Table 3. Late Glacial-, Neoglacial- and Historical-glacier positions, snow-line depressions and absolute ages on the south slope of the Cho Oyu Himalayas (see Figure 3 and 19; Table 1)

1	2	3	4	5	6	7	8	9	10	11	12
Location of ice margin (in degrees/minutes/seconds)	Stages III–X and recent	Highest summit (m a.s.l.)	Average altitude of catchment area (m a.s.l.)	Altitude of ice margin (m a.s.l.)	Exposure	Orographic mathematical snow-line (m a.s.l.) (ELA)	Length of glacier (km) measured from the highest point of the catchment area	Recent snow-line altitude (m a.s.l) (ELA)	Snow-line (ELA) depression (m)	C14 age (years before 1950)	Comments
East Khumbui Yul Lha glacier: location: Figure 3 on the left of Panorama 144 (compare with Figure 19)											
27°51′ N/86°44′15″ E	III	5761	ca. 5580	3850	E	4715	2.75	ca. 5600	885	Older than 4165	Dhampu-Stage, late glacial, cirque glacier, 'Breitboden' glacier
27°51′ N/86°44′05″ E	V	5761	4950	5620	E	4935	2.00	ca. 5600	ca. 665	4165	Nauri-Stage, neoglacial, cirque glacier, 'Breitboden' glacier
Dole glacier (hanging valley glacier): location: Figure 3 next to Panorama 142 (compare with Figure 19)											
27°52′ N/86°44′15″ E	IV	5629	5550	3980	E	4765	4.20	ca. 5600	835	Older than 4165	Dhampu-Stage, late glacial
27°52′ N/86°44′ E	V	5629	5559	4230	E	4890	2.40	5600	710	4165	Nauri-Stage, neoglacial
Upper Dole glacier (hanging valley glacier, cirque glacier): location: Figure 3 on the left of Panorama 141 (compare with Figure 19)											
27°52′30″ N/86°43′45″	VI	5629	5600	4400	E	5000	2.70	5600	600	2050–2400	Older Dhaulagiri-Stage, neoglacial
27°52′40″ N/86°42′30″ E	′VII	5629	5610	4680	E	5145	1.70	5600	455	Older than 440 and younger than 2050	Middle Dhaulagiri-Stage, neoglacial
South Luza glacier: location: Figure 3 left of Panorama 139 (compare with Figure 19)											
27°53′ N/86°43′30″ E	V	5726	5630	4330	E	4980	2.50	5600	620	ca. 4165	Nauri-Stage, neoglacial
27°54′ N/86°43′ E	VI	5726	5630	4490	E	5060	1.80	5600	540	2050–2400	older Dhaulagiri-Stage, neoglacial
27°53′20″ N/84°42′05″ E	Recent	5726	5660	5440	E	5550	0.30	5550	0	Recent	S (m) descends further down in the wind screen of the cirque form than at older stages
North Luza glacier: location: Figure 3 left of Panorama 138 (compare with Figure 19)											
27°53′30″ N/86°43′35″ E	V	5726	5630	4340	E	4985	2.80	5600	615	ca. 4165	Nauri-Stage, neoglacial
27°53′35″ N/86°43′20″ E	VI	5726	5630	4450	E	5040	2.00	5600	560	2050–2400	older Dhaulagiri-Stage, neoglacial
27°53′35″ N/86°43′15″ E	VII	5726	5650	4600	E	5125	1.50	5500	375	Younger than 2050	Middle Dhaulagiri-Stage, neoglacial
27°53′35″ N/86°43′10″ E	′VII	5726	5650	4700	E	5175	1.25	5500	325	ca. 440?	Younger Dhaulagiri-Stage, recent
27°53′25″ N/86°42′25″ E	VIII	5726	5660	5000	E	5330	1.00	5450	120	ca. 320	Youngest Dhaulagiri-Stage, recent 320 years + time needed for plant settlement

27°53′20″ N/86°42′10″ E	Recent	5726	5660	5100	E	5380	0.70	5380	0	Recent	S (m) descends further down in the wind screen of the cirque form than at older stages
Machhermo glacier: location: Figure 3 half-left above of Panorama 134 (compare with Figure 19)											
27°54′N/86°43′40″ E	VI	6186	5800	4400	ESE	5100	7.20	5550	450	ca. 2350 ± 295	Older Dhaulagiri-Stage, stepped valley glacier (2 levels)
27°54′32″ N/86°47′ E	′VII	6186	5800	4560	ESE	5180	4.60	5550	370	Younger than 2050	Middle Dhaulagiri-Stage, older than 440 years, stepped hanging trough glacier
South Machhermo glacier: location: Figure 3 on the left of Photo 136 (compare with Figure 19)											
27°54′30″ N/86°41′10″ E	VII or VIII	6186	5880	4960	NE	5420	1.50	5565	145	ca. 320–440	Younger or youngest Dhaulagiri-Stage hanging glacier with 2 firn basins
27°54′30″ N/86°41′20″ E	Recent	6100	5780	5120	N	5450	0.80	5450	0	Recent	S (m) descends further down in the wind screen of the cirque form than at older stages
27°54′40″ N/86°40′50″ E	Recent	6186	5940	5190	E	5565	0.85	5565	0	Recent	S (m) descends further down in the wind screen of the cirque form than at older stages
North Machhermo glacier: location: Figure 3 on the left of No. 69 (compare with Figure 19)											
27°54′40″ N/86°41′45″ E	VII	6073	5750	4900	SE	5325	3.30	5530	205	ca. 440	High valley glacier with some avalanche nourishment; tongue hangs down steep slope
27°54′55″ N/86°41′05″ E	Recent	6073	5800	5250	SSE	5525	2.70	5525	0	Recent	S (m) descends further down in the wind screen of the cirque form than at older stages
East Pa Ri glacier: location: Figure 3 on the left of Photo 132 (compare with Figure 19)											
27°55′05″ N/86°42′30″ E	VI	6073	5700	4570	E	5135	2.65	5630	495	ca. 2050–2400	Presently avalanche caldron glacier, formerly a hanging valley glacier
27°55′20″ N/86°42′25″ E	′VII	6073	5750	4760	E	5255	1.90	5630	375	Younger than 2050 older than 440 years	Increasing portion of avalanche nourishment
27°55′30″ N/86°42′ E	VII	6073	5800	4840	E	5340	1.25	5630	290	ca. 440	Hanging glacier with avalanche nourishment
27°55′30″ N/86°41′43″ E	VIII	6073	5900	5080	E	5490	1.10	5630	140	ca. 320	Hanging to wall glacier with avalanche nourishment
27°55′30″ N/86°41′40″ E	Recent	6073	5900	5120	E	5510	1.00	5510	0	Recent	S (m) descends further down in the wind screen of the cirque form than at older stages

Table 3. Continued

1 Location of ice margin (in degrees/minutes/seconds)	2 Stage III–X and recent	3 Highest summit (m a.s.l.)	4 Average altitude of catchment area (m a.s.l.)	5 Altitude of ice margin (m a.s.l.)	6 Exposure	7 Orographic mathematical snow-line (m a.s.l.) (ELA)	8 Length of glacier (km) measured from the highest point of the catchment area	9 Recent snow-line altitude (m a.s.l) (ELA)	10 Snow-line (ELA) depression (m)	11 C14 age (years before 1950)	12 Comments
Northeast Pa Ri glacier: location: Figure 3 half-left below of Photo 127 (compare with Figure 19)											
27°56′25″ N/86°42′ E	′VII	6073	5900	4720	NE	5310	2.20	5480	170	Younger than 2050 older than 440	Wall-foot glacier with avalanche nourishment; ice core preserved by thick upper moraine block cover
27°56′15″ N/86°41′40″ E	VIII	6073	5950	4880	NE	5415	1.40	5480	65	ca. 320	mean elevation of catchment area shifts more and more toward summit
27°56′N/86°41′30″ E	IX	6073	5950	5020	NE	5435	1.25	5480	45	Younger than 320	Elevation of catchment area shifts more and more toward summit
27°56′N/86°41′20″ E	Recent	6073	5950	4950	NE	5450	1.15	5450	0	Recent	Calculated S (m) is ca. 30 m too low due to the avalanche nourishment of the wall-foot glacier
East Gokyo glacier: location: Figure 3 half-left below of Panorama 131 (compare with Figure 19)											
27°51′N/86°41′50″ E	VI	5977	5600	Deeper than 4740	E	Deeper than 5170	5.20	5450	Over 280	2050–2400	confluence with the main Ngozumpa glacier, thus no end moraines
27°57′N/86° 41′ 20″ E	′VII	5977	5600	4730	E	5165	4.40	5450	285	Older than 1165 younger than 2050	Hummock in tongue basin dated to be 1165 ± 110 years
5977-m summit glacier (South Gokyo glacier): location: Figure 3 half-left above of Photo 127 (compare with Figure 19)											
27°56′55″ N/86°40′15″ E	Recent	5977	5700	5150	N	5425	1.60	5425	0	Recent	S (m) descends further down in the wind screen of the cirque form than at older stages
East Gokyo glacier, northern source component: location: Figure 3 on the left of Panorama 130 (compare with Figure 19)											
27°57′15″ N/86°40′35″ E	VII	5941	5650	4920	SE	5325	3.00	5450	125	ca. 440	Large cirque glacier; age correlated with the neighbouring ice margin position
27°57′20″ N/86°40′ E	VIII	5941	5650	5080	SE	5365	2.20	5450	85	ca. 320	large cirque glacier; age correlated with the neighbouring ice margin position

