a-, b- and c-structures of the outcropping edges of the strata and bedding planes, as well as the jointing „tremendous Reverse folds and Fractures and Thrustplanes“ in the „Palaeozoic sediments“ (limestone, dolomite, quartzites, slates, sandstones, conglomerates, phyllites) (Hagen 1968: 56/57). In addition, glacigenic truncated spurs, more or less orientated according to structural faces, are preserved in remnants (◓). The interglacial, i.e. Holocene to current glaciation of the cirques and short hanging side valleys set into this main valley flank, as well as current rock crumblings (⊠), modify the flanks of

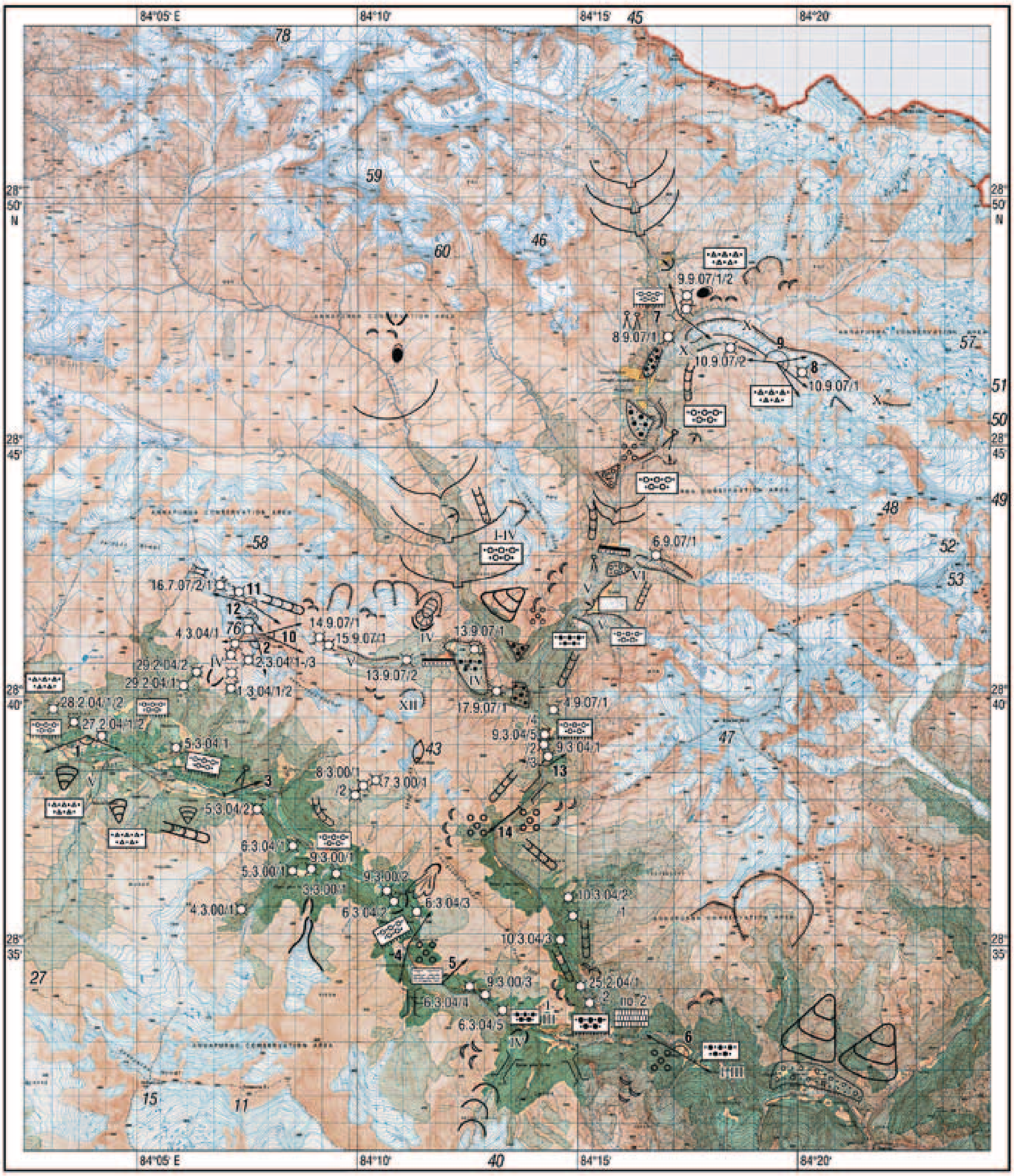


**Figure 13:** Quaternary-geological and glacio-geomorphological map 1:160,000 of the middle Marsyandi Nadi and the Damodar-Himal N of Annapurna Himalaya with localities of the analogue photographs and photo-panoramas (Photos 1-14) and the sedimentological samples (Figs. 2-12). Basic topographic maps: Nepal 1:50 000: His Majesty's Government of Nepal, Survey Department in co-operation with the Government of Finland (2001): Sheet No. 2884 01, 02, 05, 06. See Fig. 1; Tabs. 1 and 2.

the Marsyandi Nadi. The uppermost past polish line and thus highest verifiable LGP (LGM?) ice level of the Marsyandi parent glacier runs at 5400 m asl (---- left half of the panorama).

The main-valley upward transfluence pass with a trough-shaped cross-profile situated in the area of the orographic left side valleys of the Marsyandi Khola, that leads into the Kanla Khola, proves a communicating LGP (LGM-) minimum glacier level at even 5500-5600 m asl (Photo 2 ---- white on the right). Accordingly, here must have existed an approximately corresponding ice level in the two neighboring valleys (cf. 3.5.)

### 2.3 The valley chambers between Pisan and the junction of the Nar Khola (Fig. 13)

Down the main valley of the Chauwi Khola junction (below Annapurna II, No. 11), there continues a classic trough valley cross profile (Photo 1 ◡). The valley bottom is covered by ground moraines (Photo 4 ■) that develop pedestal ground moraine terraces on both sides of the Marsyandi river. Immediately down- valley of the Chauwi Khola sample 9.3.2000/1 (Fig. 13; Fig. 2 No. 21) has been taken. Due to 98.4 % glacially crushed and 1.6 % fluvially polished $SiO^2$ grains, c. 8.5 % clay and a bimodal course of the grain size cumulative curve it proves a local moraine of the Neoglacial (Stage V-VI, see Tab. 1) Chauwi glacier. The lime content of 67.3% points to the Annapurna II- NE flank (Fig. 13 No. 11) as area of origin. The chronological classification of this side valley glacier advance up to a main valley that at that time necessarily was free of ice (see above 2.1 and 2.2) results from an

*LEGENDE* / REFERENCE:

- *Rundhöcker und ähnliche glaziäre Schliffformen* / roches montonnées and related features of glacial polishing
- *Sedimentproben* / sampling
- *Grundmoräne mit erratischen Blöcken* / basal till, ground moraine with erratics
- *Gletschertorschotterflur u. Gletschertorschotterflur-Terrassen* / glacier mouth gravel floor and alluvial terraces in contact with moraines
- no. 2 *Gletschertor-Schotterflur-Stadium* / stages of outwash-terraces (explanation in text)
- *Kames* / kames
- *Kar* / cirque
- *Transfluenzpass* / transfluence pass
- *glaziärer Flankenschliff* / glacial flank polishing and abrasion
- *glaziäre Dreieckshänge* / glacially triangular-shaped slopes (truncated spurs)
- *Endmoränen von Talgletschern im Gebirge* / terminal moraines of valley glaciers
- *Ufermoräne, Mittelmoräne, Endmoräne* / lateral moraine, terminal moraine (former ice margin)
- *glazialer Trog* / glacial trough
- *schluchtförmiger Trog* / gorge-like trough
- *subglaziale Klamm im Trogtalgrund* / subglacial gorge cut into the floor of a glacial trough
- *Gletscherschrammen* / glacier striae
- *glaziales Horn* / glacial horn
- I-V *Spätglaziale, neoglaziale bis historische Gletscherstände* / Late glacial, Neo-glacial to historical glacier stages (explanation in text)
- *Podestmoräne, Grundmoränensockel mit Terrassenstufe und erratischen Blöcken* / pedestal ground moraine with escarpment and erratic boulders
- *Podestmoräne, Grundmoränensockel mit Terrassenstufe* / pedestal ground moraine with escarpment
- *Grundmoräne ohne große Blöcke* / ground moraine without big boulders
- *Grundmoräne mit großen nicht erratischen Blöcken* / ground moraine with big non-erratic boulders
- *glazilimnische Seeterrassen* / glacio-limnic lake terraces
- *Blockgletscher* / rock glacier
- *Felsnachbrüche an vorzeitlichen Flankenschliffen* / rock crumblings on past flank polishings
- *Erdpyramiden* / Earthpyramids
- *Bergsturz* / rock avalanche
- *Strudeltöpfe* / pot-holes
- *Moränenrutschung* / moraine slide
- *Klamm* / subglacial glacigenic gorge
- 10.3.04/1 *Probenentnahmestelle mit Datum der Probenentnahme oder Probennummer* / Sampling locality with date or number
- 3 *Photo 3 mit Aufnahmerichtung* / Direction of Photo 3
- 2 *Panoramaphoto 2 mit Aufnahmerichtung* / Direction of panoramaphoto 2
- 57 *Lokalität* / locality / *Gipfel* / peak
- *Fluß* / river
- *Gletscher* / glacier

0 2 4 6 8 10 km

*Kartographie*/Cartography: A. Flemnitz

*Entwurf*/Draft: M. Kuhle


**Photo 4**: C. 200°-panorama at c. 3020 m asl (28°35'00''N/84°10'12''E; map: 1:50 000, No. 2884 05; Fig. 13 Panorama Photo 4) from the orographic left valley side of the Marsyandi Nadi, 1 km up-valley of the Bhratan settlement, looking from facing SSW down the river, via NW up the main valley, up to facing NNE the winding talweg of the Marsyandi Khola upwards. (■) mark a pedestal ground moraine cut by the river (⇩) over 100 m deep. It is classified as belonging to the Late Glacial from Stage II to IV (see Tab. 1). The exposure indicates its typically coarse and only aproximately horizontal bedding (on the right of ■ white and of II-IV). During Stage IV (Sirkung Stage after KUHLE 1982) the sedimentation of this ground moraine was settled due to the development of an end moraine, i.e. with the ice margin position of Stage IV. (∆) is an active debris cone of moraine material that is in the process of tipping over; due to crumblings like these earth pyramids are brought into being. (⌂) are areas with steep faces where crumblings have taken place continually since the deglaciation and still go on; they are prepared by the ac-jointing. Analogue photo M. Kuhle, 09/03/2000.

ELA-depression of c. 300 m. Due to the important valley incline, even an ELA-depression of only c. 200 m would be enough for a surge-like glacier advance to reach this moraine locality.

The connnected valley chamber down the Marsyandi Khola-main valley shows a classical trough-cross-profile (Photo 1 ∪) reaching high up the flanks and containing a late Late Glacial tongue basin with two small lakes (Fig. 13 on the left of sample 9.3.00/2 and the Dhikur Pokhari settlement). This tongue basin belongs to a stagnation during the process of back-melting of the late Late Glacial Stage IV (Sirkung Stage, Tab. 1). It is restricted down-valley by a counter slope, i.e. due to a sort of end moraine dam (Photo 1 below ∪), that has been worked out of an older Late Glacial pedestal ground moraine. Samples 9.3.2000/2 and 6.3.04/2 (Fig. 13; Fig. 2 No. 22; as well as Fig. 7 and Fig. 2 No. 23) confirm this geomorphological finding by a maximum sorting coefficient So = 7.23, a bi- and trimodal course of the grain size cumulative curve, a maximum clay portion of 12 % and up to 98.1 % glacigenically crushed quartz grains; the rest of the $SiO^2$-grains is fluvially polished. The lime content of 39.6 - 40.5 % that in both samples is nearly identical, proves a corresponding area of origin from the high glacier catchment areas of the Annapurna II to -IV-NE flanks through their connected side glaciers as e.g. the Sabse K. glacier, the Chaichanwa- and the Chauwi glacier. The talweg has dissected this moraine and runs c. 40-50 m below this pedestal- i.e. end moraine ridge. On grounds of form and structure of the steep bedding plane slope, which down-valley from here builds-up the orographic left Marsyandi K.-flank (Photo 4 ↙), a participation of rock avalanche material in this end moraine accumulation, i.e. its Postglacial raising by the concerning rock avalanche material from this valley flank from the Pisangtse-S-crest (Fig. 13 No. 43) is probable (Photo 4 ↙).

The down-valley connected section of the Marsyandi Nadi (valley chamber of Bhratan) is filled by an over 100 m-thick pedestal ground moraine (Photo 4 ■ white, II-IV). For the last time its build-up took place during the Late Glacial Taglung-, Dhampu- and Sirkung Stage (II to IV, see Tab. 1). The geomorphological as well as macroscopic-sedimentological pedestal ground moraine character has been further assured by laboratory analyses: sample 6.3.2004/3 (Fig. 13; Photo 4 ↙; Fig. 2 No. 24) confirms this finding by a sorting coefficient of So = 6.1 and a bimodal course of the grain size cumulative curve, the relatively high clay content and 98 % glacially crushed $SiO^2$-grains as well as several fluvially polished quartz-grains. The last can be explained by subglacial meltwater.