27°57′20″ N/86°39′35″ E	IX	5941	5650	5140	SE	5395	1.70	5450	55	Younger than 320	large cirque glacier; age correlated with the neighbouring ice margin position; 1820–1850-Stage?
5941-m summit southeast glacier: location: Figure 3 on the right of No. 72 (compare with Figure 19)											
27°57′30″ N/86°39′50″ E	Recent	5941	5650	5190	SE	5420	1.60	5420	0	Recent	S (m) descends further down in the wind screen of the cirque form than at older stages
East Donag glacier: location: Figure 3 right above of No. 72 (compare with Figure 19)											
27°58′30″ N/86°41′20″ E	VI–V	5977	5650	Deeper than 4840	E	Deeper than 5245	5.90	5500	Over 255	ca. 2050	Confluence with the main Ngozumpa glacier, thus no end moraine
Partial flow from 5800-m summit (Donag glacier): location: Figure 3 on the left of Photo 124 (compare with Figure 19)											
27°58′30″ N/86°40′25″ E	V	5800	5600	4920	S	5260	2.30	5850	590	ca. 4165	Steeper, narrow adjacent-valley glacier (cirque-gorge glacier)
27°59′10″ N/86°40′30″ E	′VII	5800	5630	5240	S	5435	1.40	5850	415	Older than 440 younger than 2050	Steeper, narrow adjacent-valley glacier (cirque-gorge glacier)
27°59′25″ N/86°40′10″ E	VII	5800	5740	5400	S	5570	0.75	5850	280	ca. 440	Wall-foot or cirque glacier
Partial flow from 5813-summit (Donag glacier): location: Figure 3 on the left of Photo 123 and below of No. 71 (compare with Figure 19)											
27°58′30″ N/86° 40′ 25″ E	′VII	5813	5650	4880	SE	5265	3.70	5540	275	Older than 440 younger than 2050	Thin, wide large cirque glacier
27°58′55″ N/86°40′E	VII	5813	5650	5070	SE	5360	2.70	5540	180	ca. 440	Large cirque glacier
27°59′20″ N/86°39′50″ E	VIII	5813	5680	5200	SE	5440	1.80	5540	100	ca. 320	Moderately steep stepped cirque glacier
27°59′30″ N/86°40′ E	IX	5813	5680	5260	ESE	5470	1.90	5540	70	Younger than 320	1820–1850-Stage? Unsure whether it is balanced
28° 00′ N/86° 39′ 30″ E	Recent	5813	5680	5400	ESE	5540	1.55	5540	0	Recent	Ice margin calculated from 2 tongue termini (averaged)
Partial flow from 5977-m summit (Donag glacier): location: Figure 3 half-left below of No. 71 (compare with Figure 19)											
27°58′25″ N/86°40′05″ E	′VII	5977	5760	4920	SE	5340	4.30	5540	200	Older than 440 younger than 2050	Thin, wide, stepped large cirque glacier
27°58′20″ N/86°39′55″ E	VII	5977	5760	5000	SE	5380	3.50	5540	160	ca. 440	Thin, wide, stepped large cirque glacier
27°58′40″ N/86°39′45″ E	VIII	5977	5820	5070	SE	5445	3.15	5540	95	ca. 320	Thin, wide, stepped large cirque glacier
27°58′50″ N/86°39′30″ E	IX	5977	5820	5140	SSE	5480	2.70	5540	60	Younger than 320	1820–1850 shade? Cirque glacier
27°59′20″ N/86°40′25″ E	Recent	5977	5820	5260	SSE	5540	2.00	5540	0	Recent	‘Cirque gorge’ glacier, stepped
Partial flow from 5941-m summit (Donag glacier): location: Figure 3 half-right above of No. 72 (compare with Figure 19)											
27°58′20″ N/86°40′30″ E	′VII	5941	5700	4920	NE	5310	2.70	5560	250	Older than 440 younger than 2050	
27°58′15″ N/86°40′ E	VII	5941	5700	5010	NE	5355	2.10	5560	205	ca. 440	Wall-foot glacier with at least 50% avalanche nourishment

Table 3. Continued

1	2	3	4	5	6	7	8	9	10	11	12
Location of ice margin (in degrees/minutes/seconds)	Stage III–X and recent	Highest summit (m a.s.l.)	Average altitude of catchment area (m a.s.l.)	Altitude of ice margin (m a.s.l.)	Exposure	Orographic mathematical snow-line (m a.s.l.) (ELA)	Length of glacier (km) measured from the highest point of the catchment area	Recent snow-line altitude (m a.s.l) (ELA)	Snow-line (ELA) depression (m)	C14 age (years before 1950)	Comments
27°58′15″ N/86°38′55″ E	VIII	5941	5700	5040	NE	5370	1.55	5560	190	ca. 320	Wall-foot glacier of the avalanche cone type (Kuhle, 1982: 173)
27°58′15″ N/86°39′30″ E	IX	5941	5300	5150	NE	5475	1.10	5560	85	Younger than 320	Wall-foot glacier, avalanche cone glacier
27°58′05″ N/86°39′15″ E	Recent	5941	5820	5310	NE	5565	0.45	5565	0	Recent	1820–1850-Stage?
Kendezhung glacier: location Figure 3 next to Photo 123 (compare with Figure 19)											
28°00′05″ N/86°41′20″ E	VI	5927	5689	Deeper than 4970	E	Deeper than 5325	Min 4.00	5520	Over 195	ca. 2050–2400	Confluence with main Ngozumpa glacier, thus no sure end moraines
28°00′40″ N/86°40′20″ E	′VII	5927	5680	5030	E	5355	2.05	5520	165	Older than 440 younger than 2050	Consists of 3 partial flows with very little avalanche nourishment
28°00′35″ N/86°39′50″ E	VII	5927	5680	5140	E	5410	1.40	5520	110	ca. 440	Large cirque glacier
28°00′30″ N/86°39′30″ E	VIII	5813	5660	5250	ENE	5455	0.80	5480	25	ca. 320	Wall-foot glacier with avalanche nourishment; block glacier tongue still active today
28°00′20″ N/86°39′20″ E	Recent	5813	5660	5300	NE	5480	0.60	5480	0	Recent	Avalanche cone glacier (Kuhle, 1982: 173)
5800 m-summit north glacier: location: Figure 3 half-left above of Photo 123 (compare with Figure 19)											
28°00′30″ N/86°39′55″ E	VII	5800	5700	5180	N	5440	1.40	5520	80	ca. 440	Steep hanging valley glacier, lacking avalanche supply
28°00′10″ N/86°39′45″ E	Recent	5800	5640	5400	N	5520	1.00	5520	0	Recent	Steep hanging valley glacier, lacking avalanche supply
5885 m-summit south glacier: location: Figure 3 half-right above No. 71 (compare with Figure 19)											
28°00′35″ N/86°39′45″ E	VII	5927	5750	5150	S	5450	1.80	5550	100	ca. 440	Short trough or hanging valley glacier with avalanche nourishment
28°00′50″ N/86°39′50″ E	VIII	5885	5700	5300	S	5500	1.20	5550	50	ca. 320	Short trough or hanging valley glacier with avalanche nourishment
28°01′05″ N/86°39′55″ E	Recent	5885	5750	5350	S	5550	0.65	5550	0	Recent	Wall-foot glacier

Gyazumpa glacier: location: Figure 3 between No. 71 and Photo 128 (compare with Figure 19)											
28°01′20″ N/86°41′30″ E	′VII	5885	5610	5130	E	5370	3.30	5525	395	Younger than 2050	Stepped valley glacier with very little avalanche nourishment
28°01′40″ N/86°41′ E	VII	5885	5670	5160	E	5415	2.50	5525	110	ca. 440	Firn field or firn depression glacier (after H.J. Schneider, 1962)
28°01′40″ N/86°40′55″ E	VIII	5885	5670	5180	E	5425	2.20	5525	100	ca. 320	Firn field or firn depression glacier (after H.J. Schneider, 1962)
28°01′40″ N/86°40′45″ E	IX	5885	5690	5210	E	5450	1.90	5525	75	Younger than 320	1820–1850-Stage ?
28°01′40″ N/86°40′20″ E	Recent	5885	5720	5330	E	5525	1.30	5525	0	Recent	Avalanche nourishment has relatively increased
Lhabtshan 5560 m-summit south glacier: location: Figure 3 below Panorama 119 (compare with Figure 19)											
28°01′30″ N/86°40′50″ E	VII	5560	5500	5290	S	5395	0.80	5525	130	440	Age plus time needed for plant settlement; cirque glacier; no glacier at present
Southeast Nangpai Gosum glacier: location: Figure 3 above Photo 118 (compare with Figure 19)											
28°02′25″ N/86°40′55″ E	′VII	6500	5720	5230	SE	5475	3.00	5700	225	Older than 440 younger than 2050	Large cirque glacier with some avalanche nourishment
28°02′20″ N/86°40′40″ E	VII	6500	5850	5270	SE	5560	2.00	5700	140	ca. 440	Large cirque glacier with avalanche nourishment
28°02′20″ N/86°40′20″ E	VIII	6500	5900	5320	ESE	5610	1.60	5700	90	ca. 320	Large cirque glacier with avalanche nourishment
Middle glacier tongue: location: Figure 3 half-left far above of Photo 118 (compare with Figure 19)											
28°02′20″ N/86°40′ E	Recent	6500	5970	5470	SE	5720	1.40	5710	0	Recent	Glacier lies in precipitation shadow of the 5560-m summit
W glacier lobe: location: Figure 3 above Panorama 116 (compare with Figure 19)											
28°02′20″ N/86°39′50″ E	Recent	5980	5750	5560	E	5655	0.80	5655	0	Recent	Nearly exclusively primary nourishment (snow)
E glacier tongue: location: Figure 3 half-left far above of Panorama 119 (compare with Figure 19)											
28°02′30″ N/86°40′20″ E	Recent	6500	6060	5320	SE	5690	1.80	5690	0	Recent	Avalanche nourishment predominates
Lungsampa 6066-peak east glacier (south glacier tongue): location: Figure 3 right of No. 67 (compare with Figure 19)											
28°02′05″ N/86°42′30″ E	VIII	6086	5900	5280	ESE	5590	2.20	5650	60	ca. 320	Stepped hanging glacier with diffluence tongue
28°02′20″ N/86°42′25″ E	IX orX	6086	5930	5310	E	5620	1.80	5650	30	Younger than 320	The ice margin still existed in 1955–1963 (Schneider, 1978: Khumbu Himal 1:50,000)
28°02′30″ N/86°42′20″ E	Recent	6086	5950	5350	E	5650	1.40	5650	0	Recent	
Gyuba Tshomoche 5677-m summit NW glacier: location: Figure 3 half-right below Panorama 122 (compare with Figure 19)											
28°01′10″ N/86°43′15″ E	VIII	5677	5600	5100	NW	5350	2.30	5420	70	ca. 320	Shallow hanging glacier without upper moraine
28°01′N/86°43′30″ E	IX	5677	5600	5160	NW	5380	1.70	5420	40	Younger than 320	1820–1850 or 1920-Stage

Table 3. Continued

1 Location of ice margin (in degrees/minutes/seconds)	2 Stage III–X and recent	3 Highest summit (m a.s.l.)	4 Average altitude of catchment area (m a.s.l.)	5 Altitude of ice margin (m a.s.l.)	6 Exposure	7 Orographic mathematical snow-line (m a.s.l.) (ELA)	8 Length of glacier (km) measured from the highest point of the catchment area	9 Recent snow-line altitude (m a.s.l) (ELA)	10 Snow-line (ELA) depression (m)	11 C14 age (years before 1950)	12 Comments
28°00′35″ N/86°43′45″ E	Recent	5677	5600	5240	NW	5420	1.20	5420	0	Recent	
5913-m summit NW glacier: location Figure 3 half-left below of No. 15 (compare with Figure 19)											
28°01′10″ N/86°44′ E	IX	5913	5800	5230	NW	5515	1.30	5535	20	Younger than 320	1820–1850 or 1920-Stage
28°01′05″ N/86°44′10″ E	Recent	5913	5689	5270	NW	5535	1.10	5535	0	Recent	Hanging glacier with bare ice tongue
5913-m summit SSW glacier: location Figure 3 far above of No. 57 (compare with Figure 19)											
28°00′10″ N/86°44′30″ E	VIII	5913	5850	5360	SSW	5605	1.50	5660	55	ca. 320	Wall-foot glacier tongue, avalanche nourishment
28°00′15″ N/86°44′35″ E	Recent	5913	5850	5470	SSW	5660	1.30	5660	0	Recent	Wall-foot glacier tongue, avalanche nourishment; snow-line drop of ca. 125 m from S to N
SSW Kangchung glacier: location Figure 3 right of Panorama 125 (compare with Figure 19)											
27°57′45″ N/86°42′35″ E	VI	6089	5700	4780	SSW	5240	3.40	5720	480	ca. 2050–2400	Valley glacier with avalanche nourishment, avalanche caldron
27°57′50″ N/86°43′ E	′VII	6089	5700	5040	SSW	5370	2.40	5720	330	Older than 440 younger than 2050	Glacier with debris covered tongue
27°58′15″ N/86°43′20″ E	VII	6089	5880	5120	SSW	5500	1.80	5720	220	ca. 440	Composed of several avalanche cones; avalanche cone glacier
27°58′20″ N/86°43′30″ E	VIII	6089	5920	5240	SSW	5580	1.30	5720	140	ca. 320	Consists of several avalanche cones, avalanche cone glacier
SE tongue: location Figure 3 below No. 57 (compare with Figure 19)											
27°58′15″ N/86°43′35″ E	VIII	6040	5900	5230	SSW	5565	1.25	5720	155	ca. 320	Avalanche cone glacier
27°58′30″ N/86°43′40″ E	Recent	6040	6000	5440	SSW	5720	0.85	5720	0	Recent	Avalanche cone glacier
Kangchung S glacier (Nyimagawa glacier): location Figure 3 far below of No. 57 (compare with Figure 19)											
27°55′30″ N/86°43′20″ E	V	6103	5600	Deeper than 4600	S	Deeper than 5100	Over 7.00	5595	Over 495	ca. 4165	Confluence with the Ngozumpa main glacier

27°55′45″ N/86°43′30″ E	VI	6103	5600	4760	S	5180	6.70	5595	415	ca. 2050–2400	valley glacier with connected hanging glaciers and firn depressions so that there are different exposures involved
27°56′15″ N/86°44′15″ E	′VII	6103	5600	4930	S	5265	4.60	5595	330	Older than 440 younger than 2050	Valley glacier with connected hanging glaciers and firn depressions so that there are different exposures involved
27°57′10″ N/86°44′30″ E	VII	6103	5600	5080	S	5340	3.30	5595	255	ca. 440	Primary nourishment through snow fall is dominant
27°57′25″ N/86°44′30″ E	VIII	6103	5650	5200	S	5425	3.00	5595	170	ca. 320	Primary nourishment through snow fall is dominant
27°58′05″ N/86°44′30″ E	IX	6103	5680	5310	SSE	5495	1.50	5595	100	Younger than 320	1820–1850-Stage? bare ice tongue
27°58′30″ N/86°44′20″ E	X	6103	5750	5360	SSE	5555	1.35	5595	40	Subrecent	1900–1920-Stage or even younger
27°58′35″ N/86°44′15″ E	Recent	6103	5800	5390	SSE	5595	1.00	5595	0	Recent	
Nyimagawa glacier, E tongue which flows down from the 5540-m anticline: location: Figure 3 half-right below No. 57 (compare with Figure 19)											
27°57′59″ N/86°44′40″ E	X	6103	5590	5210	SSW	5400	1.55	5415	15	Subrecent	1900–1920-Stage or even younger
27°58′15″ N/86°44′42″ E	Recent	6103	5590	5240	SSW	5415	1.00	5415	0	Recent	
Jobo Lhaptshan W glacier from Stage VI and older confluence with the Nyimagawa glacier: location Figure 3 left above of No. 53 and right above of Photo 133 (compare with Figure 19)											
27°54′50″ N/86°43′30″ E	′VII	6440	5700	4560	W	5130	4.40	5500	370	Older than 440 younger than 2050	Firn caldron glacier composed of 2 flows
27°55′10″ N/86°43′45″ E	VII	6440	5700	4700	W	5200	4.10	5500	300	ca. 440	Firn caldron glacier composed of 2 flows
Northern W glacier: Location Figure 3 far half-left above of No. 53 (compare with Figure 19)											
27°55′55″ N/86°44′30″ E	VIII	5939	5650	4900	W	5275	2.40	5360	85	ca. 320	Combinations of hanging and avalanche cone glacier
27°55′52″ N/86°44′40″ E	IX	5800	5650	4950	W	5300	2.00	5360	60	Younger than 320	1820–1850?
27°55′52″ N/86°45′05″W	Recent	5800	5700	5020	W	5360	1.30	5360	0	Recent	Hanging glacier with bare ice tongue
Southern W glacier: location Figure 3 left above of No. 53; Photo 133 (compare with Figure 19)											
27°55′20″ N/86°44′25″ E	VIII	6440	5860	4750	W	5305	3.00	5420	115	ca. 320	Hanging glacier with little avalanche nourishment
27°55′15″ N/86°44′25″ E	IX	6440	5930	4920	W	5425	2.00	5500	75	Younger than 320	1820–1850?
27°55′15″ N/86°45′03″ E	Recent	6440	6000	5000	W	5500	1.65	5500	0	Recent	S (m) shifts up the lee side of the cirque basin (5420–5500)
Jobo Lhaptshan SW glacier from V and older, confluence with the Ngozumpa glacier): location: Figure 3 half-right above of Panorama 134 (compare with Figure 19)											
27°54′40′ N/86°43′30″ E	V	5540	5240	ca. 4400	SW	4820	2.45	5500	680	ca. 4165	Contact with the Ngozumpa glacier through a ground moraine ramp (platform moraine) (Kuhle, 1983a, p. 238)
27°54′40″ N/86°44′05″ E	VI	5540	5240	4760	SW	5000	1.45	5500	500	ca. 2050–2400	

Table 3. Continued

1 Location of ice margin (in degrees/minutes/seconds)	2 Stage III–X and recent	3 Highest summit (m a.s.l.)	4 Average altitude of catchment area (m a.s.l.)	5 Altitude of ice margin (m a.s.l.)	6 Exposure	7 Orographic mathematical snow-line (m a.s.l.) (ELA)	8 Length of glacier (km) measured from the highest point of the catchment area	9 Recent snow-line altitude (m a.s.l) (ELA)	10 Snow-line (ELA) depression (m)	11 C14 age (years before 1950)	12 Comments
27°54′45″ N/86°44′30″ E	′VII	5540	5300	4940	SW	5120	0.80	5500	380	Younger than 2050 older than 440	Increasing avalanche nourishment
Gyalagba glacier (or Tshom glacier): location Figure 3 left below of No. 53 (compare with Figure 19)											
27°53′35″ N/86°43′48″ E	VI	6367	5900	deeper than 4300	WSW	deeper than 5100	over 4.80	5450	over 350	ca. 2050–2400	The glacier overrides the main Ngozumpa glacier: confluence
27°53′35″ N/86°43′48″ E	′VII	6367	5940	4300	WSW	5120	over 4.80	5450	330	Older than 440 younger than 2050	Mix between avalanche caldron and hanging glacier with primary nourishment
27°53′50″ N/86°44′22″ E	VIII	6367	5970	4720	WSW	5345	4.10	5450	105	ca. 320	Stage VII is not confirmed
27°53′57″ N/86°44′30″ E	Recent	6367	6000	4900	WSW	5450	3.70	5450	0	Recent	glacier tongue is thickly covered with debris up to the back wall, transition from avalanche caldron (H.J. Schneider 1962) to avalanche cone glacier (Kuhle, 1982: 173)
5743-m summit SW glacier: location Figure 3 right of Panorama 139 (compare with Figure 19)											
27°53′10″ N/86°44′10″ E	VI	5743	5460	4350	SW	4905	2.70	5450	545	ca. 2050–2400	3 steeper hanging and cirque glaciers
27°53′15″ N/86°44′35″ E	′VII	5743	5520	4620	SW	5070	2.00	5450	380	younger than 2050	Large cirque glacier that transports much moraine material
Konar glacier: location Figure 3 left of No. 40, right of Panorama 144 (compare with Figure 19)											
27°51′25″ N/86°44′43″ E	IV	6542	5800	3720	S	4760	5.90	5525	765	older than 4165	Glacier flowed down from a stepped short trough over a confluence step into the main valley
27°51′35″ N/86°45′E	V	6542	5840	4000	S	4920	5.25	5525	605	ca. 4165	Avalanche nourishment increased proportionally with glacier retreat
27°51′52″ N/86°45′37″ E	VI	6542	5980	4150	S	5065	4.40	5525	460	2050–2400	Avalanche nourishment increased proportionally with glacier retreat
27°52′21″ N/86°45′45″ E	VII	6542	6140	4580	S	5360	3.40	5525	165	ca. 440	Avalanche nourishment increased proportionally with glacier retreat

27°52′37″ N/86°45′52″ E	VIII	6542	6200	4780	S	5490	2.80	5525	35	ca. 320	Avalanche nourishment increased proportionally with glacier retreat
27°52′42″ N/86°45′53″ E	Recent	6542	6230	4820	S	5525	2.70	5525	0	Recent	largely debris-covered glacier tongue
Ngozumpa main glacier (now comprised of components of Lungsampa, Ngozumpa and Gyubanare glaciers): location: Figure 3 between Nos. 4, 9, 7, 66, 15 and Panorama 148 (compare with Figure 19)											
27°51′12″ N/86°44′45″ E	IV	8202	7300	3580	S	5440	30.20	6000	560	older than 4165	Sirkung-Stage, late glacial
27°52′N/86°44′20″ E	V	8202	7300	3780	S	5540	28.70	6000	460	ca. 4165	dominant exposition is south
27°51′08″ N/86°43′30″ E	VI	8202	7350	4200	S	5775	25.10	6000	225	ca. 3345–4550	Mix between dendritic valley glacier composed of firn caldron, firn flow and firn field glacier
27°55′ 40″ N/86°43′ 10′ E	′VI	8202	7350	4280	S	5815	24.10	6000	185	ca. 2050	On the lateral moraines of Stage VI or ‘VI Rhizocarpon geographical with Ø up to 25 cm (2000–3000 years old) is growing / years
27°55′ 08″ N/86°43′ 00″ E	′VII	8202	7400	4380	S	5890	23.30	6000	110	younger than 2050	Since about the middle age only the surface level has changed, not the ice margin. Exception: small-scale lateral breakouts of the glacier tongue.
27°55′11″ N/86°43′00″ E	VII	8202	7400	4560	S	5980	22.40	6000	20	ca. 440	Since about the middle age only the surface level has changed, not the ice margin. Exception: small-scale lateral breakouts of the glacier tongue.
27°55′25″ N/86°43′00″ E	VIII-recent	8202	7400	4600	S	6000	22.25	6000	0	ca. 320-recent	Since about the middle age only the surface level has changed, not the ice margin. Exception: small-scale lateral breakouts of the glacier tongue.

corresponding altitude of the cirque level between 3300 and 3600 m a.s.l. (Photo 26; Figure 11 on the right and half-right above No. 46). The Kasuwa glacier, which in an extreme windward position is exposed to precipitation, testifies to a local Ice Age ELA at only just 3025 m a.s.l. (2.3.).

The Arun parent glacier is at the same time an outlet glacier from the margin of the S-Tibetan ice stream network (2.4.). Thus, the Himalaya lee-side with its snow-line about 4200–4300 m (cf. Figure 17), has also been considered with regard to the joint lowest ice margin position at 450 m a.s.l. An averaging of the orographic snow-lines in windward- and leeward positions yields an ELA at ca. 3640 m a.s.l. (4250−3025 = 1225; 1225:2 = 612.5; 3025 + 612.5 = 3637.5). A favourable factor, which despite this snow-line – which against the 3500 m-ELA (see above) calculated for the Himalaya SSE-slope was 140 m-higher – enabled the Arun outlet- and parent glacier to extend down to 450 m a.s.l., is the ca. 1300–2000 m-thickness of the Ice Age ice stream network on the S-margin of Tibet (2.4.). This feed-back self-heightening of the cold-based ice stream network due to the flat gradient of discharge, must have been the cause for a secondary heightening and extension of the feeding areas.