This pedestal ground moraine continues in remnants preserved down the main valley (Photo 4 ■ black). On the orographic left valley flank there are preserved glacigenic flank polishings and fluvial rock dents, i.e. concave rock wall bowls, as they develop due to subglacially confined water and cavitation corrasion between glacier ice and solid bedrock (Photo 5 ○ white). 1 km down-valley of the Bhratan settlement polishings with glacial striae can be observed on a roche moutonnée, the rock faces of which just recently have been covered and preserved by ground moraine (Photo 5). At a distance of 3.5 km between the Bhratan and Talekhu settlements, samples have been taken of the important pedestal ground moraine bases on three representative localities 50-150 m above the talweg (Fig. 13: 6.3.2004/4; 9.3.2000/3; 6.3.2004/5; Fig. 2 No. 25, 27, 26). Analyses confirm the ground moraine character of the fine material matrix into which - isolated from each other - metre-sized, round-edged and facetted boulders are embedded. The sorting coefficient of the matrix lies between 6.52 and 7.62, the clay content is 7 to 10.5 %, its grain size cumulative curves are bimodal, c. 99 % of the $SiO^2$-grains contained in the medium sand fraction are glacially crushed and only some few grains are fluvially polished. Where the pedestal moraine base is deeply exposed in a terrace form, earth pyramids have been developed which are also typical of ground moraines. The course of the pedestal ground moraine terrace concerned, continuing down-valley, is used for the fields of the Talekhu settlement (Fig. 13). Part of the large up to very large boulders on the surface - beside the moraine boulders of an always surficial ablation moraine with its portions of rock avalanche moraine - could be boulders of rock avalanches accumulated only in Holocene to Historical times since the deglaciation. It is obvious that these might have fallen down from the steep valley flanks due to crumblings. The smaller, mainly round-edged moraine boulders have been gathered from the recent fields and used for walls. From down-valley of the Talekhu settlement looking up-valley, glaciofluvial gravel strings are unmistakable. They make visible pathes of meltwater discharge that happened during and after deglaciation. Probably the ground moraine of the main valley cut by the Marsyandi river is older than the young-Late Glacial Sirkung Stage. On its

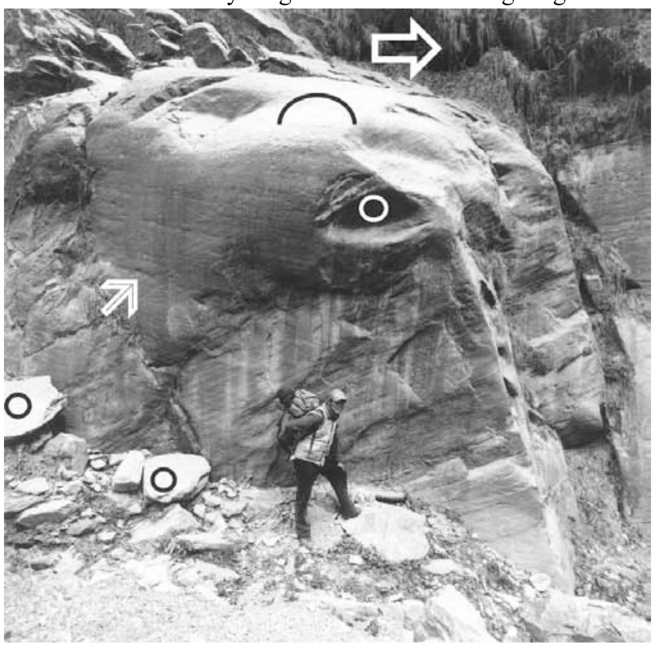

**Photo 5***:* Taken at c. 2880 m asl (28°34'19''N/84°11'54''E; map: 1:50 000, No. 2884 05; Fig. 13 Panorama Photo 5) from 0.7 km down-valley of the Bhratan settlement facing NE seen into the orographic left valley side of the Marsyandi Nadi. (∩) shows a rock head consisting of outcropping gneiss, which for the last time was polished and rounded by the orographic right tributary glacier, the "Annapurna II-NE-glacier" (Fig. 13) that during the Late Glacial Stage IV (see Tab. 1) still bent into the Marsyandi main valley; (⇨) indicates the flow direction of the past ice. (↗) marks classic glacier striae slightly bent from left above towards right below, i.e. down-valley, at right angles (45°) to the banding of the gneiss that runs relatively steeply from left below to right above (clearly visible behind the person). (O white) is a bowl-like, vertical meltwater form, subglacially arranged by cavitation corrasion under pressure and a correspondingly high velocity of flow. Its damage due to shell breaks on its left margin above, points to sygenetic development with the glacier polishing. (O black) are moraine boulders exposed by denudation and rearranged. Analogue photo M. Kuhle, 06/03/2004.

surface is an end moraine hill on which the houses of Talekhu are situated. During the Sirkung Stage (Tab. 1) this hill has been overthrust by the Thada Khola glacier, the tongue ends of which at that time have reached the already ice-free Marsyandi Nadi. The Thada K. glacier (Photo 2 left below No. 40; Fig. 13) that immediately flowed down from the steep, high catchment areas of the Lamjung Himal-N-flank at over 6400 m asl, has left behind a classical hanging trough valley. The High- to Late Glacial (Stage 0 to III or IV, Tab. 1) Marsyandi parent glacier received a corresponding orographic right influx of a side glacier from the WNW-parallel (unnamed) tributary valley S of the valley chamber of Bhratan (Photo 2 below No. 40; Fig. 13). A corresponding Late Glacial glaciation of a hanging valley existed, too, in the ESE-adjacent Tirohyun Halda Khola, S-opposite the inflow of the Nar Khola (Fig. 13). In the area of the hanging inflows of all three side valleys we are speaking about, subglacially developed meltwater cuts (subglacial glacigenic ravines or gorges) have been formed.

Between the valley chambers of the Bhratan and Koto settlements the Marsyandi Nadi main-valley-trough, the slopes of which steepen toward above, in many places has been Late- to Postglacially reshaped and at least roughened by crumblings.

As a summary of this section (2.3.) there will be described the course of the altitude of the reconstructed LGM-ice-level and, accordingly, the reconstructed thickness of the Marsyandi Nadi main glacier in the c. 14 km long valley section between Pisan and the junction of the Nar Khola we are speaking about. From the Annapurna II (No. 11) NE-flank (Photo 2 ----), i.e. Pisan Peak (No. 43) SW-flank, the ice level from c. 5400 m asl (Photo 3 ----) up to the junction of the Nar Khola near Koto to c. 4700 - 4500 m asl (cf. 3.7.) is almost not steeper than the valley bottom incline, i.e. it has dropped nearly parallel to the valley incline (cf. Photo 6 ---- on the left; Fig. 13). All synchronously connected side glacier levels were adjusted to this ice level. In this main valley section the ice was c. 2200 - 2100 m thick.

## 3. The highest former trim-lines and glacier thicknesses of the Nar (Naur) Khola, its side valleys and uppermost catchment areas up to its inflow into the Marsyandi Nadi (Khola)-main valley (Fig. 13)

### 3.1. The LGP (LGM) glaciation of the Layju Khola in the Lugula- and Peri-Himal-N-slope (Fig. 13)

From this S-Tibetan border-crest (Photo 7 on the very left; Photo 9 No. 45) that represents a watershed, the 8 - 10 km wide, high-lying valley with its numerous talwegs that are more or less deeply inset by Postglacial backward erosion, leads down to the S to the Phu Khola (Photo 7 from right to left). The outcropping Mesozoic phyllites (metamorphic sedimentary rocks) that due to folding and tilting have been diverted from their normal position, below the recent glaciers and their forefields with Historical to Neoglacial moraines are covered on a large scale by ground moraines (Photo 7 II-IV, ■ on the left). The fluvially dissected valley bottom consists of decametre- thick pedestal ground moraines (II-IV on the right), the last development of which can be explained by the Late Glacial glacier covering (Stages II - IV). From the down-slope ground moraine cover a sample has been taken exemplarily (sample 9.9.07/1: Fig. 13; Fig. 2 No. 28). The bimodal course of the grain size cumulative curve in the matrix, the high clay portion (18 %!) despite an important slope, the sorting coefficient and also the portions of glacigenically crushed and fluvially polished $SiO^2$-grains (portions of quartz grains of the medium sand fraction, however, are insignificant) confirm the finding in the field of a ground moraine. The participitation of subglacial meltwater in its building-up speaks in favour of its Late Glacial age. Matrix sample 9.9.07/2 (Fig. 13; Photo 7 ②; Fig. 8; 2 No. 29) has been taken from the pedestal moraine. The course of its grain size cumulative curve is trimodal, the sorting coefficient So = 8 is very large and also the clay content is relatively high. All this, as well as the morphoscopic indicators of the medium sand grains confirm the finding in the field of ground moraine. Its massive pedestal ground moraine character is proved by exposures with earth pyramids (Photo 7 ♠; Fig. 13). The highest remnants of ground moraine covers have been evidenced at a height in excess of 4720 m up the valley flanks (Fig. 2 No. 28); up-slope they can be increasingly classified as belonging to the LGM (Stage 0, Tab. 1). At the same time more and more situated above the corresponding ELA, the production of ground moraines has decreased toward above. Above the thinning-out ground moraine covers (Photo 7 ■ on the left) pure glacigenic abrasion forms are beginning regularly. Due to polish- i.e. abrasion limits (Photo 7 ---- right half of the panorama), roundings of mountain spurs and the mountain crest of the intermediate valley ridge to the SE-adjacent upper Phu-Pangri Khola (Photo 9 ∩ below No. 46 - 45) they verify a maximum past ice level in the Layju Khola of 5900 (Photo 7 ---- on the right) down to 5600 and 5500 m (0----; and Photo 9 ---- below No. 46 – 45).

Sample 8.9.07/1 (Fig. 13) concerns a younger, namely Neoglacial pedestal ground moraine in the inset between Layju- and Phu Pangri Khola. This is a Late Glacial longitudinal moraine that has become a Neoglacial medial moraine (Stage IV to 'VII, see Tab. 1). The large polymictic boulders that contain granite boulders from the upper Phu Khola, are embedded into a matrix with a bimodal grain size cumulative curve with a secondary maximum in the clay (13.5 %!). The sorting coefficient amounts to So = 6.75 which is typical of moraine. Besides the granite boulders, the here - compared with the samples in the Layju Khola (see above) - enormously increased $SiO^2$-grain portion proves that the ice mainly derives from the upper Phu Khola with the currently still relatively large Pangri glacier (Fig. 13). The supremacy of crushed grains and the remaining fluvially polished grains of medium sand exceeding 5 %, additionally confirm the character of a ground moraine accumulated below the ELA (Fig. 2 No. 30).

### 3.2. The current up to LGP (LGM)-glaciation of the upper Phu- Pangri Khola (Fig. 13)

During the LGP (LGM, MIS 3-2, Stage 0, Tab. 1) the greater height of the catchment area of the upper Phu-Pangri Khola compared with that of the Layju Khola was not important for the glaciation, because the ELA has run below the lowest section of the valley bottom. Currently, historically and also back into the Neoglacial (Holocene) there has led and still leads the great height of the catchment area to a relatively large valley

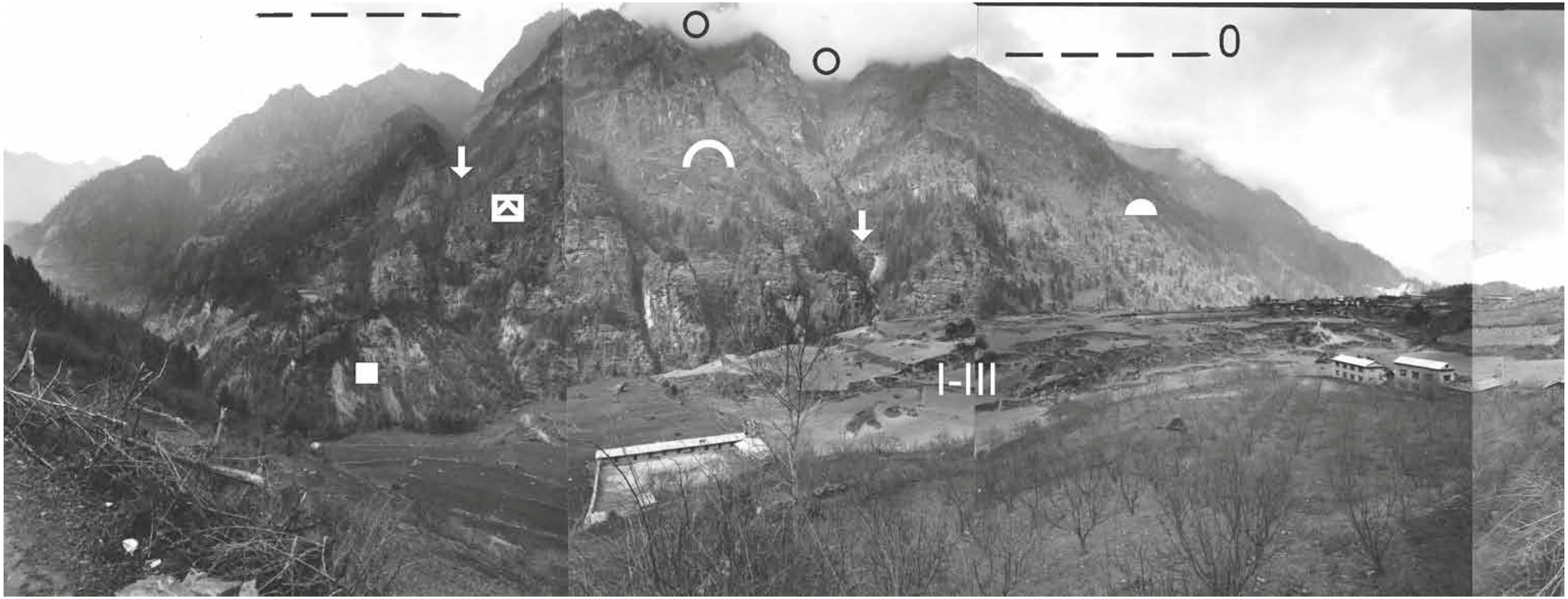


**Photo 6***:* C. 180°-panorama at c. 2640 m asl (28°32'54''N/84°17'18''E; map: 1:50 000, No. 2884 06; Fig. 13 Panorama Photo 6) from the orographic right flank of the Marsyandi Nadi 0.4 km W of the Thancho settlement from facing NW (left margin) via facing N into the left valley flank and facing up to ESE along the right valley flank looking down- valley. The fields of Thancho are situated on a c. 160 m high pedestal ground moraine (I-III), which for the last time has been covered and finally built up by the Marsyandi parent glacier during the Late Glacial Dhampu Stage III (see Tab. 1). (■) marks the continuation of this ground moraine pedestal on the left valley side beyond the 160 m-deep cut of the Marsyandi Khola (-river); (◓) is a glacigenically back-abraded mountain spur between two small steep side valleys, the basal slope of which is covered by remnants of ground moraine; (∩) shows glacigenic flank abrasion on an outcropping slope of a stratum; (↓) signify steep, very narrow, small side valleys, i.e. slope gorges that dewater cirque-like source depressions (O) and cut the slopes of flank abrasion (∩); (⊠) indicates rock crumblings controlled by ac- and bc-clefts that are typical of trough-cross-profiles after the deglaciation. (---- and ----0) show the decline of the LGP-glacier level from c. 4500 to c. 4350 m asl. Analogue photo M. Kuhle, 07/03/2004.