As for the lowest ice margin position at 450 m a.s.l. (see above) the High Glacial snow-line of the Arun glacier established about 3500 m a.s.l. (see above) corresponds to a medium height of the glacier feeding area of 6550 m (3500−450 = 3050; 3500 + 3050 = 6550). This applies approximately to the catchment area built up from S-Tibet and the High Himalaya which here rises up to 8481 (8475) m. Comparable heights of catchment areas made up of N- and S-slope have also been calculated for the Dhaulagiri- and Annapurna Himalaya (Kuhle, 1982, pp. 150–152) and the Mt. Everest- and Shisha Pangma massifs (Kuhle, 1986g: 443–452, Tab. 3; 1988b: 468–470).

In the Kangchendzönga massif 100 km further to the E, the reconstructed High Glacial ELA ran at about 3900 m a.s.l., i.e. ca. 400 m-higher than in this investigation area. According to the current state of knowledge the reconstructed snow-line in the Kangchendzönga massif amounted to ca. 1660 m (Kuhle, 1990: 420), i.e. 290 m less than the ELA-depression of 1950 m calculated for this research area.

From the last High Glacial maximum, i.e. the last glacial period (Würm or Stage 0) up to the contemporary glacier margins, 14 glacier positions marked by glacier advances in High Asia are established in Table 1. Only part of it has been preserved by unambiguous advance moraines (Figures 3 and 11) in the narrow, sometimes gorge-like valley courses of the Barun- and Irkhuwa Khola as well as the Arun Nadi. Since deglaciation large parts of the older, i.e. mainly Late Glacial, moraines have been fluvially reshaped or completely removed in these valleys exposed to a monsoonal precipitation about 4000 mm/per year. In some places only the corresponding glacier mouth gravel floors (gravel fields, sanders) have been left behind as terrace remnants (Figure 11). Beyond these 14 stages, which can be evidenced in many mountain areas of High Asia (Kuhle, 1986g: 443–452, Tab. 3; 1998a, two further glacier stages have been met in the Dhaulagiri- and Annapurna Himalaya situated 350 km further W. They have been classified as pre-Ghasa Stagnation 1 and 2 (Kuhle, 1982: 153) and mark early Late Glacial stagnations in the state of thawing out which lasted long enough so that kames- terraces and similar bank forms could develop as indicators of ice margins without glacier advance. In the Arun Nadi, too, at least one locality is situated which can be approached as being a lateral moraine ledge of the advance of the Ghasa-Stage (Photo 32 ■ I), but also as a bank formation of a pre-Ghasa Stagnation. Correspondingly, the numbering of the gravel floors (gravel field, sander; Table 1) would also shift, if during a pre-Ghasa Stagnation a similar accumulation of gravels might have occurred than at the advance of Ghasa Stage (I). However, according to the theory, this variation has to be ruled out, because glaciofluvial gravel accumulations are dependent on glacier advances. They are not due to a reduced process of thawing out – hence the expression 'advance gravels'.

3. The highest former trim-lines and glacier thicknesses in the Khumbu Himalaya: Mt. Everest, Lhotse- and Cho Oyu-S- and W-slopes

The glaciation history of the Khumbu Himal, i.e. of the Himalaya- and especially of the Mt. Everest-S-slope can only be reconstructed and understood if one also has a detailed knowledge of the N-slope of the area, because the High- to Late Glacial ice stream networks on the Tibetan side of the Mt. Everest-massif here, too, were connected to the Himalaya S-side and have run over into the S-slope. The author has undertaken two three-month expeditions, one of two-months and a one-month expedition to the areas connected in this respect: in 1982 to the Khumbu-area, in 1984 to the Mt. Everest-N-side to S-Tibet, in 1996 to the N-side of Cho Oyu and S-Tibet and, for further details, in 2003 again to the Mt. Everest-S- and to the Cho Oyu-W-side (Kuhle, 1988b, 1991a, 1999b). The reconstruction of the Ice Age glaciation has led to a S-Tibetan connected ice stream network, the outlet glaciers of which have flowed down through the Arun Nadi (see above 2.4.7) and across the Rapui La into the Karma Chu (Figures 4 and 11) into the S-slope, as well as via the Lho La transfluence pass (Figure 3 No. 50) into the Khumbu valley and across the Nangpa La (or Khumbu La, No. 62, 5716 m) into the upper Bhote Koshi or Nangpa Drangka. The knowledge of these transfluences proves that the Ice Age glacier feeding areas were much more extended than the crest fringes of the contemporary, comparably small and thin valley glaciers. Today the glaciers are mainly fed by avalanches. During the last glacial period (Stage

0 to IV, Table 1), however, it was mainly the primary precipitation of snow which fell down on the decakilometres-long ramifications of the ice stream network N and also S of the Himalaya main ridge. The increasing thickness of the separate branches of the valley glaciers caused the glacier network to merge and the outlet glaciers to flow from the N- to the S-slope and thus to contribute to the feeding. These are the results published so far.

Now we have to take a look at the separate glacier connections from the N- to the S-slope at the valley heads of the areas of the S-slope discussed here.

3.1. Reconstruction of the Ice Age glacier supply from Tibet, i.e. from the Mt. Everest-N-slope with the Rongbuk glacier

Currently two saddles at the sources of the East Rongbuk- and the Rongbuk glacier, the 6548 m-high Rapui La (Figure 3 and Photo 53 No. 51) and the 6026 m-high Lho La (No. 50) form the lowest points of the ice divides between Everest-N- and S-slope. The Rapui La mediates into the Karma Chu which leads into the Arun Nadi (Figures 4 and 11); the Lho La into the Khumbu Drangka (Khola) (Photo 53 on the left below No. 14) and further down into the Imja Drangka and Dudh Koshi. Glacier ice with a thickness of a few decametres still flows today over the two saddles into the Himalaya-S-slope (Photo 54 No. 50; Photo 55 below No. 49; Photo 56 on the left below No. 52; Photo 57 below No. 6; Kuhle, 1988b). The 7066 m-high Chang La (Photo 53 No. 49) is the local ice divide between East Rongbuk- (on the left of No. 49) and Rongbuk glacier (on the right of No. 49). It is already situated on the Tibetan side of Mt. Everest. As has been empirically reconstructed in detail (Kuhle, 1988b: 493–507), the existence of the S-Tibetan ice stream network has caused a heightening of the glacier surface above the Lho La by ca. 450 m (ibid.: 506), i.e. it lay at ca. 6400–6500 m a.s.l. (Photo 53 on the right; 54 centre). However, here this glacier surface was not the highest one of the Rongbuk glacier – as is the case nowadays above the Lho La – but the lowest one. The direction of ice flow was reversed, so that the height of the glacier surface has increased toward the N, i.e. toward Tibet, and the Rongbuk outlet glacier has flowed down from N to S via the Lho La into the Himalaya S-side. The reason for this was the development of an ice stream network in S-Tibet (Figures 4 and 11). These facts are important with regard to the knowledge and understanding of the huge feeding areas at over 6400 m and – due to feedback-heightening – still higher firn areas. Accordingly, with the Rongbuk glacier discussed here, these S-Tibetan ice stream networks have fed an outlet glacier, which must have been most productive as to the feeding of the Ice Age Khumbu glacier, i.e. the significant High Glacial glacier ice filling of the Khumbu Drangka (see below). Owing to this, the great supply of semi-arid continental cold ice had an important or even the most important part in the extended Ice Age ice filling of the Himalaya-S-slope with its lowest ice margin positions below 1000 m a.s.l.

Due to the incline of the Himalaya S-side the ice level of the Rongbuk glacier has dropped on a large scale toward the Lho La and – because of the 600 m-steep step – on a small scale from the Lho La down to the Khumbu glacier (Photo 56 on the left below No. 52; 57 below No. 6).

Further ca. 300–500 m-thick ice overflows from the N, from the West Rongbuk glacier (Rongbuk Nup glacier), have taken place via the 5985 m-high Nup La (Figure 3 No. 63), the 6146 m-high Pumori La (No. 64) and the 6150 (6126) m-high Lingtren La (No. 65) (Photo 57). The first two lie in the area of the Ngozumpa Drangka (see below).

The glacio-geomorphological indicator of the thickness of the ice flowing over the Lho La (Figure 3 No. 50) is the orographic left undercutting of the Mt. Everest West Ridge (No. 52) by flank polishing. The undercut notch runs at ca. 6500–6450 m a.s.l. (Photo 54 ... below No. 52) and indicates the 450 m-thick ice overflow. During the last glacial period (Stage 0) the ice filling of the relief has naturally led to a levelling, i.e. to the decrease of the relief of the glacier surface. So the glacier surface has nestled – as compared with today – with a flat slope to the 7066 m-high Everest-N-Saddle (Chang-La) (Photo 54 ... on the left of No. 49). Correspondingly, the ice infilling of the Khumbu Drangka has brought about that the Ice Age glacier surface of ca. 6450 m (see above) above the Lho La has fallen away to the Khumbu Drangka with only a flat slope, which has scarcely surpassed the Khumbu valley incline. This provides evidence of the nearly horizontal position of that underpolished notch (Photo 54 ... below No. 52; Photos 55 and 56 ––– on the left below No. 52), so that an only 100–200 m-step has existed from the Lho La down to the then Khumbu glacier.

3.2. The highest former glacier trim-lines and thicknesses in the Khumbu Drangka (valley) between Mt. Everest and Nuptse as well as Lingtren, Pumori, Chumbu, Jobo Laptshan and Taboche (Figure 3 Nos. 1, 8, 54, 14, 19, 53, 40)

The inclination from the upper Khumbu valley (Western Cwm) (Figure 3 between No. 1 and 8) down to the W via the steep step of the current Khumbu ice fall (Photo 56) (between No. 14 and 8) (Figure 10) is correspondingly steep as down from the Lho La. Here, too, the ice infilling has strongly diminished the surface gradient of the Ice Age glacier (Photo 54 ... on the right; Photo 56 ––– on the right below No. 8; Photo 57 ––– on the right below No. 1). The orographic left polish lines are preserved here by glacigenic roundings of abrasion at 6300–6000 m a.s.l. (Figure 10). Corresponding upper limits of abrasion have been observed at ca. 6400 and 6100 m a.s.l. on the orographic right side (Photo 57 –––

on the left of No. 6; Photo 53 ... below No. 14). Below the glacigenic rock roundings and abrasions (◠,∩,◝) the ground moraine cover, at some places attached to the rock in an upward direction, is preserved with decreasing thickness (Photo 57 ■ on the left below No. 65). The abrasions on the pillars and ribs jutting out of the flanks are a strong indicator of the thickness of the parent glacier: due to their relative height (Photo 55, ∩,◝) they cannot have been produced by steep and thus comparably thin hanging glaciers. How little freshly smoothed the Ice Age flank polishings and abrasions may be preserved even on the partly outcropping massive tourmaline granites is proved by the roughenings on both sides of the tongue of the Pumori-S-hanging glacier developed within the last 200 years since their deglaciation (Photo 55 left third).

The wall gorges developed on the glacigenically polished truncated S-spur of Khumbutse only since the High- to Late Glacial deglaciation (Photo 56↓↓ on the right below No. 33) point in the same direction. As is also evidenced by the debris cones (▼) at the exits of the gorges which so far have not been worn down, within only 20,000–10,000 years rock- and ice falls have polished these gullies into the granite wall down to a depth of 10–50 m. This destruction of the polishing, even immediately above the contemporary Khumbu glacier, shows that only remnants of abrasion are available for the reconstruction of the Ice Age glaciation but no large-scale complete forms of flank polishing. The current Khumbu glacier, too, destroys the past glacigenic flank polishing by lateral erosion. This becomes especially clear at the margin of the fast-flowing Khumbu ice fall (ca. 2 m/day have been observed) (between No. 2 and △ below ◝bottom). Here, the past rock smoothings (◝ below) have been and are still undercut. Similar conditions also occur on the orographic left side of the Changri Shar glacier at the southern slope-foot of Pumori where the current glacier margin has undercut past flank abrasion (Photo 58◠ on the left below No. 14).

The two connected glacier cauldrons of the Changri Shar- and Changri Nup glacier had a High Glacial ice filling up to levels between 6000 and 6100 m (Photo 58 – – –,...). From the orographic right side this ice filling flowed into the Khumbu Drangka (Photo 59), but it was also in contact with the S-adjacent Lobuche glacier (... centre of the panorama) via the orographic right notches of the Changri Nup glacier. Glacigenic sharpenings of the crest, similar to those between Changri Nup- and Lobuche glacier, have taken place on the orographic right side of the Ice Age Khumbu glacier. There, too, a transfluence-like contact with the E-adjacent tributary stream of the Ice Age upper Imja glacier has existed (– – –; Figure 3 in the middle between Panorama 62 and No. 8). The sharpening of the crest and the rock pillars has been caused by flank polishing on both sides, brought about by parallel glacier rivers, so that glacial horns and related full forms, interrupted by notches, have been developed (Figure 3 No. 55 and in the middle between Panorama 62 and No. 8).

Obviously the High Glacial ice stream has directly flowed down from the Lho La through the Khumbu Drangka following the valley axis toward the S. This is shown by the orographic left glacial horns and the glacigenically triangular-shaped slopes developed from polished-back mountain spurs (truncated spurs) (Photo 59◠, ∩ left half of the panorama; 61◠,∩,◝). In the course of the upper Khumbu valley discussed here, the indicators and preserved upper limits of abrasion testify to a decrease in height of the glacier trim-line from ca. 6100 to 6000 m (Photo 59 ... and – – – on the left of No. 20; Photo 61 ... on the very left and on the very right) to ca. 5700–5600 m a.s.l. (Photo 59 ... on the right below No. 20 and 40; Photo 61 ____ on the left).

At nine localities postglacial rock crumblings and -avalanches as well as slides have also been observed in the ground moraine material situated on the steep slope (▼, ■ below No. 53,▽; Photos 57, 59 and 63: ▼). They can be explained by the missing abutment of the attached valley glacier ice since the deglaciation and the over-steepening of the slopes by flank polishing. This concerns a postglacial reshaping independent of the rock tending from the Ice Age trough-valley to the interglacial V-shaped valley. Generally and here, too, the ground moraines preserved increase from the valley flanks toward the valley bottom (Photo 60; Figures 20 and 21). Due to altitudes of over 5000 m, and thus a height of 1000–2000 m above the lower limit of solifluction in the area of the permafrost line (Kuhle, 1978a, b; 1982, 1983b; 1984b; 1985c) since the deglaciation reshaping by solifluction has taken and still takes place, as e.g. in the form of solifluction tongues (■) but also by slides of ground moraines (○) and denudative flushing.

The neoglacial to historical lateral moraine landscape of the Khumbu valley (Stages V–XII; see Table 1) and the arrangement of the positions in detail can be taken from the photos and their texts, so that no further explanations are necessary. However, several deposits of ground moraines in high slope- and spur positions, which naturally are very seldom preserved, have to be stressed (Photo 55 and 60 ■, 57■ on the left of No. 8, 59■ below No. 20, 61■ below No. 53, 62 ■ on the left of No. 14).

The orographic right inflow of the Lobuche valley into the Khumbu Drangka and – in the past – of the Lobuche glacier into the Khumbu glacier shows complicated interlockings of High- to Late Glacial with neoglacial to historical deposits of moraines (Photos 62, 63; Figure 3 Panoramas 62, 63). So, the Lobuche glacier has eroded itself simultaneously and in an analogous way into the pedestal ground moraines of Stages IV–V (Table 1) (Photo 62 IV–V) as the Khumbu parent glacier and its other tributaries (Photos 58, 59, 61, 63V, 64V on the left). In many places remnants of the ground or lateral moraine of the neoglacial Stage VI (■ IV) have been buried and modified by the lateral moraines of the historical Stages VII–X (VII–X) (cf. also Photos 59 and 61). However, the main interest is the maximum past ice filling of the valleys for which evidence is provided by the high deposits of moraines (Photo 62 the two ■ on the left of No. 14). Because of their relatively significant thickness of several metres and an absent catchment area for the development of a debris cone, they cannot be mistaken for residual detritus developed *in situ* or locally. As for the moraine remnants on the orographic left ledge in the Lobuche valley (second ■ on the left of No. 14), a secondary cover of coarse boulders (▽) on top of the moraine overlay deriving from crumblings since the deglaciation can be observed (Photo 64 ■ on the right below No. 19). Here, the minimum altitude of the Ice Age glacier surface lies about 5700 m a.s.l. The spatially greater connection of the orographic right flank polishings and polish lines across the junctions of the side valleys in the area of the Lobuche valley and their mountain spurs are shown in Photo 64 (... on the right below No. 19).

In a similar way as the Lobuche side glacier the former hanging glaciers from the cirques on the orographic left side (Photo 63 ○ and ■ on the very right) have been adjusted to the past Khumbu glacier. However, this was only correct when the High Glacial glacier level had decreased from 5700 to 5500 m (the 2 ... in the centre) to a Late Glacial level at ca. 5200 m close to the cirque bottoms. Only then was there sufficient space for a cirque glacier. Before that the Khumbu parent glacier had completely sealed the two cirque forms and was about to polish round the truncated spurs, i.e. glacigenically triangular-shaped slopes (∩ centre) situated in between up to a height of 5500–5700 m (the 2 ... in the centre) and partly to mantle it with ground moraine (Figure 21).

Comparing the current Lobuche- and Khumbu glacier, the importance of glacier-length and volume with regard to the way of glacier reactions to climate variations becomes obvious: the surface of the much more extended Khumbu glacier has dropped during the last decades (Photos 59, 61, 63: □), but the position of the glacier tongue end has not changed (Photo 64 □). The Lobuche glacier, however, has melted back over 1 km since 1955 i.e. 1963 (Photo 62). Besides this difference, it is of importance that the larger part of the feeding area of the Khumbu glacier is situated on steep walls. Accordingly, the uplift of the ELA does not affect the faces and thus feeding to such an extent as in the case of the Lobuche glacier with its flatter feeding areas.

The orographic right flank abrasions of the Khumbu Drangka (Photo 64 ∩ below No. 19) and the ground moraines preserved up the valley flank mediate to the junction with a further orographic right side valley, the Tsholo Drangka and into its orographic left flank (∩ below No. 56; Photo 66 ■ ∩ below No. 57). Here, a continuous glacier trim-line from the Tsholo Drangka into the Khumbu Drangka can be evidenced (... below No. 57; Photo 64 ... below No. 56).

The ca. 8 km-long Tsholo Drangka glacier which joins the Khumbu valley here, has derived from a 5690 m-high saddle at the valley head (Photo 65 below No. 57; Figure 3 on the right of No. 57) still glaciated today, via which a High Glacial transfluence stream from the Ngozumpa glacier has existed. Its orographic right flank, partly consisting of the ENE-faces of the Jobo Laptshan-massif, indicate a continuous polish line up to heights of 5800–5600 m (– – –, ...).

Several of the up to 5939 m-high rock summits towering above have been sharpened to glacial horns by glacigenic undercutting (Figure 3 between No. 57 and 53; Photo 65 the peak on the left of No. 57). The valley bottom is covered by neoglacial to historical ground- and end moraines (Stages V–X, see Table 1) superimposed upon the older High- to Late Glacial ground moraines. They are only cut by the talwegs and the two torrents (↓). With regard to the principle of actualism the basements of ground-, pedestal- or dam moraines built-up by two contemporary glaciers of the Jobo Laptshan-NE-flank are interesting: with its 90 (inner slope) and 180 m-high (outer slope) basement (Photo 66 □) the Tshola glacier dams up the Tshola Tso (lake). The ground moraine basement of the Jobo Laptshan-NE-glacier situated 2 km up-valley is also still currently elevated by the built-up of its basement (Photo 65 left margin).

A fundamentally similar picture provides the tongue end of the Khumbu glacier (Photo 64 □) which, too, lies on a historical (Stages VII–X) basement of ground moraine.

Due to the debris accumulations in the valleys, understandable by the past glaciations (e.g. Tshola Drangka; Photo 65), the modern pedestal glaciers mentioned above also point to the former ice filling of the relief. As will be increasingly shown (see below and Section 3.3) by ground moraine pedestals, e.g. in the Imja Khola, verifiable for the High Glacial of the last glacial period (Würm, Stage 0) and the following Late Glacial, these are also an indication of the pre-last (Riß, Stage -I; Table 1) and still older pleistocene periods of glaciation (Günz, Mindel etc.).

Down-valley of the Khumbu glacier on the orographic right side a terrace of a ground moraine pedestal belonging to the youngest Late Glacial (Sirkung Stage IV) continues up to the Imja Khola junction (Photos 64 and 66 IV; Figure 3 IV half-right above No. 40). On the valley slopes of this lower section of the Khumbu Drangka flank abrasions have been preserved up to a polish line at 5500 m (Figure 22) (Photo 64 ∩ white; 66 ∩ black below No. 40).They are covered by High- to Late Glacial ground moraines up to a good 5000 m a.s.l. (■ below No. 19; Photo 64 ■ below and on the left below No. 14 and on the left below No. 56). A misinterpretation and mistaking of the moraine overlays for slope debris *in situ* on the orographic left side can be ruled out by three indicators: (1) further above the slope sections taper to a point and pass into crests, so that a catchment area of slope debris is absent (■ below and on the left below No. 14); (2) the thickness of the loose material, especially on the middle slope, is in the process of removal due to fluvial denudation and rill rinsing (below of ■ below and on the left below No. 14), so that it could not develop under the present conditions. (3) on the orographic right side at the height (5000 m) concerned are up to very large gneiss boulders. A catchment area of the rock fall is lacking (Photo 66 ■ on the left below No. 40). There are also erratic tourmaline-granite boulders (Photo 79 and 80).