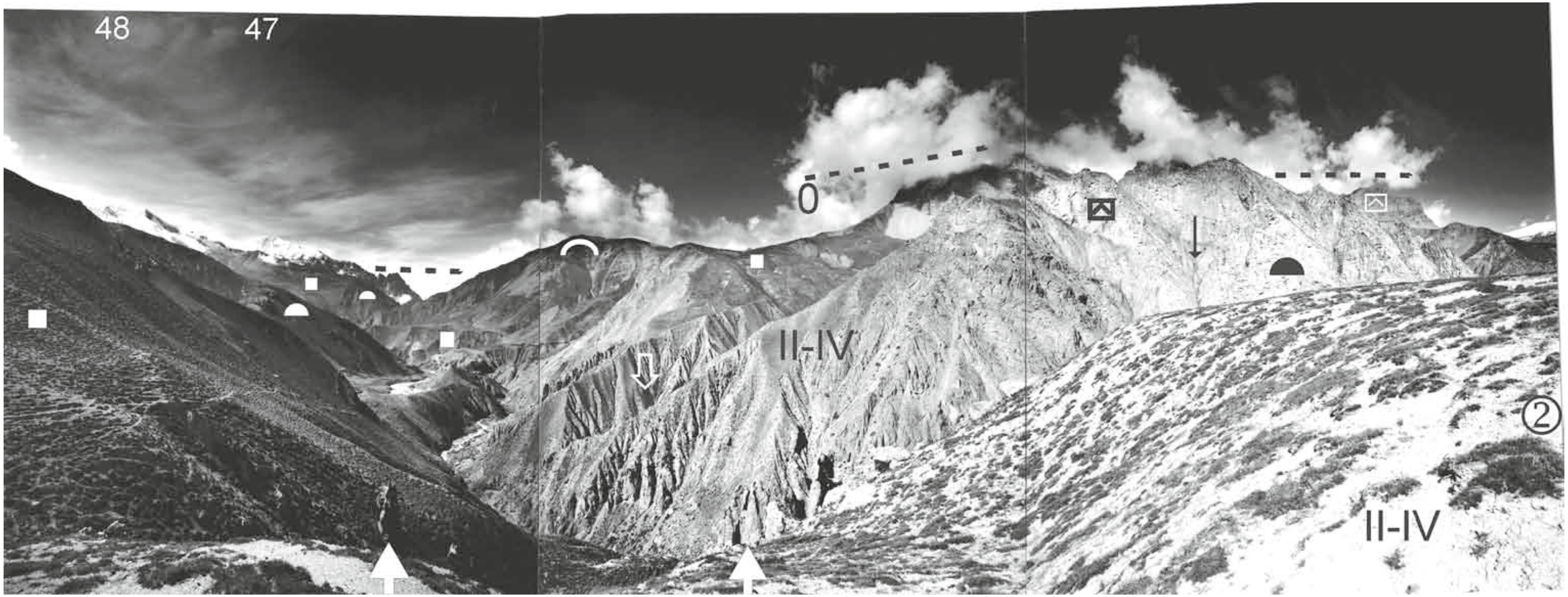


**Photo 7**: C. 225°-panorama at c. 4445 m asl (28°47'36''N/84°17'02''E; map: 1:50 000, No. 2884 02; Fig. 13 Panorama Photo 7) from the orographic left flank of the Layju Khola from a Late Glacial ground moraine pedestal (II-IV on the right and ②) 2.4 km up-valley of Phugau, from facing ESE (left margin) with the 7074-m-peak (No. 48, Tab. 2), via facing SSE with Kangaru (No. 47, 6981 m) and down the Phu Khola via facing NNW to the western spur of the Lugula-Himal in S-Tibet. (■) signify Late Glacial ground moraine covers and pedestal ground moraines on the valley bottom (■ and II-IV) (Stage II to IV, Tab. 1); (②) marks the locality of sample 09.09.07/2 (Fig. 2); (⇩) is the incision of a side valley brook through Late Glacial remnants of pedestal moraine that develop runnels and earth pyramides; (▲) mark earth pyramides on the slope of the pedestal ground moraine in the fore- to middle ground; (↓) is a wall runnel eroded into the horizontal sedimentary rocks of the Pokarkan-massif, (⌒) shows a 5247-m-high glacigenically rounded mountain ridge; (◓) are glacigenically abraded spurs of valley flanks in the bedrock; (⊠) indicate parts of a rock face where crumblings controlled by ac- and bc-clefts roughen the glacigenic flank abrasion since the deglaciation, (---- and 0----) show the LGP- (LGM-) glacier level of the Layju Khola up to down through the Phu K. from about 5900 m (on the right) via 5600 m (centre) as far as down to c. 5150 m asl (on the left). Analogue photo M. Kuhle, 09/09/2007.

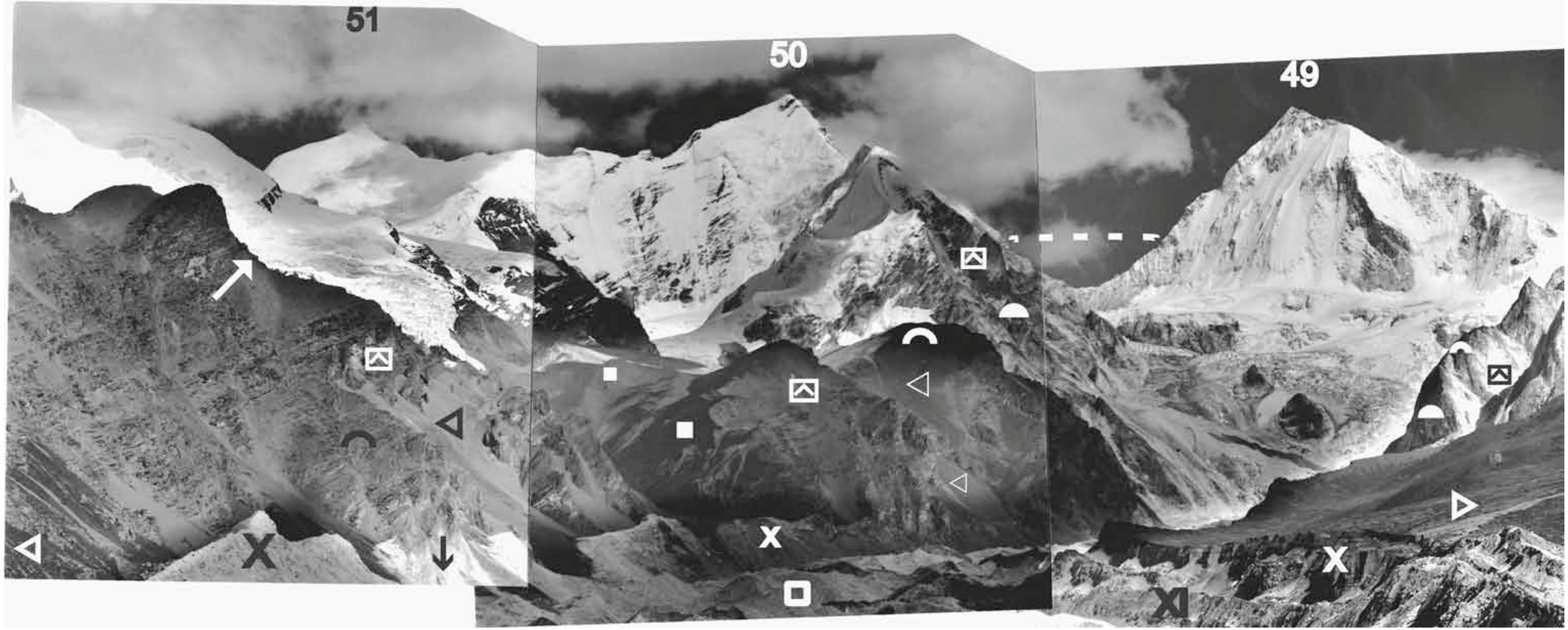


**Photo 8***:* 45°-panorama at 4720 m asl (aneorid measurement) (28°46'44''N/84°19'32''E; map: 1:50 000, No. 2884 02; Fig. 13 Panorama Photo 8) seen from the highest orographic left lateral moraine of the Pangri glacier up-valley from facing E (left margin of the photo) on to the 7128 m-high Himlun (No. 51) via facing ESE to the 7092 m-high Nemjun Goth (No. 50) and across the beginning of the glacier, where at a distance of 11 km the nameless 7140 m-peak is situated (No. 49). (☐) marks the Pangri glacier covered with surface moraine, (XI) is its c. 90 to 60 years old lateral moraine rampart (Stage XI, see Tab. 1), (X) are the lateral moraine ramparts which are c. 240 to 90 years old (Stage X): compared with these two stages there belong to the current depression of the glacier surface - by analogy with the neighbouring Himalaya areas - ELA-increases of c. 40 to 20 m. (↓) marks a rock area that as an outer bank has been abraded (separated) from the historical glacier rim and thus undercut. Accordingly, it still crumbles away to an increasing extent. (⍓) mark crumblings situated clearly higher, that take place since the Late Glacial deglaciation. They destroy i.e. roughen the LGP- up to Late Glacial flank polishings and -abrasions (∩) inclusive of several back-abraded mountain spurs (◓). (↗) shows a classic cross-profile of a trough-flank in homogeneously outcropping stratified rock dipping to the N. (■) are Late Glacial to historical remnants of end - and ground moraine, (◁ and ▷) indicate current debris slopes and debris flow fans. The trough-cross-profile above the 6373-m-saddle which has developed a transfluence-pass to the Ponkar glacier into the E-adjacent Dhud Khola, makes probable an LGP-level of the ice stream network about 6600 m asl (----). Analogue photo M. Kuhle, 10/09/2007.

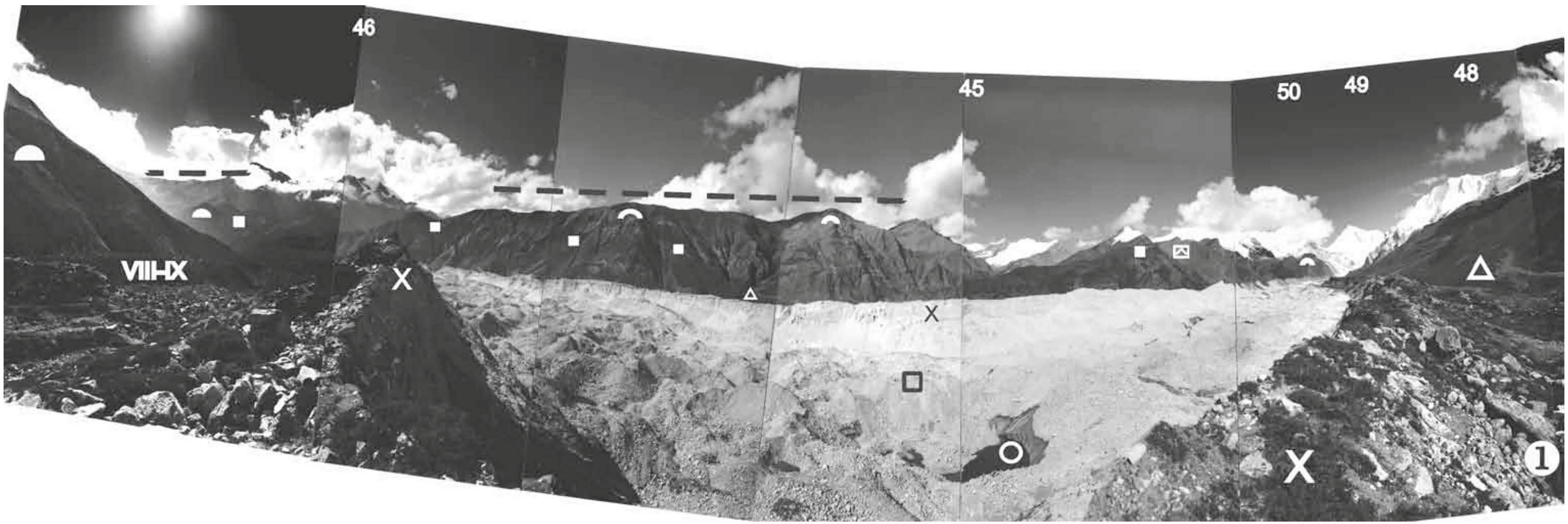


**Photo 9**: C. 225°-panorama at 4720 m asl (28°46'44"N/84°19'32"E; map: 1:50 000, No. 2884 02; Fig. 13 Panorama Photo 9) from the highest orographic left lateral moraine of the Pangri glacier up-valley, facing ESE to the 7092 m-high Nemjun Goth (No. 50) and across the beginning of the glacier with the 7140 m-Peak (No. 49), via facing SE to the 7074 m-Peak (No. 48) and up the orographic left valley flank; then across the right valley flank with the 6899 m-high Lugula (No. 45) in the NNW-background and down the glacier, i.e. down the valley facing WNW to W (left margin) with the 6372 m-high Pokaran (No. 46), looking again to the left valley flank. (☐) marks the Pangri glacier covered with surface moraine, (○) is a supra-glacial meltwater pond on the left below a dirty-grey blank ice ramp; (X) indicate its lateral moraine dams that are about 240-90 years old (Stage X, Tab. 1). (❶) signifies the locality where sample 10.09.07/1 has been taken (Fig. 2). The current depression of the glacier surface (☐) against these moraine crests (X) amounts to approx. 40 m. (VIII-IX) are further historical lateral moraines of Stages VIII to IX arranged beyond a first small lateral valley. They have been accumulated c. 460-215 years ago and give evidence of ELA-depressions of 40-50 m (Tab. 1). (■) mark High- to Late Glacial remnants of ground moraines in higher slope positions, (Δ) are current debris flow fans, debris cones and -slopes which for a large part receive debris from these covers of ground moraine, (◓) shows back-abraded mountain spurs, (∩) are 5045-5585 m-high, glacigenically rounded mountain ridges, (⊠) mark current crumblings, i.e. rock excavation niches under the control of the clefts which roughen the glacigenically abraded surface of the bedrock since the deglaciation, (---- and ----0) indicate the accompanying LGP-glacier level about 6000-5900 m (on the left of 45) and as far as down to c. 5600 m (on the left of 46). Analogue photo M. Kuhle, 10/09/2007.