The matrix between these erratic boulders has been analysed (Figure 38) and the moraine diagnosis sedimentologically substantiated by the relatively high content of clay and the course of the curve of the grain size histogram. 80% of the microscopically analysed quartz grains are freshly weathered, i.e. glacially crushed (Figure 37 No. 18). Because a many metres- thick debris cover is concerned, which contains erratic boulders, the possibility has to be ruled out that the quartz grains *in situ* from the bedrock could be freshly weathered, i.e. they are glacially crushed. A further sample of the matrix has been taken on the same slope, but 220 m lower (Figure 39). Basically it shows the same picture typical of ground moraine. The sorting coefficient is even higher (4.62), i.e. more typical of moraine, but the fluvially reshaped quartz grains increase at the expense of the glacially crushed grains to 22% against 17% at the 220 m-higher ground moraine locality (Figure 37 cf. Nos. 19 and 18). The latter proves the increase of glacifluvial modification of the ground moraine because of the rising amount of subglacial meltwater from the upper slopes toward the valley bottom.

The Ice Age glacier surface is very clearly shown by the 6542 m-high Taboche (No. 40). Its summit has the characteristics of a classic glacial horn, which like a nunatak has towered a good 1000 m above the surface of the ice stream network. The lower ca. 1300 m of the mountain form a rounded pedestal (Photo 66 ... below No. 40) whilst, due to undercutting, beyond 5500 m a.s.l. it is marked by steep rock walls without a debris cover. (Cf. also Photos 61, 74, 76 and 83: No. 40). This line of undercutting is not orientated according to a rock limit in the outcropping Jurassic to Proterozoic Lower Tibetan gneisses of many varieties (6b after Nepal Geological Map 1985: Sheet No. 72I-B). According to the only known alternative, a mountain pedestal must be concerned, polished and rounded by the ice stream network. The line of undercutting (Photo 66 ... below No. 40) was the bergschrund line between glacier margin and rock wall up to which the flank polishing was effective. The mountain pedestal itself is a pre-glacial remnant of an old plain, i.e. valley bottom, known from the history of uplift and erosion of the European Alps and – even more typical – from the Fennoscandian mountain- and fjell-landscapes in N-Europe. The rounding of the mountain pedestal with its polished-back mountain spurs (Photo 66 ∩ white below No. 40; Photo 83 ➘ on the right below No. 40), however, is purely glacigenic.

Comparably significant, but somewhat less marked, is the undercutting of the 6440 m-high Jobo Laptshan-summit (No. 53) by a polish cavetto at 5800–5600 m a.s.l. at the valley exit of the Tshola Drangka (Photo 68 – – – below No. 53). Here, the maximum Ice Age glacier trim-line of 5500 m on Taboche (___ below No. 40; Figure 22) has continued up the tributary valley.

In this High Glacial glacigenic valley chamber with ground moraines and flank polishings up to 5400–5500 m, the Khumbu glacier has pushed its way with a merely 200–120 m-thick tongue up to the Imja Khola-junction, i.e. up to ca. 4150 m a.s.l., as is evidenced by the lateral- and end moraines (Photos 64, 66 and 78–80: V; Figure 3 above and next to Photo 81). This has taken place for the last time during the neoglacial Nauri Stage (V) (Table 1). The current Khumbu glacier comes to an end at ca. 4800 m. From this an ELA-depression of a good 300 m can be calculated ($4800-4150=650{:}2=325$) for the Nauri-Stage (V) ca. 5500–4000 years ago.

In the area of this ice margin position 180 m above the Khumbu Drangka talweg on the outer slope of the moraine, above the Pheriche settlement, a wood-sample has been dug from a depth of 0.60 m (Photo 66⇓; Figure 3 Sample 15). The C14-dating yielded an age younger than 1955 (Table 2 No. 15). This shows the great dynamics of modern solifluction processes and reshaping of moraines at this altitude and the difficulty of absolute moraine dating. The classification as belonging to the neoglacial Nauri-Stage V (see above) is, however, reliable as a relative geomorphological dating. Further E, in the direction of Dingpoche, three smaller, older end moraine dams follow (Photo 78 on the right of IV; Figure 37 No. 20; Figure 40), which can be classified as belonging to the youngest Late Glacial Stage IV (Sirkung Stage; Table 1). They are genetically connected to the pedestal moraine IV of the same age (Photos 64 and 66: IV).

In the tongue basin of that innermost neoglacial glacier position (Photo 66 V) the Pheriche settlement is situated on glaciofluvial gravel fields (sanders) of the accumulation stages −1 to −8 (Table 1; Photo 66; Figure 3 −1 to −8, on the left of Panorama 66) filled in this tongue basin since the deglaciation.

Summary of Section 3.2: Due to its thickness the S-Tibetan ice stream network has flowed via the 6026 m-high Lho La (No. 50) to the Khumbu glacier, i.e. from the Himalaya N- into the S-slope. Accordingly, during the Ice Age the upper ca. 400 m of the Rongbuk glacier had changed their current direction of flow from the N to the S. Down-valley from the Khumbu ice fall and Lho La the Khumbu Drangka had an ice-filling up to 6300 m, so that neither below the Lho La nor below the Western Cwm in the area of the modern Khumbu ice fall has a steep step worth mentioning existed in the Khumbu glacier surface from N and S of the summit-superstructure of Mt. Everest down to the SW. All the side valleys of the Khumbu Drangka up to the Imja Khola junction have also been filled with ice up to the glacier trim-line of the Khumbu parent glacier of the last glacial period, i.e. their surfaces were adjusted to the surface of the Khumbu glacier. Up to the confluence with the then tributary stream of the Imja Khola glacier (Section 3.3) the Khumbu glacier surface has slanted down to ca. 5400 m a.s.l. Its thickness has increased from ca. 1000 m below the contemporary Khumbu ice fall to ca. 1200 m close to the Imja Khola confluence.

The ice margin position at 4150 m a.s.l. near the Pheriche settlement recognizable by fresh moraines, belongs to the oldest neoglacial (holocene) Stage V (Nauri-Stage, Table 1) and verifies a snow-line depression of somewhat above 300 m.

3.3. The highest former trim-lines and glacier thicknesses in the upper Imja Drangka (Khola) and its tributary valleys between Cho Polu, Shar Tse, Lhotse, Nuptse on the orographic right side and Baruntse, 6238 m-peak, 6430 m-peak, Amai Dablang on the orographic left side (Figure 3 Nos. 29, 10, 2, 8 and 13, 58, 59, 20)

At present the uppermost valley head of the Imja Drangka below Lhotse Shar (on the right of No. 2), Shar Tse (No. 10) and Cho Polu (No. 29) is still filled with the at most 2.2 m-wide Lhotse Shar glacier situated below the snow-line which – as well as the opposite Amphu glacier – flows into the Imja glacier (Photo 67). Beyond the historical lateral moraines (Stages VII–X; Table 1) and their small lateral valleys with lateral sanders (□) oldest neoglacial Stages (Stage V) and High- to Late Glacial remnants of ground moraine (■) are preserved (Figure 3 on the right side of Panorama 68; half-right above No. 58). As to the latter, only the material is concerned, because the form has been modified many times and buried by the debris of rock fall and dislocated higher moraine debris (▽) (Figure 3 above and on the right above Panorama 67). Above the ground moraine remnants reaching up to 5500 m (■ below▽), the increasing temporal distance from today becomes obvious in the Late- to High Glacial flank abrasions, glacigenic roundings and triangle-shaped slopes (Figure 3 on the left below No. 29; on the right above No. 58) (and) kept clear from there on: the highest sections of the valley flanks abraded by the glacier in the past have undergone the earliest deglaciation. Accordingly, they have been roughened longest by weathering. So, the grade of preservation of the roundings and polishings decreases from below to above (cf. white with black on the left below No. 13).

The highest glacier-trim-line verifiable e.g. by glacigenic undercuttings, i.e. forms similar to polish cavettos (Photos 67 and 68 ... on the right below Nos. 29 and 13; Photo 69 ... on the right below No. 13) runs at ca. 6300 and 6200 m a.s.l. Accordingly, during the glacial period connected glacier surfaces have existed between this side of the Imja glacier and the Barun glacier beyond Cho Polu (No. 29) and Baruntse (No. 13) across the 6220 and 6190 m-high notches and passes (Photo 67 ... between No. 10 and 29 and on the left below No. 13; Figure 3 between No. 10 and 13). This is also confirmed by the reconstructed ice levels of the then upper Barun glacier system (see Section 2.1). Additionally, the ice of the Imja glacier has flowed with a minor-thickness across the 5780 m-high notch of Amphu Labtsa into the Hunku Drangka (... on the left of No. 58 above V–X; Figure 3 between No. 13 and 59). The Ice Age Hunku glacier has flowed down to the S much more straightly and steeply than the Barun glacier, so that here a clear direction of transfluence must have existed from the Imja- to the Hunku glacier. The U-profile of the 6190 m- pass only understandable by glacial erosion (Photo 69) pleads for a temporarily increased ice flow between Imja- and Barun glacier. Up to now it is not clear in which direction and at which time.

At this place and down-valley, where the three source branches of the Imja glacier (Photo 68 □ on the left and right below No. 13) merge into the Imja glacier tongue with its ice-dammed lake (○), and again down-valley where the Lhotse glacier turns into the Imja Khola (□ above ⇩), the reshaping of the High- to Late Glacial glacier traces by the neoglacial to historical glaciers is evident. Only down-valley of the current glacier ends (■ and ∩ on the left and right below Nos. 40 and 53 in the background) the preserved Ice Age glacier traces do increase. As to the valley bottom the mantling by neoglacial to historical moraines (V–XI) has to be mentioned as well as the corresponding lateral valleys and their gravel fillings (Photo 69 □); as to the valley flanks, the destructive effect of hanging glaciers as e.g. that of the steep and minor-thick E Imjatse-S-hanging glacier (Photo 68 between black and white on the very left; Figure 23) have been observed. It erodes at a right angle to the Ice Age flank polishing and on a small width, i.e. nearly linearly, so that this becomes destroyed. Between broad ravines such as these and also those created in the meantime by melted hanging glaciers (Photo 68 right third of the panorama in the foreground), however, rounded rock ribs and remnants of mountain spurs have been preserved (below No. 13 and below No. 40, middleground; Photo 69 , ⌒) which are in the process of dispersion by frost weathering. The erratic tourmaline-granite boulders met on one of these ribs (Photo 68 ○) might also derive from the tourmaline-granite outcropping up-slope below the actual firn-helmet of the Imjatse. Accordingly, no conclusions can be drawn from these erratics with regard to the level of the main glacier. But also interglacial and finally holocene, i.e. neoglacial cirque forms (Figure 3 on the left and left below Panorama 68) have destroyed and are still destroying the High Glacial forms. Despite that the glacigenic large-scale forms as e.g. the trough valley cross-profiles reaching up to ca. 6000 m are well preserved (Figure 23; Photo 69 from −−− left to No. 58).

A very similar destruction of the Ice Age traces of glaciation has occurred and still takes place through the holocene (neoglacial) and historical to current glaciation in the orographic right side valleys of the Imja Drangka in which the Lhotse-, the Lhotse Nup- (Photo 71) and the Nuptse glacier flow down (Photo 72 below No. 3 up to below No. 40). The Ice Age glacier level has towered above the two intermediate valley ridges between these three side valleys and has lain at 6100 m (Photo 71 ... on the very right) down to 5800 m (−−− on the very left)

(Photo 75 ... from right to left; Figure 24). However, as today, the then ice flow has followed the directions of the side valleys and -slopes toward the Imja main glacier. This is verifiable by the traces of flank abrasions and remnants of glacigenic triangular faces preserved on the upper slopes of the flanks of the side valleys (Figure 3 between Photo 73 and Panorama 68; Photos 70▲ large, left margin; 71▲, ∩;73▲). The direction of ice flow can be explained by the canalization through those side valleys and by the feeding of the ice streams concerned from the up to 7879 and 8501 m-high, at the valley head of these valleys nearly 10 km-long Lhotse–Nuptse-S-wall by ravines which during the Ice Age, too, was predominant (Photo 83 from the left of No. 8 up to the right of No. 2; Figure 3 Nos. 2 and 8). This wall towers above all the other glacier feeding areas of the Ice Age catchment area of the Imja glacier about 500–1300 m.

Because the historical to contemporary orographic snow-lines run across the steep wall of Lhotse-Nuptse, i.e. several hundred metres above the wall foot and the cones of ice avalanches (Photo 71 ▼), the climatic variations of increase or decrease of the ELA merely turn into a small-scale reduction or enlargement of the feeding area. The consequences are nearly constant ice margin positions of the three glaciers concerned since Stage X or even since Stage VII (younger Dhaulagiri-Stage) ca. 1700 years ago (cf. Table 1) (X; Photos 70, 72 and 76: VII–X). Only the ice thicknesses, i.e. the altitudes of the glacier surfaces, pulsate. At present, i.e. during Stages XI and XII, the surfaces of these glaciers have dropped by several decametres against their lateral moraines of Stages X, i.e. VII without having retreated from the lateral- to end moraines fringing them (Photo 70 the four □ from the left; Photo 71 □ white; Photo 72 the five □ from the left; Photo 76 □ on the very right).

This observation applies to all larger glaciers among the largely avalanche-fed historical to current glaciers in the Imja Drangka caldron (Photo 67 □ large; 68 the three □ from the left; 76 second □ from the left). It is representative for most Himalaya glaciers.

In the course of the lower half of the Imja Drangka High- to Late Glacial terraces of ground moraines (Stage 0–IV) have been preserved down-valley in an increasing extension of the basal face and an increasing height above the talweg (Photo 68 ■ below and on the right below No. 53 and the second ■ on the left below No. 40; Photo 72 the three ■ large in the foreground and the second ■ from the left; Photo 74 ■ on the right; Photo 75 ■; Photo 76 ■ below No. 40–53; Photo 70 ■ black; see Figures 24, 25; cf. Figure 3). In many places remnants of these level of pedestal moraines have been preserved in niches, i.e. in the denudation shadow of mountain spurs (Photo 71 ■; Photo 72 ■ white below No. 2; ■ black below No. 3).

At some places these glacial remnants of ground moraine have already been glacigenically modified in the neoglacial period (Nauri Stage V) or even in the late Late Glacial, in the Sirkung Stage IV (Photo 69 IV; Photo 70 IV, IV–V, V; Photo 72 IV, IV–V, V; Photo 74 V; Photo 76 IV, V). Looking from the Khumbu Drangka up-valley into the Imja Drangka (Photo 82) it becomes even clearer that during the Ice Age a filling of ground moraine (■) has existed, rising about 310–540 m above the current talweg of the Imja river, the substantial remnants of which can still be recognized. The current glaciers are adjusted to part of them (□ black; Photo 72 the two □ on the right; Photo 74 and 76: □). Naturally, they have partly removed, i.e. somewhat lowered, the ground moraine pedestal concerned. It sets in with a comparably very insignificant but growing thickness at the valley head of the Imja Drangka (Photos 67 and 68: V and V–X). Here, in correspondence with the higher altitude, it has been increasingly reshaped by the younger, i.e. neoglacial to historical, glacier positions (Stages V–X).

The matrix composition of the samples taken from the ground moraine pedestals shall be introduced exemplarily by means of Figures 44 and 45. Both the samples bear all relevant sedimentological characteristics of moraine matrix with respect to the trimodal accumulation curves of the grain sizes as well as to the peak in the clay of 7–18%. Informative in this connection are the samples taken for comparison from much younger historical moraines (Stage VI–X; Table 1), partly still with ice contact, in the Imja Drangka, i.e. in a petrographically comparable catchment area (Figures 41–43). The characteristics of the grain sizes are identical, though here just 6.5–8% clay is contained. The primary maxima in the fine sand of these samples correspond with 28–41%. The sorting coefficient of the samples of the ground moraine pedestal amounts to $So = 3.27$–5.03; as for the samples near to the actual glacier ice it lies at $So = 2.47$–3.35. This is an even more insignificant and thus less glacial degree of mixing. Measurements for comparison carried out in the Rondane-mountains (S-Norway/Scandinavia) have also yielded a So between 3.2 and 5.8 for ground moraines; however, glaciofluvial terrace sediments there have shown values between $So = 1.7$–2.6. The microscopical-morphoscopic analyses of the matrix concerned yielded 87.3–91.3% glacially crushed quartz grains (Figure 37 No. 21 and 22), the samples near to the ice 79.7–98.8% glacially crushed quartz grains (Figure 37 Nos. 23, 24, 25).

On the orographic right side of the Duwo glacier in the N-flank of Amai Dablang an erratic biotite-amphibolite-gneiss boulder is situated at 4750 m a.s.l. (Figure 46; Figure 3 at IV above No. 20; Photo 70 above ■ IV) on the orographic left side on the Imja Drangka pedestal ground moraine a good 400 m above the Imja river. Samples taken from the bedrock of the Amai Dablang N-flank (Photo 72 on the right of ■ directly below No. 36) provide evidence of outcropping tourmaline-granite. Biotite-amphibolite gneiss, however, does not outcrop anywhere in this area. The locality where this bedrock can be found is 12–20 km away at the valley head of the Imja Khola as well as in the Lhotse-S-wall (Figure 3 below Nos. 2–10) and also in the area of Amphu Labtsa (on the right below No. 58). Accordingly, this erratic boulder proves an at least 20 km-long Imja Drangka glacier which, inevitably starting from the valley head, must still have been a good 400 m-thick at the exit of the Imja Drangka. It can be suggested that a glacier such as this has existed for the last time during the Late Glacial Sirkung-Stage (IV) (see Table 1).

Generally the pedestal ground moraines of the Ice Age Imja glacier are made up from polymict boulders of phyllites and tourmaline granite, embedded in a matrix of fine material. They are edged to rounded at the edges, i.e. glacigenically faceted (Photo 75 ■; Photo 76 ■ below Nos. 40–53). A petrographically similar composition is shown by the surface moraine of the current Nuptse glacier, in which large tourmaline-granite boulders have been encountered (Photo 72 □ on the very left). They come from the upper sections of the Nuptse-S-wall (Photo 74 on the left below No. 8).

The High Glacial glacier trim-lines recognizable by ground moraine covers on the slopes as well as glacigenic abrasions and roundings on the outcropping rocks of the valley flanks reaching beyond them, up to the partly well-preserved upper limits of abrasion run down from the valley head of the Imja Drangka at 6300 m a.s.l. (Photo 67 ... on the very left) via 6100 m (Photo 68 ... and – – – on the left below No. 58; Photo 72 ... below No. 2, ... on the left below No. 3 and – – – on the left below No. 58; Photo 74 ... between No. 59 and on the right below No. 8; Photo 75 ... Figure 23) and 6000 m (Photo 74 ... on both sides below No. 8; Figure 24) in the middle course of the valley, up to 5700–5500 m (Photo 74 on the left of No. 8 and on the right of No. 53; Photo 72 ..., – – – between and below Nos. 14 and 40; Figures 25, 21, 22) and up to 5400 m at the exit of the Imja Drangka (Photo 74 below No. 40). There the confluence with the Khumbu glacier has taken place at the same surface level (Photo 72 ... below No. 40; Figure 22). A clearly fresher Late Glacial polish line than the abrasion forms above has been preserved on the rock spur N of Amai Dablang at 5400–5500 m (Photo 68 ____ white; Photo 70 – – – on the right; Photo 72 – – – on the right; Photo 74____ below No. 20; Photo 82 ... below No. 58). It belongs to the Late Glacial Ghasa Stage (I) (Table 1). Obviously, the High Glacial glacier trim-line (Stage 0) has lain here noticeable higher, namely at 5600 up to nearly 6000 m a.s.l. (Figures 24 and 25). This is evidenced by truncated spurs reaching up to this altitude (Photo 68 above ____ white below No. 20).

Summary of Section 3.3: During the last glacial period (Stage 0; Table 1) the Imja Drangka and its side valleys have been filled with 1050–1300 m-thick ice of the valley glacier (Figures 13–15). This Imja glacier has gradually built-up a ground moraine pedestal from the High Glacial up to the late Late Glacial (Stage 0 to III or IV). It is preserved in the form of terraces of ground moraine which down-valley become relatively higher from 120 m via 310 m up to 540 m (Photo 75 ■). Owing to this, a Late Glacial subglacial (between Stage III and IV) and postglacial to current glaciofluvial cutting of the Imja river into this ground moraine pedestal has taken place, leading to this development of terraces (Photo 75 and 82:▽). Then the Imja glacier tongue of the advancing late Late Glacial glacier of the Sirkung Stage has already advanced in the glaciofluvial valley between the ground moraine terraces and has placed its orographic left lateral moraine in apposition to the remnant of the ground moraine pedestal of the next-older Late Glacial Dhampu Stage (III) (Table 1) (Photo 77 IV). The neoglacial to historical glacier tongues have been adjusted to the remnants of ground moraine pedestals, i.e. terraces. This applies also to the contemporary glacier tongues of the Imja Drangka and its side valleys (Photo 82 □ black; Figure 3).

The cirques (Photo 78 ●) are Late Glacial features of Stages III–IV. They could only be created, i.e. their further development could only take place during the last glacial period, when the High- to early Late Glacial (Stage 0–II) glacier level had dropped so far that these hollow forms could be exposed and polished out by hanging glaciers. Here, too, cirques such as these are a polyglacial development during the early and late phases of the numerous Pleistocene ice ages.

As is evidenced by erratic tourmaline-granite boulders in the orographic right flank above the Khumbu- and Imja Drangka confluence at 4860 m (Photo 78 ○ foreground; Figure 3 Panorama 78) and on the orographic left side by the erratic biotite-amphibolite gneiss boulder at 4750 m, 2 km in front of the valley exit of the Imja Drangka (between ■ below No. 29 and ▼ below No. 3, Figure 3 IV above No. 20) as well as by samples of ground moraine, the Ice Age Imja- and Khumbu Drangka glacier had a minimum thickness of 400–700 m at their confluence. As has been shown by ground moraine covers and glacigenic upper lines of polishing and abrasion, reaching up to ca. 5200 m as well as by the forming of glacial horns (Figure 3 No. 40; Photo 66 and 83 No. 40), the glacier level in the confluence of the two valleys has reached an altitude of 5400 m (Photo 72 ... and – – – on the very left and – – – and ... on the very right; Photo 83 ... on the right below No. 14). Accordingly, an ice thickness of ca. 1250 m can be verified.