glacier, the Pangri glacier (Photo 9; Fig. 13). Even today it is up to c. 2 km wide and altogether 14.5 km long below the ELA and flows down to 4460 m asl up to the exit of the Phu Pangri Khola without leaving the valley. In its catchment area there participate four mountains in excess of 7000 m, from which the name-less 7140 m-Peak (Tab. 2 No. 49) is the highest one (Photo 8). Below of 5100 m the avalanche nourishment leads to a downward increasing surface moraine cover. The historical glacier extension and -thickness of Stages VIII to X (age position see Tab. 1) can be found in detail in Photos 8 and 9. For comparison with the older moraine matrixes that at this high altitudinal level may have a Neoglacial to at most late Late Glacial age, the at most 180 years old sample of the historical lateral moraine matrix (Stage X) is informative. This sample 10.9.07/1 (Fig. 13), taken from the outer slope of the lateral moraine, has neither a high sorting coefficient nor a bimodal course of the grain size cumulative curve or high clay portion. All this speaks in favour of glaciofluvial reshaping. This, however, cannot have been intensive - what is immediately proved by the geomorphological condition of the outer slope of the lateral moraine we are speaking about (Photo 9 ❶) - because 99.3 % of the $SiO^2$-grains are glacially crushed and only 0.07 % (i.e. 1 of 150 analysed grains) is fluvially polished (Fig. 2 No. 31). Sample 10.9.07/2 (Fig. 13), also from the orographic left side of the Pangri glacier, has been taken from a pedestal ground moraine of Stages IV - 'VII, that means it is also of a Late- to late-Neoglacial age (Tab. 1). Its grain size histogram shows a trimodal course of the cumulative curve with still 10 % clay as Tertiary peak, a sorting coefficient of So = 4.85, 94.6 % glacially broken and the rest of 5.4 % fluvially polished $SiO^2$-grains (Fig. 2 No. 40). This striking difference to sample 10.9.07/1 (see above) has to be explained - under

**Table 1:** Glacier stadia 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, Gandise Shan, Nyainquen Tanglha, Namche Bawar, Minya Gonka, Chola and others ) from the pre-Last High Glacial (pre-LGM) to the present-day glacier margins and the pertinent sanders (glaciofluvial gravel fields and gravel field terraces) with their approximate age (after Kuhle 1974-2011). The author infers comparable data for older Pleistocene/Neogene glaciations as well. Older times with a lower elevation of the Tibet Plateau are inferred to have also reduced glaciations. See Figure 13.

| 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 | No. 4 | 17 000 - | 15 000 | | c. 1100 |
| II | = Taglung-Stage | No. 3 | 15 000 - | 14 250 | | c. 1000 |
| III | = Dhampu-Stage | No. 2 | 14 250 - | 13 500 | | c. 800 - 900 |
| IV | = Sirkung-Stage | No. 1 | 13 500 - | 13 000 | (older than 12 870) | c. 700 |
| V - ´VII | = Neo-Glacial | No. -0 - No. -2 | 5 500 - | 1 700 | (older than 1 610) | c. 300 - 80 |
| V | = Nauri-Stage | No. -0 | 5 500 - | 4 000 | (4 165) | c. 150 - 300 |
| VI | = older Dhaulagiri-Stage | No. -1 | 4 000 - | 2 000 | (2 050) | c. 100 - 200 |
| ´VII | = middle Dhaulagiri-Stage | No. -2 | 2 000 - | 1 700 | (older than 1 610) | c. 80 - 150 |
| VII - XI | = historical glacier stages | No. -3 - No. -6 | 1 700 - | 0 | (= 1950) | c. 80 - 20 |
| VII | = younger Dhaulagiri-Stage | No. -3 | 1 700 - | 400 | (440 resp. older than 355) | c. 60 - 80 |
| VIII | =Stage VIII | No. -4 | 400 - | 300 | (320) | c. 50 |
| IX | = Stage IX | No. -5 | 300 - | 180 | (older than 155) | c. 40 |
| X | = Stage X | No. -6 | 180 - | 30 | (before 1950) | c. 30 - 40 |
| XI | = Stage XI | No. -7 | 30 - | 0 | (= 1950) | c. 20 |
| XII | = Stage XII = recent resp. present glacier stages | No. -8 | +0 - | +30 | (1950 - 1980) | c. 10 - 20 |

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**Table 2:** Peaks and saddles in the research area. See Figure 13

| No. | Peak | **Altitude (m asl)** |
|---|---|---|
| 9 | Annapurna III | 7548 |
| 11 | Annapurna II | 7937 |
| 15 | Annapurna IV | 7525 |
| 24 | Gangapurna | 7454 |
| 27 | Seti Gap | 5501 |
| 40 | Lamjung Himal | 6988 |
| 43 | Pisangtse (Pisan Peak) | 6149 (6091) |
| 45 | Lugula | 6899 |
| 46 | Pokarkan | 6372 |
| 47 | Kangaru Himal | 6981 |
| 48 | 7074m-Peak | 7074 |

| No. | Peak | **Altitude (m asl)** |
|---|---|---|
| 49 | 7140m-Peak | 7140 |
| 50 | Nemjun Goth | 7092 |
| 51 | Himlun | 7128 |
| 56 | Chombi | 6704 |
| 57 | 6421m-Peak | 6421 |
| 58 | 5921m-Peak | 5921 |
| 59 | Amatsan Himal | 6393 |
| 60 | 6100m-Peak | 6100 |
| 76 | Kang La (Kanla Bhanjyan) | 5365 (5306) |
| 78 | Khumjungar Himal | 6759 |

otherwise equal relief-specific and petrographic conditions - by the significant glacio-physical difference from lateral- to ground moraine.

The reconstruction of the High Glacial maximum (LGP, LGM, Stage 0) glacier level at the valley head bases on a trough-shaped transfluence pass across the 6373 m-notch between Nemjun Goth (No. 50) and the 7140 m-peak (No. 49). This trough-shaped cross-profile of a transfluence pass reaches up to c. 6600 m asl (Photo 8 ---- and 9). Because the heights of the valley bottom and ice level in the Bhimdan Khola (upper Dudh Khola, cf. Fig. 1) are similar to that in the Phu-Pangri Khola concerned, no indication can be seen as to the direction of transfluence from W to E or reverse. Because of the straighter and shorter, i.e. steeper ice discharge to the S into the Marsyandi Khola main-valley down to below of 2000 m asl, the Dudh Khola-glacier must have flowed down faster than the Phu-Nar- Khola-glacier. Therefore the c. 230 m-thick ice transfluence probably will have taken place from W to E into the Bhimdan Khola (upper Dudh Khola).

On the valley slopes of the Phu Pangri Khola the past glacigenic flank abrasion is preserved in all places (Photo 8 and 9: ∩) where it has not been covered and reshaped at a right angle by current hanging glaciers or destroyed by rock crumblings down from the high mountains (⊠). Further classic remnants of trough profiles are also preserved (Photo 8 ↗). Remnants of ground moraine covers that are dependent on flatter inclines do‘nt reach quite as high up as flank polishings (Photo 9 ■). The substrate of the remnants of the ground moraine cover has been dislocated by solifluction as well as by occurrences of debris flow as far as into the Neoglacial (Holocene) to Historical lateral valleys. The ice level that in the glacio-geomorphological sense is rather clear and which on the orographic right side together with that of the Layju Khola has developed an approximately connected level without any steps (see above), during the valley course of the Phu-Pangri Khola has fallen away up to down into the Phu K. from c. 6600 (Photo 8 ----) via 6000 - 5900 and 5800 - 5700 to 5600 m asl (Photo 7: ---- on the right and 0----; Photo 9 ----).

### 3.3. The LGP (LGM) glaciation of the middle Phu Khola between the valley chamber of Phugau and Kyan (Fig. 13)

In the centre of the valley chamber of Phugau the c. 200 m-thick pedestal ground moraine is deposited (Photo 7 below second ■ from the right; Photo 9 below ■ on the left), which - marginally eroded by the talwegs of the Layju Khola and Phu- Kangri Khola - has been left here. This pedestal ground moraine that genetically has to be classified as belonging to the Late Glacial stages II-IV (Tab. 1) continues in corresponding surface levels along the two valley flanks down the Phu Khola (Photo 7 II-IV). Ground moraine covers on both valley flanks - in part with erratics - have to be classified as being from the same glacier stages. The ground moraine mantling of the valley chamber is modified by small-scale glaciolimnic accumulations and glaciofluvial cuttings (⇓) as well as moraine scourings and Neoglacial to recent development of glacier outlet gravel floors (sander) (-5 to -7 and -6 to -8; cf. gravel field (sander) in Tab. 1). But also debris cones and debris flow fans are Postglacial dislocations of the ground moraines concerned. The glaciolimnic accumulations have been dammed up by moraine slides and debris flow fans. In many places earth pyramids have been developed on the edges of pedestal ground moraines (Photo 7 ▲).

The glacigenically back-polished mountain spurs (◓ white on the left) and the abrasion roundings developed still further upwards (∩) prove that the intermediate valley ridges on both sides of the Phu-Kangri Khola have been overflowed by the glacier ice during the LGP- or LGM (Stage 0, Tab. 1) glaciation. Corresponding abrasion roundings are also situated up to the same sea level on mountain spurs down-valley of the Phugau settlement; here - especially in the W-flank of the 7074 m-peak (No. 48) - mountain spurs back-polished by the valley glacier are also preserved. In some places, however, the abrasion- and polish forms have been destroyed by crumblings. The glacier level of the LGP-Phu Khola parent glacier has been reconstructed according to the uppermost polish lines above the occurrence of ground moraines at c. 5600 up to c. 5500 m asl (Photo 7: 0----).

Geomorphologically noticeable is the c. 0.7 km-long gorge-stretch down-valley of the valley chamber of Phugau (Fig. 13). It must have subglacially developed by meltwater in the bottom of the glacier valley of the Phu Khola. In order to make this possible at a sea level about 4000 m, the ELA must have run already several hundred metres above 4000 m asl. This was the case not before the Late Glacial during Stages II-IV (Tab. 1). Accordingly, the glacial gorge has come into being sygenetically with the ground moraine pedestal of Stages II-IV. Down- and up-valley of the glacial gorge there flows the Phu Khola mountain river on a narrow gravel floor, i.e. it forms a Historical to current gravel floor track (Tab. 1: sander, gravel field No. -5 to -8). Its material are rather large to metre-sized stone- and block components taken in by lateral erosion from the pedestal ground moraine bases, the morainic matrix of which has been washed out. The ground moraine character of the primary substrate on the slopes among others has been evidenced by the development of earth pyramids. In some places of the lower valley cross profile, there occur exposed interlockings of older, higher situated glaciofluvial remnants of the gravel floor with ground moraines. Besides that undercutting, also side valley- or small side valley cuttings that on the upper slope cut through the ground moraine covers and on the lower slope the pedestal ground moraine base, lead to the redeposition of the moraine material and its resedimentation into debris flow- and alluvial fans as far as down into the area of the talweg. A second glacial gorge stretch that also follows the vertical jointing in approximately shallowly lying sedimentary rocks, is situated c. 3.5 km up-valley of the wasteland of the Kyan settlement (Fig. 13). Its pothole walls and bi-concave forms of the roofs confirm the subglacial development of the gorge. In the chronologically and genetically same connection of Late Glacial subglacial meltwater forming there belong forms of wall gorges (organs) as visible in the orographic right valley flank at c. 3900 m asl (28°44‘42“N/84°16‘30“E) (Fig. 13). Down-valley decametre-thick pedestal ground moraines are preserved on the orographic left side. Since the late Late-Glacial deglaciation they have been - and still are - geomorphologically reshaped by debris flow cones. Their material becomes dislocated near to the surface. These redepositions push the talweg to the orographic right valley side and at the same time are vertically undercut by the Phu Khola river.

In this valley cross profile that during the course of 3 km down-valley up to the valley chamber of the wasteland of the Kyan settlement narrows into a trough-shaped gorge, i.e. a „gorge-like trough" (Fig. 13), has run the glacial (LGP, LGM, Stage 0) level of the ice stream network at c. 5500 to 5400 m asl (Photo 10 ---- on the left below 48 to 52).

The valley chamber in which the wasteland of the Kyan Kampa- settlement is situated, is a c. 2 km wide confluence- and junction area of the orographic left Miuju (also Lyapche-) Khola into the Phu Khola main valley (Photo 10 below 52; Fig. 13). The seemingly spaciousness and width of this excavation area profits from an over 120 m-thick filling of the valley bottom. This consists of basal ground moraine of the Late Glacial Stage IV that since the deglaciation in the late Late Glacial (after Stage IV, Tab. 1) and in the Holocene has been glaciofluvially truncated. On this truncation face Neoglacial glaciofluvial advance gravels („Vorstoßschotter") of Stages V and VI (Tab. 1 No. -0 to -1) have been accumulated. Without doubt the glacier outlet gravel floors (gravel field, sander) of the Miuju (also Lyapche Khola-) glacier (Photo 10 ∪ below 52; Fig. 13) have had priority as to this accumulation process. The author is not able to indicate the influence of the Neoglacial Phu glacier advance and its advance gravels which at that time was also probable. Despite the gorge-like erosion stretch of c. 4 - 5 km situated in between, remnants of a gravel floor are preserved selectively. Glacier outlet gravel floor accumulation No.-0 to -1 has been cut by the glacier stream of the Miuju Khola glacier. Afterwards, that means during the last Neoglacial advance (Stage 'VII; cf. Tab. 1) this cut has been filled with a further glacier outlet gravel floor (No. -2; cf. Tab. 1). In the meantime, in the course of the further, i.e. historical glacier retreat, this has also been cut into a terrace form by a past glacier stream of the Miuju glacier. The current glacier stream of the Miuju glacier is very erosion-intensive, too. It cuts - starting from the Phu Khola talweg - backward into the Neoglacial tongue basin (Stage 'VII) of the Miuju (Lyapche Khola -) glacier.

The geomorphological-sedimentological condition of the end moraine, more exactly of the orographic right lateral moraine of the Neoglacial Stage 'VII of the Miuju Khola glacier, can be seen in sample 6.9.2007/1 (Fig. 13; Fig. 2 No. 32). Beside the bimodal course of the grain size cumulative curve, the portion of 96.6 % glacigenically crushed grains, mixed up with 3.4 % fluvially polished $SiO^2$-grains and the characteristic ramp-form is typical of moraine.

During the oldest Neoglacial Stage, the Nauri Stage (V, see Tab.1), the Miuju glacier has flowed down up to the valley chamber of the wasteland of the Chyako settlement at c. 3600 m asl (Fig. 13). This happened at an ELA-depression of c. 430 m, because the current glacier tongue ends up at 4460 m (Photo 10 below ∪), 860 m above that Neoglacial (Holocene) glacier end (V). This corresponds to a temperature depression of more than 2°C at a current gradient of c. 0.5°C/100 altitude metres. In the geomorphological sense the noticeable- fresh condition of lateral moraine V contrasts strongly to the older moraines and proves their Holocene age (cf. Fig. 13).

Situated in between, that means in the valley cross-profile with regard to the height above the valley bottom as also in the longitudinal profile, there is the Neoglacial Stage VI between the younger Neoglacial Stage 'VII and that older Neoglacial Stage V. Its lowest ice margin reached down on a pedestal ground moraine up to c. 3760 m asl as far as into the Phu Khola. This proves an ELA-depression of c. 350 m for this stage (700:2=350).

The time leap between the Neoglacial and the youngest Late Glacial moraine accumulations can be clearly recognized in the junction area of the Miuju Khola. In contrast to Stages VI and V no lateral moraines at all are preserved from the Late Glacial glacier of Stage IV, but there is a ground moraine overlay covering the valley flank concordantly. Without exception the still older Late- to High Glacial moraines have already been reshaped during the late Late Glacial.

Above those ground moraine covers on the valley slopes, in the area of the outcropping rocks, flank abrasions are preserved in the shape of smoothings and roundings (Photo 10 ∩ below 53). Since deglaciation, however, these abrasion forms have been roughened by weathering of crumbled rock masses (⌺ below 56) in many places. The highest glacial glacigenic abrasion level according to which the surface of the icestream-network in the confluence area of the Miuju- and Phu Khola glacier could be reconstructed, runs at c. 5500-5350 m asl (Photo 10 ---- below No. 48; cf. Fig. 13).

### 3.4. The LGP (LGM) glaciation of the Phu Khola between the valley chamber of Kyan and Chyako and the junction of the Lapse- and Ghatte Khola (lower Kanla- or Kang La Khola) near Metagau (Fig. 13)

In the valley bottom of the valley chamber of Kyan there have been accumulated Holocene to Historical loose rocks, so that geomorphologically fresh end moraines and gravel floors (sander) built up the surface (see 3.3.). The valley flanks above, however, are covered by Late Glacial ground moraine (Photo 10 the two ■ below 54). Between these two areas of forming, i.e. between valley bottom and valley slopes, there lies a geomorphological leap of time of c. 10 Ka (Late Glacial up to middle and younger Holocene). This leap is caused topographically by a decreasing glacier thickness. The topographically determined chronological regularity is also repeated down the Phu K., in the valley chamber of Chyako. Here the Holocene Junam Khola glacier (i.e. „Kangaru-Chombi-W-glacier": Photo 10 ⇨) as well as the Miuju (also Lyapche Khola-) glacier reached down from its side valley up to the valley ground of the Phu Khola-main valley. During the oldest Neoglacial Stage (V) with ELA-depressions exceeding 400 (430-480) m (see 3.3.), the tongues of Miuju- and Junam glacier might have touched during a simultaneous advance (Fig. 13). This cannot be clearly recognized by the end moraines preserved, because they only preserve the last time before the back-melting - the stagnation -, but not the preceding phase of advance. A classic lateral- or lateral valley formation, that consists of lateral sander and kame terrace and has been heaped up against the outer slope of the lateral moraine (Stage V) and the Miuju glacier, is shown by the fields of the abandoned Kampa-settlement Chyako.

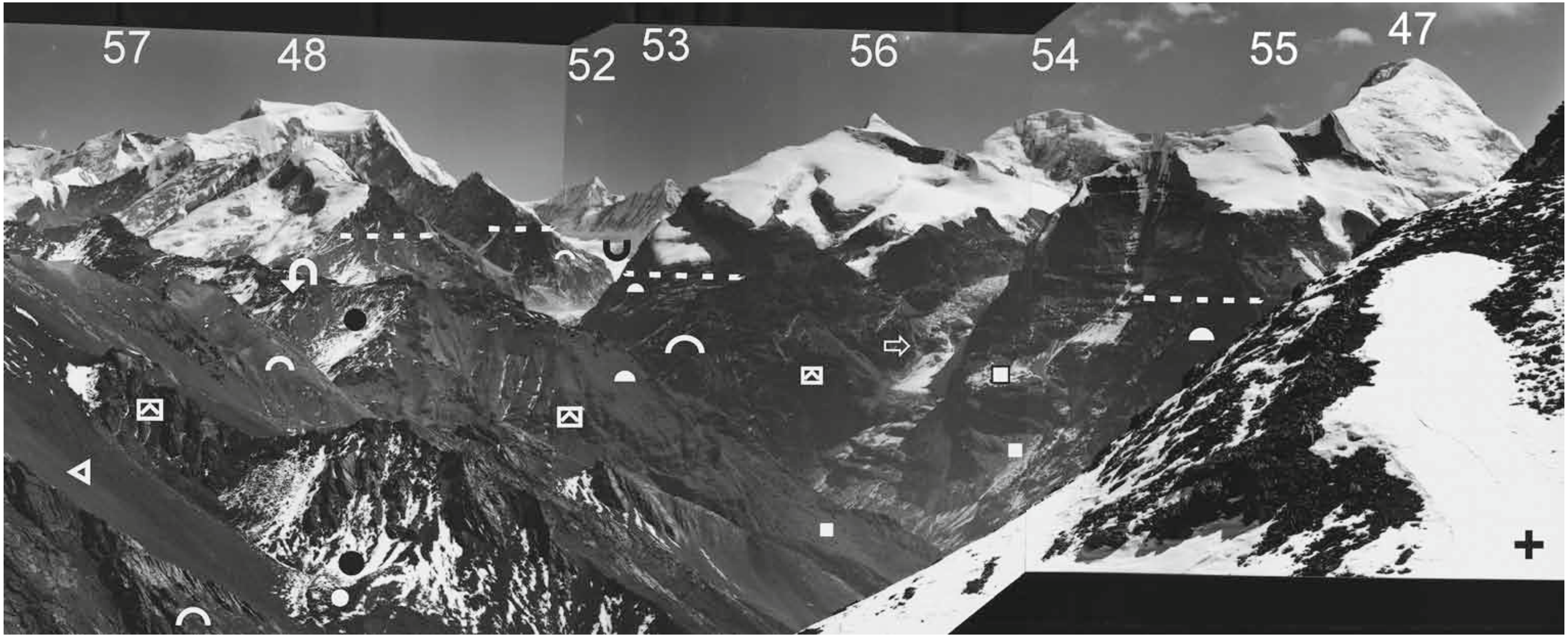


**Photo 10**: C. 40°-panorama at c. 5330 m asl (28°41'20"N/84°07'45"E; map: 1:50 000, No. 2884 05; Fig. 13 Panoramaphoto 10) from Kanla Bhanjyan (No. 76) from facing ENE to the 6421 m-Peak (No. 57) via E to Chombi (No. 56, 6704 m) up to facing ESE to Kangaru (No. 47, 6981 m) seen straight across the Phu Khola. The highest mountain is the un-named 7074 m-summit (No. 48) with a glaciated, at least 2 km long and c. 1 km wide summit plateau between 7074 and 6820 m in height which is a remnant of an old surface in the bedrock granite. As to the rest of the summits see Tab. 2. (◡) marks the more than 10 km-long Lyapche glacier in its trough valley, (⇨) is the ice fall at the tongue end of the 7 km-long "Chombi-WSW-glacier", (↰) shows a c. 5330 m high ice transfluence area of the LGP (Stage 0) between Phu- and Lapse Khola, (◁) are km-stretches of debris covers between 4200 and 5200 m asl consisting of local moraine and fine-splintery phyllite debris (mica schist); (◓) mark mountain spurs along the valley flank stretches which for the last time have been back-abraded by the LGP-icestream network. (∩) are convex glacigenic forms of flank abrasion; (⊠) show rock crumblings on the valley faces since the deglaciation, (■) are remnants of ground moraines on the valley slopes and upon rock terraces, (● black) show cirque-like hollow forms in a SW-exposition which now take up the places of former hanging glaciers that existed during the Late Glacial; partly even during the Neoglacial. (● white) marks a Late Glacial to Neoglacial end moraine of a cirque glacier, the debris of which has still moved like a rock glacier, i.e. under the permafrost after the deglaciation („Fließzungen schuttbedeckt mit Eiskern" und „durchgebogene bzw. sichelförmige Grobschuttwülste» after Kuhle 1982: 137-139, Abb. 9, 19 Segment 3 u. Abb. 184). (----) is the LGP- (LGM-, Stage 0, see Tab. 1) level of the ice stream network between c. 5450 m on the left and 5150 m asl on the right side. Analogue photo M. Kuhle, 04/03/2004.

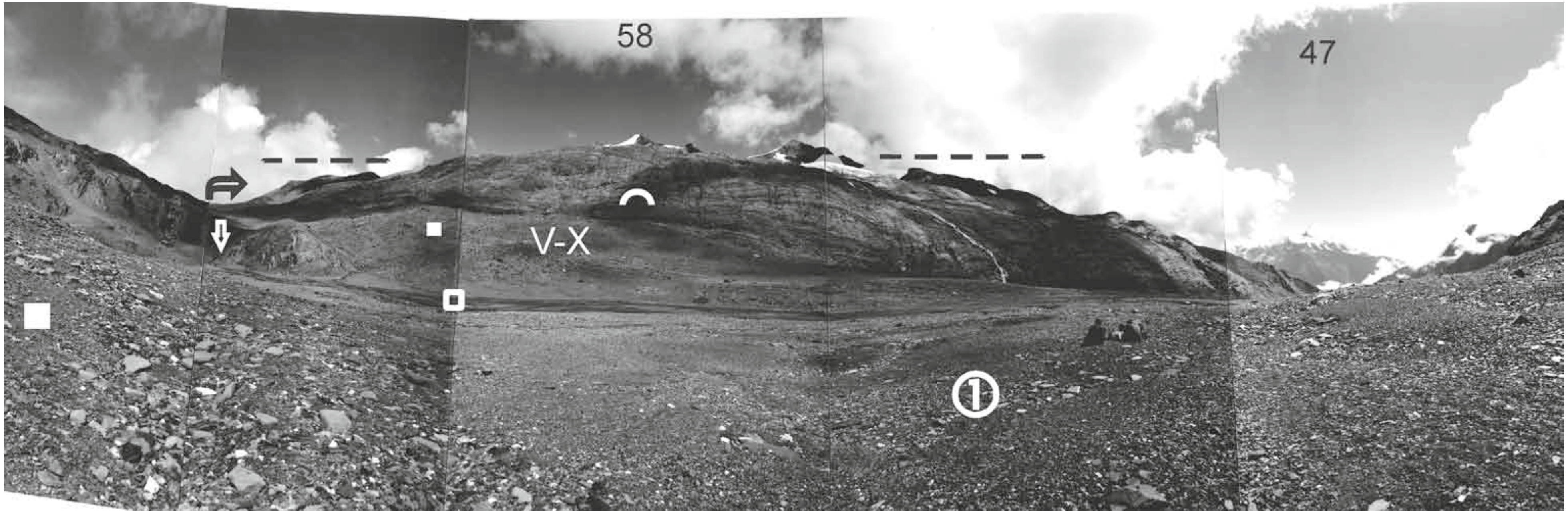


**Photo 11**: C. 200°-panorama at c. 5200 m asl (28°41’54’’N/84°06’36’’E; map 1: 50 000, No. 2884 05; Fig. 13 Panoramaphoto 11) from the upper Kanla Khola not far away from the valley head (↱) seen from facing WNW up-valley via facing N to the 5921 m-Peak (No. 58), and facing ESE down-valley to Kangaru (No. 47, 6981 m). (①) marks the sampling locality of sample 16.09.07/1 (Fig. 2). (■) show ground moraine covers, which currently are solifluidally reshaped near to the surface; (V-X) are end- i.e. lateral moraines of the Neoglacial to Historical glacier stages V to X (cf. Tab. 1); (□) is the gravel floor of the glacier outlet of these stages within this valley chamber; (⇩) shows a small stretch of a V-shaped valley in the form of a gorge, which has been subglacially developed during the Neoglacial and later on has determined the position of a historical glacier outlet. (∩) signify well-preserved glacigenic flank polishings and abrasion roundings; (↱) marks the c. 5300-5400 m-high transfluence pass across which the glacier ice has flowed down from the Marsyandi Khola; (----) indicates the minimum height of the LGP-glacier level in the Kanla K. about 5600-5500 m asl. Analogue photo M. Kuhle, 16/09/2007.

The valley section described upward of Chyako as well as that over a length of 5 km down-valley, up to the junction of the Lapse Khola (Photo 10 ■ totally below; Fig. 13), is trough-valley-shaped. The valley bottom is covered by partly intact remnants of formerly connected pedestal ground moraine. Since the deglaciation the last has been cut by subaerial fluvial erosion for the last time and modified into pedestal ground moraine terraces. The minimum thickness dignosable by that amounts to several decametres. Without alternative the last glacier cover of these ground moraines can be classified as belonging to the late Late Glacial, i.e. Stage IV (Nauri Stage, Tab. 1). The same age applies for the glacigenic flank polishing preserved on the valley flanks above. In places the terrace faces of pedestal ground moraines are covered by glacier outlet gravel floors (coarse- grained sanders). Apart from pebbles they also contain moraine boulders that have been redeposited down-slope as well as eroded and further rounded.

However, due to glacier-physical reasons the primary phase of development of these comparably minor-thick pedestal ground moraines has to be classified as belonging to Stage I (Ghasa- Stage, Tab. 1), i.e. to the earliest Late Glacial. In order to understand this, one has to remember, that the sedimentation of ground moraines has only taken place below the ELA and its thickness increases according to the vertical distance below the ELA. What means, that here in the area of the LGM-ELA (High Glacial altitude of the snowline) the valley glaciers were lying upon the rocky valley ground and not yet on ground moraine. This is proved by trough valley profiles caused by glacigenic ground polishing (see above) in the valley chamber concerned. In the early Late Glacial (Stage I-II) the ELA was upliftet so far, that the concerning altitude of the valley grounds remained below the ELA, so that first deposits of ground moraines have taken place. With the further uplift of the snowline, the ground moraine grew thicker, so that the most important pedestal moraines have developed up to the late Late Glacial (Stage III-IV). Accordingly, the late Late Glacial valley glaciers flowed on up to over 100 m-thick pedestal ground moraines, replacing the loss of ice at least in part by moraine sedimentation.

As to these modalities the junction area of the two right side valleys, the Lapse- and the Ghatte Khola (Photo 10 around ■ totally below), provides useful illustrative material. Since the deglaciation deeply-fluvially cut by the rivers of the Lapse-, Ghatte- and Phu Khola, four Late Glacial remnants of pedestal ground moraine terraces are preserved here. The highest level of pedestal ground moraine is the stratigraphically youngest (Stage IV), because the three older Late Glacial (Stage III to I) deposits of pedestal ground moraines are situated in the underlying, on which the youngest layer of pedestal ground moraine has been deposited. This youngest ground moraine level (Stage IV) lies at 4000 m asl (Fig. 13), c. 450 m above the oldest one (Stage I). However, because there is a solid rock core in that Late Glacial, terrace-like stepped body of pedestal ground moraine that consists of 4 layers, its maximum thickness obviously is less than 450 m.

Samples have been taken from the highest level, level IV (Fig. 13: sample 17.9.07/1), and sedimentologically confirmed as being a moraine with a peak of c. 7 % in the clay and a bimodal course of the grain size cumulative curve. 98 % of the $SiO^2$-grains of the medium sand fraction in the matrix between not down-slope but horizontally transported large boulders are broken sharp-edged (Fig. 2 No. 33), so that they can be addressed as being glacially crushed without alternative.

The question as to sequence and extent of the reworking of those pedestal moraines as a result of post-Late Glacial deglaciation in the confluence area concerned, will not be investigated here. They both are dependent on the order according to which the valley glacier tongues of all three valleys have left their confluence area due to back-melting. In this treatise, however, the LGP- and LGM-glaciation is main-subject of the comments.
The Metagau settlement is situated on a further main-valley-downward remnant of pedestal ground moraine (Photo 13: I-IV; Fig. 13), that has to be classified as belonging to a Late Glacial (Stages I-IV) Phu- or Nar-main valley glacier overlay and the synchronously joining Kangaru-W-valley glacier. Since the deglaciation, i.e. in the Holocene, a debris flow cone has been sedimentated on its surface. It consists of dislocated moraine from the steep Kangaru-W-valley, the valley head of which due to the up to 6981 m-high catchment area is still today glaciated (Photo 10 and Tab. 2: No. 47). The analyses of samples 9.3.04/4 and /5 (Fig. 13; Fig. 2 Nos. 34 and 35) are unambiguously proof - among others by a trimodal course of the grain size cumulative curve - of the glacial genesis of the pedestal material situated below the debris flow fan (with the fields of Metagau). The fluvial cutting of the pedestal moraine by the Kangaru-W-valley stream exceeding 200 m (Photo 13 I-IV), in addition made possible the basal sampling 9.3.04/2 (Fig. 13; Fig. 2 No. 36; Photo 13 below I-IV). It provides a further confirmation of the pedestal-ground-moraine character of the primary matrix between the large far-travelled boulders. In all three samples the erratic ground masses contain about 98-99% glacially crushed quartz grains. The remaining fluvially polished $SiO^2$-grains confirm a certain influence of the subglacial meltwater as it is characteristic in damp ground moraines below the ELA.

Very thick pedestal ground moraine sediments like these continue down-valley through the Nar (Naur-) Khola gorge (see below 3.7.).
On the valley flanks, up to far above those pedestal ground moraine terraces of the valley bottoms, ground moraine covers have been met (Photo 10 ■ and below ◓ on the right) and sedimentologically analyzed with topographically representative spot samples (Fig. 13: 4.9.07/1; Photo 13 left below ∩ black). For instance in this spot sample 95.2% of the $SiO^2$ medium sand grains are angularly broken and the rest is fluvially polished (Fig. 2 No. 37). Therefore the latter shows a subglacial reworking by meltwater, because this fluvial grain polishing definitely would not be possible by a subaerial down-slope transport over only some 100 m. The composition of the grain sizes, too, points to a glacigenic sedimentation.

Above these remnants of a ground moraine cover, which by solifluction are slightly surficially redeposited down-slope, flank abrasions and -polishings (Photo 10 ∩ on the right; 13 ∩ black) prove a maximum glacier level in the valley section concerned between 5450 m asl above Kyan (gau) and 5150 m above Meta (gau) (----).

### 3.5. The maximum past, i.e. LGP (LGM) glaciation of the Kanla (Kang La) or Ghatte Khola up to its inflow into the Phu Khola SE of Nar (Nargau) Fig. 13

The real valley head of the Kanla Khola is lacking, because it is a “gekoepftes” (beheaded) valley. The Julu Khola, which is subject to strong backward erosion, has beheaded the Kanla Khola at a right angle. Instead of coming to an end in a steep valley head basin (kettle), the only minor-inclined valley bottom continues shallowly up to a steep break-off down into the Julu Khola, ending there with a geomorphologically fresh working-edge (Photo 11 ). Cause of this is the short, steep and accordingly erosion-intensive connection of the Julu Khola to the talweg of the Marsyandi Khola main valley situated only 7 km away to the SSW. The talweg of the Kanla Khola, however, needs double the distance to reach the same height of 3400 m asl and thus is only half as steep (Photos 11, 12).

That this pass has been overflowed by glacier ice (Fig. 13), is proved by its ground moraine cover with large boulders and glacigenic flank abrasions (Photo 11 ∩) on both sides of the pass depression. The proof that generally ground moraine is concerned from the valley bottom up to the saddle, has also been carried out sedimentologically (Fig. 13: 16.09.07/2; Fig. 9; Fig. 2 No. 38 and Fig. 13: 16.09.07/1 Photo 11 ① ; Fig. 2 No. 39). Fluvial portions of the matrix of the lodgement till (18-19% are fluvially polished) must be explained by subglacial meltwater activities of the last, i.e. late Late Glacial to even Neoglacial glacier cover. The bimodal course of the grain size cumulative curve of the sample situated directly on the pass (16.09.2007/2), its high clay portion and great sorting coefficient of So = 10.90 (!) clearly show the only little solifluidally modified glacigenic character. The observation of a uniformly high, High Glacial ice level, extracted from the flank abrasions cited and therefore heightened up to beyond of the most south-western crest-ridge of the Kanla Himal, cannot be reduced to a local hanging glaciation from the N. In the N the still currently glaciated S-slope of the 5912 m-peak (No. 58) is situated. From this only a steep and therefore minor-thick hanging glacier can have flowed down. This applies the more, as the steep Julu Khola, leading down further 2000 altitude metres (see above) - being the past glacier outlet channel of the hanging glacier tongue concerned - must have kept this glacier tongue minor-thick up to its end. In order to explain the preserved glacigenic abrasions and the ice level that has been proved in accordance to it, a large-scale level of the ice-stream-network about c. 5500-5600 m asl (Photos 11:----; 12 ---- left half of the panorama) must be concluded. At the same time this ice level was that one of the LGM-Marsyandi Khola main valley glacier (parent glacier) (Photos 1 ____ ; 2 ---- on the right) to which all synchronous side glacier levels have been adjusted. Accordingly, this pass at the source of the Kanla Khola is a small transfluence pass (Fig. 13; Photo 11 ), over which the orographically left Marsyandi Khola main valley glacier edge flowed into the Kanla Khola, that means it has run over into it (cf. 2.2.).

Along the orographic right valley flank the analysis of the further valley course downwards facing ESE confirms a correspondingly high ice level about 5600 to 5500 m asl close to the pass (Photo 11), that then has continuously dropped from this altitude down to c. 5150 - 5100 m (Photo 12). On the orographic left valley flank two abrasion- and polish directions have overlapped each other at right angles: the Glacial- to Late-Glacial flank polishing at the time of the important ice thicknesses that have been reconstructed, as well as that one of the Neoglacial (Holocene) to Historical (Photo 11 ∩) hanging glaciation that exists still today (Photos 11 and 12). Naturally only the young (Photo 12 IV) up to youngest end- and lateral moraines of this development have been formed in the Kanla Khola and partly preserved (Photo 11 and 12: V-X).

In the orographic left valley flank it becomes exemplarily clear, how the current cirque- and hanging glaciation destroys the glacial glacier traces in the form of flank polishes (see above), but also on ground moraine covers reaching high up the slopes at a right angle, i.e. down-slope. At glacial times small side glaciers like these were adjusted to the surface of the many hundred meter up to nearly 1000 m-thick Kanla Khola glacier. They have reshaped the valley flank, the ground moraine cover of which today is reshaped by their tongue ends and end moraines. Combined with this purely glacigenic reshaping, that one combined with meltwater grooves takes place. During the Late Glacial (Stage II-IV, Tab. 1) already four glacial gorges have been laid out subglacially in the junction area of the three small side valleys on the orographic left side. Because three small hanging side valleys (in the shape of short troughs i.e. longish cirques) are concerned here, the glacial gorges are cut into steep junction thresholds. But also in the longitudinal course of the upper Kanla Khola- main valley, in the three steps of the valley ground on which forms of roches moutonnées are preserved (Photo 12 ∩ white on the left), glacial-gorge-like forms have been developed about heights of 5000, 4800 and 4650 m which had already been laid out subglacially by linear erosion (Fig. 13).

The ground- and lateral- up to end moraine deposits sedimentologically analysed on four representative localities, concern from above at 5374 (5330) up to down and in a down-valley direction up to 4370 m asl the samples 4.3.2004/1, 14.9.2007/1, 15.9.2007/1 and 13.9.2007/2 (Fig. 13; Fig. 2 Nos. 13, 41, 42, 43; Fig. 10). The highest orographic right ground moraine cover can be described by a relatively high content of clay, the sorting coefficient So = 4.43 and in addition to 98.9 % broken also 1.1 % slightly rounded $SiO^2$-grains; naturally, near to the surface it has strongly been reshaped solifluidally. The next sample proves absolutely certain, classic, Neoglacial end moraine of a reshaped, late Late Glacial ground moraine pedestal on the orographic left valley side, taken c. 100 m above the current gravel floor (Fig. 13: 14.9.07/1; above No. -1 to -8: Tab. 1). The sorting coefficient reaches So = 7.02, the clay content 10.5 % and besides a predominance of broken quartz grains, the remaining 8.7 % of fluvially polished grains show the sedimentation below the ELA. That the grains are glacially crushed and not freshly weathered is proved by the large far-travelled boulders that are embedded into the analysed matrix.

The sample taken only a little down-valley, concerns a moraine rampart situated on the orographic left side of the Kanla Khola that can be described geomorphologically as an end moraine, more exactly as a front moraine of a Neoglacial wall foot glacier in the shadowy N-flank of the Pisan Peak (Fig. 13 on the left above No. 43). The findings as to the material are obvious: a


**Photo 12***:* C. 235°-panorama at c. 5150 m asl (28°41'30''N/84°07'48''E; map: 1:50 000, No. 2884 05; Fig. 13 Panorama Photo 12) from the upper Kanla Khola (Chu) c. 1.8 km away from the trough-shaped valley head (∪), a transfluence pass, seen from an orographic right Late Glacial lateral moraine rampart (IV) (view point) from facing W into the right valley flank upward, via facing NNW to the 5921 m-peak (No. 58) via facing E along the left valley flank down-valley to the Nar- or Phu Khola-main valley with Chombi (No. 56, 6704 m), then via Kangaru (No. 47, 6981 m) and Pisangtse (No. 43, 6149 m) up to facing SE along the right valley flank. (■) mark Late Glacial remnants of a ground moraine cover on the valley flanks; (IV) is a late Late Glacial lateral moraine rampart with polymictic, colourful, sometimes round-edged boulders (foreground); (V-X) are orographic left remnants of ground moraine of the Neoglacial to Historical Stages V to X (see Tab.1); (∩) show glacigenic flank abrasions and rock polishings, in some places on truncated mountain spurs (◓); (⊠) indicate niches of crumblings roughening the glacigenic abrasions on the bedrock phyllites; they also build-up debris cones and -slopes (Δ); (----) is the minimum height of the LGP-glacier level in the Kanla K. about 5600-5500 m (left half) and 5500-5100 m asl (right half) down to the main valley. Analogue photo M. Kuhle, 16/09/2004.

16 % clay portion, a bimodal course of the cumulative curve of the grain sizes, 85.5 % glacially crushed and 14.5 % fluvially polished $SiO^2$-grains testify to a local end moraine. A rather medium sorting coefficient of So = 3.85 confirms the glaciofluvial washing-out. Due to its altitude above sea level of 4580 m it must be of a Postglacial (Holocene) age and inevitably contains redeposited late-Late Glacial (Stage IV) ground moraine, here pedestal ground moraine, as it can be met down-valley with increasing thickness (see 3.4.) and which - now as end moraine - has still further been washed out (see above).

The moraine sample situated the lowest, concerns the same geomorphologically clear end moraine that has just been described, but 2.7 km further down the Kanla Khola, and here also material of a ground moraine modified to an end moraine. It shows clear characteristics of moraine in all sedimentological indicators: so a trimodal course of the grain size cumulative curve, a sorting coefficient of So = 6.52, a clay portion of 10 % and a good 92 % broken $SiO^2$-grains in the immediate neighbourhood of far-travelled large boulders, as well as a good 7 % fluvially polished grains, evidencing the characteristic influence of meltwater and therefore also an end moraine.

Today the local orographic snowline in the concerning N-flank of the Pisan-peak WNW-satellite runs at 5050 m asl. In order to reach the wall foot and to create the end moraine at 4300 to 4600 m asl we are speaking about, an ELA-depression (Δ ELA) of c. 300 m is necessary. This corresponds to a snowline depression attained during the oldest Neoglacial (c. 4-5.5 Ka) Stage V (Nauri Stage, cf. Tab. 1). Debris cones at the wall foot point to a passed period of 4000-5500 years from the existence of that wall-foot glacier up to present-day. Now there exclusively rests a comparably narrow wall glaciation only below the 5500 m high catchment area (Fig. 13 on the left above No. 43) situated to the E. After the glacier ablation these debris cones have been accumulated in the area of excavation of the wall-foot-glacier-tongue-basin.

The current Pisan Peak-N-glacier ends on a pedestal-shaped end moraine at c. 4600 m asl (Fig. 13), that is an orographic ELA at 5050 m asl. Directly opposite to the N, in the orographic left valley flank of the Kanla Khola, a SSW-exposed cirque is situated (Photo 10 ● black below) with a medium catchment area of c. 4900 m asl. For the last time it was glaciated up to a height of c. 4480 m during the Late Glacial Stage IV (Sirkung Stage, Tab. 1) (see tongue basin: ● white and the fringing end moraines below; cf. Fig. 13), what provides evidence of an orographic ELA at c. 4690 m asl. This corresponds to an ELA-depression of c. 700 m against today (Tab. 1). In the earlier Late Glacial as well as during the LGM, the whole valley flank concerned was covered by the Kanla Khola glacier attached to it, so that this cirque glacier cannot have existed yet. Currently, however, this initial moraine accumulation forms an active rock glacier (Fig. 13), what must have led to a certain dislocation since the deglaciation, so that the derived ELA-depression must have been a little less.

The Kanla Khola valley glacier level in the middle and lower valley course can be diagnosed - aside from highest occurrences of ground moraine (Photo 12 ■ black on the left, the upper three ■ white) - by only sporadically preserved, back-polished mountain spurs and abrasion limits (Photo 12: ⌓, ∩; 10 ∩ on the left below) along the valley flanks. Due to the thin-stratified, jointed and tectonically stressed Paleozoic and Mesozoic phyllites (see Hagen 1968: 70/71 Fig. 54) the roughening due to a great density of crumblings (Photo 10 and 12: ⍓) is extremely destructive as to the glacigenic smoothings that are exposed to frost weathering since the deglaciation. The corresponding accumulations on the slopes, that are the debris cones and -slopes (Photo 10 and 12: ▷◁) overlying the glacial ground moraine covers on the lower slopes, but also the three current alluvial fans on the valley bottom, demonstrate those enormous local crumbling activities. During the maximum glaciation (LGM, LGP, Stage 0 in Tab. 1) the Kanla glacier level has run in the middle valley course at c. 5450 m and from there down to c. 5100 m in the valley exit (Photo 12 ---- black).

The junction area of the High- to Late Glacial Kanla glacier into the Phu Khola (Nar Khola) at the same time is the confluence area with the High- to Late Glacial Lapse Khola glacier (cf. Fig. 13: around 13.9.07/1 and 17.9.07/1). The Nar settlement owes its existence to the c. 4x2 km extended, nearly level area between the deeply inset talwegs of the two valleys. It is flat-wave-like and has a minimum height of 4100 to a maximum height of 4260 m. Here, Late Glacial ground moraine on a large scale lies on an outcropping rock pedestal and is marginally attached to it. Its surface form is only known selectively by several small rock hills and tors. In the area of the fields around Nar a Neoglacial glaciofluvial gravel overlay covers part of that ground moraine. In the area of the ground moraine, marginally attached to the rock pedestal that pre-glacially (during the Tertiary) as a mountain spur had developed the intermediate valley ridge between Kanla- and Lapse Khola - the ground moraine in places is up to over 100 m thick. There it forms Late Glacial pedestal ground moraines. This ground moraine pedestal is exposed most extensively and completely in the immediate junction area of the two adjacent valleys into the Phu Khola (see 3.4.). Sample 13.9.2007/1 (Fig. 13; Fig. 2 No. 44; Fig. 11) sedimentologically confirms (in the form of spot checks) the geomorphological finding of ground moraine. 92.6 % of the $SiO^2$-grains are glacially crushed, the remaining 7.4 % are fluvially polished. Despite this unambiguous, but with regard to subglacial water typical, only insignificant, fluvial influence, the matrix still contains 12 % clay. The grain size cumulative curve is bimodal and the sorting coefficient with So = 5.57 high, what is typical of moraine.

### 3.6. The maximum past, i.e. LGP (LGM) glaciation of the Lapse Khola up to its inflow into the Phu Khola E of Nar (Fig. 13)

Today - as the other large valleys of the Damodar Himalaya furnished only in the valley exit with c. 7-13 km long valley glaciers - the Lapse Khola and its side valleys lead down from catchment areas of 6000 up to a maximum of 6759 m asl (Khumjungar Himal Tab. 2 and Fig. 13: No. 78). In the course of the lower 14 km of the valley there have been developed nearly V-shaped cross-profiles with approximately stretched flank slopes as well as trough profiles, that according to the perspective can be recognized more or less clearly (Fig. 13). In many places on the valley slopes, deposits of ground moraines can be met that have to be classified as belonging to the Late

Glacial glacier stages I to IV (s. Tab. 1). On the orographic left valley flank, that is a less steep and especially less stepped bedding plane slope (Fig. 13), these ground moraines are preserved on a larger scale. There, the ground moraine covers reach maximum thicknesses of decametres that are exposed on young erosion rills on the slopes, as well as above of rock steps. Exposures like these have a tendency to develop moraine ribs up to earth pyramids. But also on the orographic right slope of outcropping edges of a stratum that along of steep bc-clefts is stepped, decametre-thick remnants of a ground moraine cover are preserved on rock balconies. The stability of its very dense loose rocks that is typical of ground moraine, is geomorphologically evidenced by vertical crumblings. The deposition of ground moraine in layers, i.e. in the form of covers that are laid down in piles, is the result of several glacier advances. Ground moraine covers like these have to be classified as belonging to one of the four Late Glacial advances (Stage I to IV; Tab. 1), so that the uppermost cover has been sedimentated during the Sirkung-Stage. Down-valley the ground moraines get thicker and thicker, so that near to the junction of the Lapse Khola into the Phu Khola c. 100 m-thick pedestal ground moraines have been developed (Fig. 13). In addition, the number of ground moraine covers increases with decreasing height of the valley ground, because more and more older, i.e. Late Glacial advances reaching at the same time deeper down - have separated more ground moraines. So e.g. Stage II and -farthest down-valley - also Stage I (Tab. 1).

Glacigenic flank abrasions that mainly have to be classified as belonging to the High Glacial (LGM), are more and more diagnosable on the orographic right side on the outcropping edges of the strata of the steep valley slope; this has to be led back to the currently largely lacking Late Glacial ground moraine overlay. The abrasions are roundings of rock heads, which in dependence of the petrography are far away from smoothings or even polishes. Cause of this is the outcropping, thinly stratified, narrow-jointed sedimentary rock (marlaceous sand- and siltstones) dipping to the S, which even below the glacier cover has remained rough and under the control of the clefts, and which is crumbling away in a periglacially forced manner. On the orographic left flank glacigenically rounded rock heads have been mapped (Fig. 13).

Due to the erosion of mountain rivers, in many places the talweg of the Lapse Khola has been cut like a glacial gorge or at least in the form of a box into the valley bottom. Accordingly, the valley flanks have been undercut (Fig. 13). This is a key form of subglacial meltwater erosion, which must have taken place below the ELA, i.e. during the Late Glacial: up-valley only in the late Late Glacial (Stage IV) and down-valley already in the early Late Glacial (Stage II-I; Tab. 1).

Since the deglaciation, i.e. since the time when a glacier overlay on the ground moraine covers of the slopes was lacking, these ground moraine covers are cut up by backward erosion rills, which are adjusted to the inset talweg, from below slope-upward.

A further current reworking of the prehistoric glacial geomorphology takes place by steep debris flow tracks on moraine slopes and debris- and moraine debris cones in which the glacial substrate becomes rearranged down-slope. This current morphodynamics that destroys the still predominating past forms, proves the diametrical change of regime from a past subglacial to a currently active subaerial forming.

Below of past, i.e. earliest Late Glacial (see below) cirques (Fig. 13) there are cirque- and hanging glacier end moraines of late Late Glacial (Stage IV) to Neoglacial and Historical times (c. Stages V to X; as to the chronology of the stages see Tab. 1). These slope- downward end moraines are in the Holocene permafrost level, so that part of them has been changed into rock glaciers and undergone dislocations.

The LGM-ice level reconstructed by ground moraines and further up the valley slopes, was situated at c. 5600-5200 m asl i.e. clearly above the level of that SW- to WSW-exposed cirques (Fig. 13) cited, so that their cirque glaciers could not have existed before the Late Glacial.

Accordingly, the Lapse Khola valley glacier branch up to the valley bottom at 4400 i.e. 3900 m asl, has had an ice thickness of c. 1200 to 1300 m.

### 3.7. The maximum past, i.e. LGP (LGM) glaciation of the Nar (Naur) Khola glacier, which bundles up the icestream network of the Damodar Himala up to its inflow into the Marsyandi main glacier (Fig. 13)

From the confluence of Phu Khola-, Kanla Khola- and Lapse Khola glacier (see above) in the large valley chamber in the area of the settlements of Nar and Metagau, there developed the Nar Khola glacier as a joint glacier tongue (Fig. 13). The last phase of its development belongs to the Late Glacial when the Nar glacier flowed on the level of the pedestal ground moraine (Photo 13 I-IV) on which the debris flow fan of the Meta settlement is situated. This is the level of Stage IV. In this pedestal moraine the ground moraines of the older Late Glacial Stages III to I are contained, too, as material cores. During the last overthrusting by the glacier of Stage IV they have been more or less reshaped. The sediment analyses carried out with this remnant of pedestal ground moraine have already been introduced in detail in Section 3.4. (see above: samples 9.3.04/4/5, Fig. 13; Fig. 2 Nos. 34 and 35; sample 9.3.04/2, Fig. 13; Fig. 2 No. 36).

The remnants of pedestal ground moraine pass the Nar gorge nearly entirely down-valley. However, they nowhere do this with a large-scale completely preserved surface of ground moraine terraces, but only in remnants in the form of decametre-high butresses, ribs, earth pyramides and ramps (Photo 13, ■ and I-IV). Down the glacial gorge of Metagau, the generally morainic character of the material has also been examined again and again by spot checking: samples 9.3.04/3 and 9.3.04/1 (Fig. 13; Fig. 2 Nos. 45 and 46; Photo 13 ■). Here, too, c. 98-99 % of the matrix of the far-travelled polymictic boulders is glacigenically broken and contains c. 1-2 % fluvially polished grains. The grain size cumulative curve of sample 9.3.04/1 is bimodal. The secondary peak is in the clay with a portion of 12 %, what means a high portion as it is typical of moraine in the steep relief here. The sorting coefficient with So = 5.30 is also typical of moraine (Fig. 12).

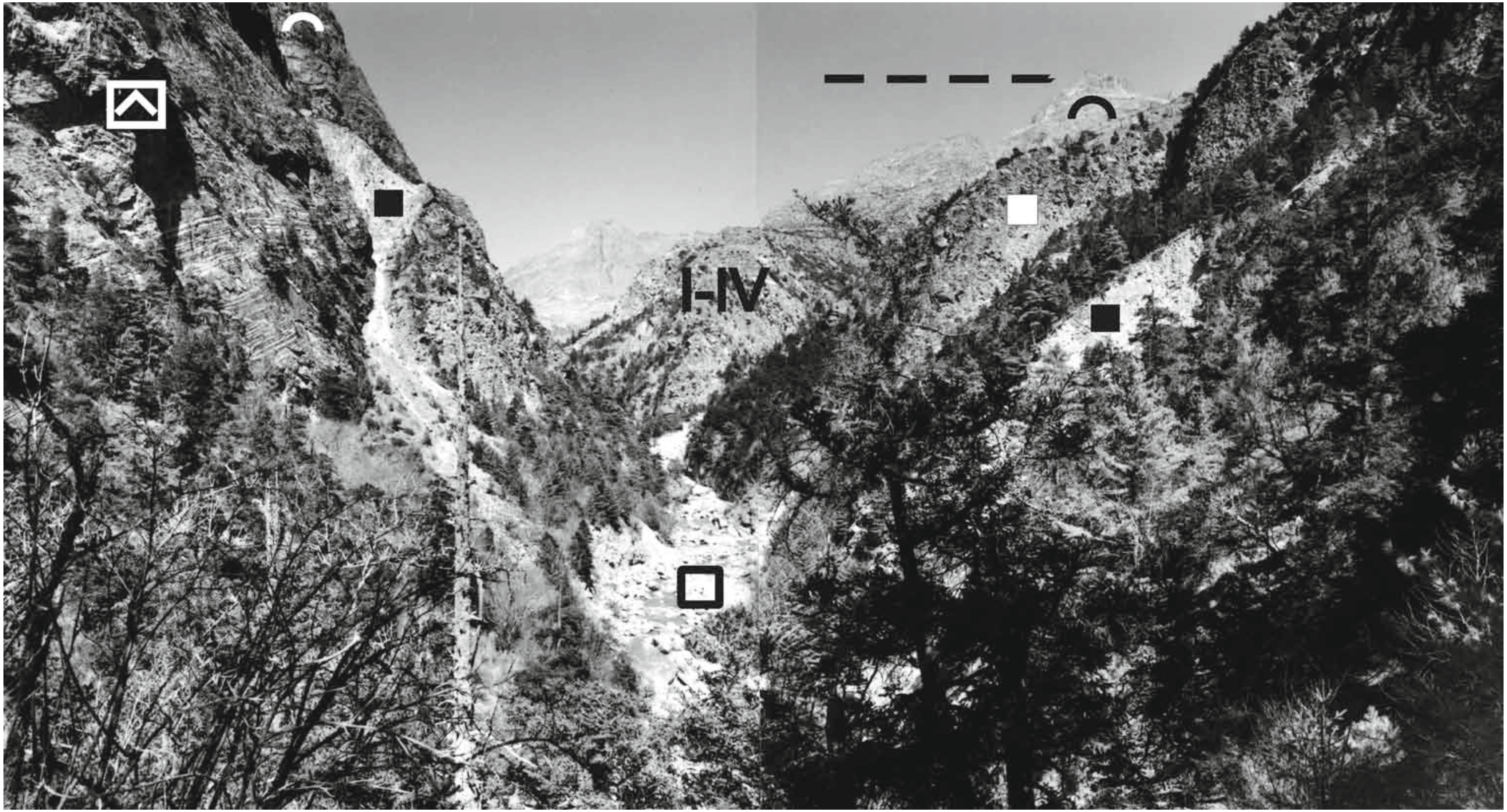


**Photo 13**: C. 115°-panorama at c. 3290 m asl (28°38'34''N/84°14'16''E; map: 1:50 000, No. 2884 05; Fig. 13 Photo 13) from the orographic left valley flank of the Nar Khola in the narrow gorge stretch, from facing WNW (left margin) into the right valley flank, via facing N up-valley (☐), up to facing NE looking into the left valley flank (right margin). (∩) mark glacigenic rock abrasions and -polishings that in places are roughened by overhanging niches of crumblings (⌂) since the deglaciation; (■ and I-IV) show remnants of the c. 200 m-thick Late Glacial (Stages I-IV, Tab. 1) pedestal ground moraine which has filled up the valley in its lowest gorge-like cross-section and has already been cut subglacially - and then even more since the deglaciation - by the Nar river (☐) and excavated into the form of a gorge. (----) signifies the High Glacial (LGP, LGM, Stage 0, Tab. 1) level of the ice stream network about 5150 m asl. Analogue photo M. Kuhle, 09/03/2004.

**Photo 14***:* At c. 3210 m asl (28°37'58''N/84°13'36''E; map: 1:50 000, No. 2884 05; Fig. 13 Photo 14) from the orographic right valley flank of the Nar K. facing SW looking into the left gorge flank and down-valley. (□) signifies a current mountain river and (↗, ○) mark still unweathered past pothole-walls and pothole-half hollows 30-40 m above with overhanging half-hollow roofs (in the shadow); (⌂) are niches of crumblings orientated according to the vertically layered linear elements of the rock structures on the gorge walls. At least 200 m above the talweg, where the basal gorge form with its slightly concave walls peters out towards above, abrasion forms in the shape of convex profile lines are recognizable (∩). The person goes along the gorge wall on a path laid out in boulder clay (ground moraine) that sticks to the rock face. Analogue photo M. Kuhle, 08/03/2004.

The genesis of the pedestal ground moraine filling in the Nar gorge can be understood by the flow dynamics of the glacier. The gorge is too narrow for a passage of a high-viscous glacier. Due to insignificant ice temperature, the viscosity was the highest during the High Glacial (LGP, LGM, Stage 0). At the same time, due to the altitude at or above the ELA, the detachment of ground moraines was lacking and, accordingly, a pedestal moraine. Therefore the gorge was filled with glacier ice, but in some respect it was a sort of dead ice, which had got stuck in the narrow gorge. The real glacier flow of the thick valley glacier concerned, that drained the whole Damodar Himal, took place sheared-off of that ice filling of the gorge, i.e. across it. Accordingly, one has to imagine a dead ice pedestal that under the body of the valley glacier was lying nearly without moving and preserved. It reaches up to the level of the preserved pedestal ground moraine. Above, there was a wider trough valley profile through which the hanging valley glacier ice could flow down on the „pedestal ice" with a comparably poor friction.

With a rising snowline the „dead pedestal ice" has been pseudomorphically replaced by ground moraine as far as to the preserved late Late Glacial pedestal ground moraines. Thus the Late Glacial Nar Khola glacier could also flow down comfortably, i.e. with only little friction, on the higher lying level of the much broader valley receptacle (Photo 13 above I-IV and ■).

The excavation and the substitution of the dead gorge-ice by preserved ground moraine, which necessarily must have happened below the ELA, took place by meltwater. The subglacial meltwater of +0°C flowing down very fast, excavated the glacier ice mechanically, i.e. purely erosively, like rock. This excavation area has been syngenetically filled from the down-flowing hanging glacier bottom by submoraine that changed into ground moraine. This has taken place under a continuous influence of subglacial meltwater, which, however, was concentrated on a bottom line on the outcropping rock ground. This concentration can be deduced from the fact that this ground moraine can easily be eroded, compared with the high resistance of the rock bottom.

Locally the participation of subglacial meltwater in the process of sedimentation can also be recognized by the composition of the grain sizes (sample 09.03.04/3: Fig. 13), where in the massive pedestal ground moraine lentils and nests of pelites (clay and silt) with an up to 26 % portion of clay can be contained and the insignificant sorting coefficient of e.g. So = 2.95 shows a typically fluvial sorting.

Even today, i.e. subaerially and thus without a continuous supply of ground moraines as it has existed subglacially, a still considerable part of the former ground moraine filling of the Nar gorge is preserved (Photo 13). In this the relatively large lime-content of the matrix of 28-34 % has its part, because due to recrystallizations it makes the pedestal ground moraines secondarily more resistant and stable.

In some parts the pre-glacial, i.e. Late Tertiary and interglacial gorge to a great extent has been cleared of the ground moraine. Here, it nearly becomes narrow like a subglacial glacigenic ravine or gorge (Photo 14; Fig. 13). There can be found overhanging alignments of rock as well as pothole walls and pothole-half hollows situated 30-70 m above the Nar-Khola river, as they are characteristic of subglacial cavitation corrasion (Photo 14).

From Metagau down the gorge over a distance of c. 5 km, below and along the approximately 3100 m high and very steep Pisan Peak-E-flank down to 2900 m asl, the Nar gorge is narrowest (Fig. 13). Then it widens into a gorge-like trough, a V-shaped valley with glacigenically, i.e. concavely polished, i.e. abraded valley slopes. So for instance on the orographic right side edges of the strata on vertically stratified phyllites have been back-abraded glacigenically (Fig. 13).

This type of valley cross-profile remains up to the inflow into the Marsyandi Khola main valley. Important remnants of pedestal ground moraines are also preserved and samples have been taken by the author. A higher series of samples is in the junction area of the Soti Khola connected to the orographic left side: Samples 10.3.2004/1-/3 (Fig. 13, Fig. 2 Nos. 47-49).

The two first samples are situated on the orographic left and sample 10.3.04/3 on the orographic right valley side of the Nar (Naur) Khola (see Fig. 13). All three matrixes contain c. 98 to nearly 99 % broken $SiO^2$-grains of the medium sand fraction as well as 1.3-2.3 % fluvially polished quartz-grains, so that as to the morphoscopy they completely correspond to the picture of moraines. Only one case of the compositions of the grain sizes is bimodal and rich in clay (sample 10.3.04/1), where, however, the clay even presents the secondary maximum. All three grain size spectra show a So = 2.13 to 2.85 that as to the most moraine types is too low. However, with regard to the pedestal ground moraines possible here, i.e. which are distinguished by a warm genesis that has taken place under the influence of meltwater, a sorting coefficient like this has often been observed.

The lowest series of samples consists of a sample situated c. 2 km away and a second sample c. 1.5 km away from the Nar Khola valley exit (Fig. 13). Sample 25.2.2004/1 (Fig. 2 No. 50) concerns a debris flow fan of ground moraine redeposited from the orographic right valley flank. Here, the sedimentological characteristics of ground moraine, as e.g. a bimodal course of the grain size cumulative curve, as well as a still high clay portion of 11 % have been preserved. The sorting coefficient So = 3.64 can also be registered in primary moraine sediments. However, it must already have been reduced here - as well as the clay portion - by redeposition. The 95.7 % crushed and 4.3 % polished $SiO^2$-grains, too - despite of redeposition - still mark the original ground moraine matrix.
The down-valley, also orographic right accumulation (sample 25.2.2004/2: Fig. 13 and Fig. 2 No. 51) shows the same geomorphological characteristics of redeposition of morainic material and resedimentation in a debris flow fan; however, the sorting coefficient has been pressed down to So = 2.16 and the content in clay - due to the redeposition - to scarcely more than 3 %. A morphoscopic modification that would make recognizable the dynamics of redeposition from ground moraine to mudflow fan with 96.3 % broken and 3.7 % fluvially polished quartz grains cannot be seen.

Further 0.65 km down-valley (Fig. 13) there are c. 30-50 m-thick, un- disturbed accumulations of ground moraine with high portions of clay. They have been marked as being the most lowest pedestal ground moraine, on the deposition of which the Nar Khola glacier of Stage III has still taken part (I-III). For this an ELA-depression about 800-900 m would be necessary. This can be considered as being probable for Dhampu Stage (III) (cf. Tab. 1). At the same time it means, that between the pedestal ground moraines of 3000 m asl described above (Photo 13: ■ and I-IV) and this position at 2570 m asl the tongue end of the Nar Khola glacier must have lain at the time of Stage IV (Sirkung Stage; Tab. 1). Despite a four-times walking of the Nar Khola gorge the author is not able to locate the ice margin position exactly. Due to the extreme narrowness of the valley, no really unambiguous traces of end moraines have been preserved within the last 13000-13500 years.

However, probably the lake sediments met at the valley exit (Fig. 13; Tab. 1 No. 2) have to be classified as belonging to an ice-dammed lake at the time of the Late Stage III. This lake has been dammed up by the Marsyandi parent glacier and its orographic left lateral moraine. This has taken place during the Late Stage III, when the smaller Nar Khola tributary glacier had already melted back a little from the original confluence with the large Marsyandi main glacier. Only by this process of back-melting the space for the ice-dammed lake has been released.

Above the narrow gorge cuttings and geomorphologically as well as sedimentologically evidenced pedestal ground moraines in the lowest valley section of the Damodar Himal, in the Nar Khola, flank abrasions are preserved in many places (Photo 13 and 14: ∩). Since the ice level had dropped during the Late Glacial and since the complete deglaciation in the Holocene, these have been more and more hurt and roughened by the outbreaking of rock boulders from the polished rock surfaces due to weathering (Photo 13 and 14: ⌂). In some places, however, also more or less well-preserved subglacial meltwater key-forms like remnants of potholes and pothole-half hollows as well as organ-pipe-like subglacially laid out meltwater gorges which have drained the Late Glacial (c. Stages III and IV; Tab. 1) glacier surfaces, have remained and confirm the attached glacier ice on the rock flanks and -walls concerned (Fig. 13; Photo 14).

In the confluence area of the glacial glacier-tributary-streams Phu Khola-, Kanla Khola and Lapse Khola glacier, where these tributary glaciers flow into a joint parent glacier, that is the Nar Khola valley glacier, the High Glacial (LGP, LGM) glacier level at c. 5100-5150 m asl has been diagnosed (see 3.5.). Down the Nar Khola (Nadi) sporadically preserved upper limits of abrasion allow the observation of a gradual depression of the glacier level at that time from at c. 5150 m (Photo 13 ----) over at c. 4950 m and at c. 4600 m asl over a distance of 16 km up to the inflow into the Marsyandi glacier (Fig. 13) down to c. 4600 - 4500 m asl (cf. 2.3.; Photo 6 ---- on the left). There existed an approximately corresponding level of the ice surface with the Marsyandi main glacier in the valley chamber of the Koto (gau) settlement.

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