3.4. The highest former trim-lines and glacier thicknesses in the Imja Drangka (Khola) and its tributary valleys from the confluence with the Khumbu Drangka up to the inflow of the Ngozumpa Drangka between Taboche on the orographic right side and Amai Dablang, 6571 m-peak and Kang Taiga on the orographic left (Figure 3 Nos. 40 and 20, 61, 27)

Below the confluence of the upper Imja Drangka with the Khumbu Drangka the orographic right upper limit of abrasion continues from 5400 m (Photo 76 ... below No. 40; Figure 3 on the right of No. 40) via 5300–5000 m (Figure 26; Photo 77 ... on the right) down to 4600–

4500 m a.s.l. (Figure 27; Photo 76 _____; Figure 3 below No. 40). On the orographic left side a polish line between 5200 and 5050 m a.s.l. (Photo 78 ... below and on the right below No. 20) has been preserved. It might belong to the Late Glacial Ghasa Stage I (see Table 1). The orographic right flank is covered with ground moraine up to an altitude above 5000 m (Photo 78). It contains erratic tourmaline granite boulders (Photo 78) which outcrop only in the upper catchment area of the Khumbu glacier on the corresponding orographic right valley flank at a distance of at least 8 km. In addition, huge gneiss boulders (Photos 79 and 80) are contained in the ground moraine. They cannot have been transported by rock falls or slides on this merely 30°-steep slope which flattens convexly above (Photo 78 on the very right and left; Photo 83 below – – – on the right below No. 40). Moreover, the character of ground moraine has been confirmed by sedimentological and morphoscopic laboratory analyses (Figures 38, 39; Figure 37 Nos. 18 and 19).

In the valley ground, in the confluence of the Imja- and Khumbu Drangka, older, i.e. High- to Late Glacial (Stage 0–IV) ground moraine (Photo 81) occurs in the underlying bed of the end moraine of the Nauri-Stage V (cf. Table 1). Its matrix shows a ram resistance of over 4.5 kg/cm^2, i.e. it is very tightly packed. This is an indication of substantial ice thicknesses up to 1200–1450 m (Figures 22 and 26).

On the orographic left side up to the inflow of the Nare Drangka, and on the orographic right side up to Pangpoche, the ground moraine covers on the slopes can also be recognized by the secondary development of slope rills (Photo 83 ↓). This corresponds to the current morphodynamics. The rain- and meltwater running off regularly today, is a down-slope process. It does not create the existing large-scale debris covers, but it dissects and then removes them by linear development of hollow forms. This elucidates a geomorphological change of regime from a two-dimensionally extended accumulation in the past to the current linear erosion. During the Ice Age a rounding rock abrasion has taken place by flank polishing and the continuing mantling with ground moraine, which, due to progressive deglaciation, must have increased toward the late glacial period. This geomorphological contrast between the past and actual forms also becomes evident on the valley bottom of the Nare Drangka filled up with Neoglacial to Late Glacial (Stages ′VII–IV) moraine. Here, the Nare river (◇), through the bed of which the high water from outbursts of glacier lakes and – caverns of the historical Nare glacier has also come down recently, and has been cut with sharp, fresh working edges into the softly shaped hill landscape of moraines (■ below Nos. 20–36).

Truncated spurs and triangle-shaped slopes rounded at their edges belong to the specific wealth of forms of glacigenic abrasion. They can be observed in different forms and stadia of development in the Imja Khola section discussed here (, ,). The clearest ones are depicted in Figure 3.

The orographic right ground moraine cover above Pangpoche (Photo 83 ■ right margin; Photo 87 ■ left margin) has also been established sedimentologically and morphoscopically (Figure 47; Figure 37 No. 17). 53.6% of the quartz grains are glacially crushed; because metre-sized, round-edged, i.e. far-travelled gneiss boulders also occur in this matrix of fine material, weathering *in situ*, i.e. the alternative 'freshly weathered' can be ruled out. The already reduced clay portion (4%) and 46.4% fluvially polished quartz grains point to an already subglacial, i.e. glaciofluvial reworking of the ground moraine during the Late Glacial; this is also confirmed by the sorting coefficient (So) of 2.43.

In order to diagnose the nunatak-form of Taboche, i.e. its shaping into a glacial horn (No. 40) by glacigenic lateral erosion of the High Glacial Imja parent glacier, the surrounding of the Pangpoche settlement, i.e. the direction from SSE and S, is especially suitable (Photo 83 No. 40). Here, the glacier trim-line has run about 5200 m a.s.l. (– – – on both sides below No. 40; Photo 87 – – – on the right below No. 40; Figure 26). On both sides of the Imja Drangka, in the valley chamber of Pangpoche, past cirques have been preserved (Photo 83 ○ large; 87 ○ below No. 61; Figure 3 on the right below and below No. 40). Their development can be understood in connection with the ice level of the Imja parent glacier and its tributary glaciers. Only these back walls of cirques lying above an altitude of 5250 m (Photo 83 – – – below No. 40), i.e. above this ice level, could be built-up further during the High Glacial (Stage 0), as e.g. on Taboche. On the orographic left flank the development of cirques has been completely prevented by the Imja glacier level during the High Glacial (Figure 26) and also during the oldest Late Glacial Stage I (= Ghasa Stage; Table 1; Photo 87 … on the right below No. 61). With the increasing thawing-down of the level of the ice stream network, the hanging glaciers and their polishing out of the cirques has become more effective. i.e. has extended further down. At the same time the flank abrasions and glacigenically triangular-shaped slopes of the Imja glacier (Photo 83 below and on the left below No. 36) have been reshaped by this Late Glacial development of cirques (○ large), i.e. cirque extension toward below and partly destroyed (Photo 66 below of ... below Nos. 27 and 36). This Late Glacial cirque development has taken place on the orographic left side between Stage II and IV: during Stages II and III the Imja parent glacier has still existed (see its ice margin position in Photo 87: III), however, the upper cirque areas have already been freed from its ice level. During Stage IV the Imja Drangka was even ice-free here. This is evidenced by the tributary glaciers, the Nare- and the Omoga glacier, reaching into the main valley (Photo 87 IV).

What has been said with regard to the valley chamber between Dingpoche, and especially around Pangpoche, in principle can also be applied to the continuing area of the Imja Drangka up to the Tengpoche monastery, i.e. the Phortse settlement (Figure 3).

The Imja Drangka is a large trough valley (Figure 27) created polyglacially and for the last time during the last glacial period (Stage 0), which from the High Glacial up to the Late Glacial (Stage 0–IV) has been mantled with ground- and end moraines and reshaped by hanging- and cirques glaciers (Photo 84). Accordingly, only those glacigenic forms of abrasion and ground moraine covers can be classified as belonging to the High Glacial of the last glacial period (Stage 0) which are situated on the very top of the valley slopes near to the highest polish lines, but not those close to the valley bottom, where the youngest Late Glacial glaciers have been effective, too.

Forms like these are the two roche moutonnées (Figure 3 Photos 85 and 86) down-valley from Pangpoche. On parts of their surfaces very well smoothed rock faces have been preserved, which for the last time have been polished during Stage III (∩). Thus, the glacier cover is evidenced. In addition, however, during the Late Glacial (Stage II and III) the subglacial meltwater erosion has marginally undercut the forms laid out in the High Glacial (Photo 85 on the right of ▽ in the centre; Photo 86 on the right below ■). Furthermore, potholes have been set into the highest sections of the lowest roche moutonnée (Photo 86 ↓). During the stages quoted, this has taken place for two reasons: (1) for the emergence of subglacial meltwater the glacier surface is bound to have already been situated below the snow-line and (2) the glacier must have been thin enough to be pressed upward to such an extent that crevasses could develop. Orientated according to these locally stable crevasses, glacier mills have now been created through which the supraglacial meltwater has exactly hit the roche moutonnée, so that potholes could have been developed there.

The orographic right valley flank of the Imja Drangka is covered with ground moraine up to at least 4300 m, i.e. up to 500–600 m above the talweg (Figure 27). Besides other polymict boulders of phyllite and gneiss it contains erratic boulders of tourmaline granite in size up 1.5 m, transported over at least 6–10 km (Figure 3; Photos 88–90, 92, 93, 95, 104). Two of the samples taken will be introduced here as representative (Figures 48 and 49; Figure 37 Nos. 26 and 27). Their sedimentological and morphological analyses have confirmed the ground moraine character of the cover of loose material on the slope.

The sorting coefficient of 3.08, i.e. 3.51 as well as the very high clay portion of 9–12% identify the matrix as a typical strongly grained matrix of ground moraine. But also the portions of 84.6–86.1% of glacially crushed quartz grains (Figure 37 Nos. 26 and 27) undoubtedly prove ground moraine. The portions of 15.4 and 13.9% lustrous quartz grains (fluvially polished) point to an insignificant reshaping by subglacial meltwater. This ought to have taken place in correspondence with the rising snow-line (ELA) during the Late Glacial (Stage I–III; Table 1). During the High Glacial (= Würmian = Stage 0) this glacier surface was still situated ca. 900–1500 m (Figures 26 and 27) above the snow-line, so that no meltwater could emerge subglacially.

On the opposite orographic left valley side two further geomorphologically representative sediment samples (Figures 50 and 51; Figure 37 Nos. 15 and 16; Photos 91 and 95↓; Photo 96 ■; Figures 3, 14. and 15.03.03/1) testify to the morainic character of the covering sediments. A reshaping by Late Glacial subglacial meltwater can be evidenced by the sorting coefficient of 2.66 i.e. 2.00 as well as by 41.6% and 32.9% lustrous (fluvially polished) quartz grains. At the same time this secondary reworking increases from the upper parts of the slopes toward the talweg. Because a secondary reworking of the grains is concerned, this proves that the originally glacigenic angular form of the fluvially treated grains has still been preserved, at least in part. The clay content of 6%, i.e. 7% and ca. 67%, i.e. 58% glacially crushed grains prove the moraine matrix anyway. In this matrix metre-long erratic boulders of tourmaline granite are contained in a round-edged to rounded shape (Photo 96 ○; Figure 3). On the orographic left valley flank the covers of ground moraine reach up to a good 4400 m a.s.l. (Photo 94 ■ on the very right; 87 ■ on the right below No. 36; 83 ■ half-left below No. 60 and ...; 90 and 91 ■; 105 ■ half-right below No. 20). The character of ground moraine can be recognized geomorphologically; so e.g. by fresh slope rills which since deglaciation have been developed without a catchment area, i.e. *in situ*, in this erratic, i.e. horizontally transported, that is glacigenic soft loose material (Photo 93 below ■ below No. 36; 95 below ■ below No. 27). The corresponding highest past glacier polish line runs between 5000 and 4500 m (Figure 27 Pro. 17 left side; Photo 66 ... below No. 27).

In the region of Tengpoche Gonda below ca. 4000 m a.s.l., the orographic left ground moraine material of the Imja Drangka passes into the area of the end- and lateral moraine of the Late Glacial Dhampu Stage (III) (Table 1) (Figure 3 III below Photo 93; Photo 95 III). The Tengpoche Gonda settlement profits from the broad ridge of this end moraine (Photo 94 and 84: III). During the Dhampu Stage (III) the related lowest ice margin position of the Imja glacier tongue was situated southward below the Phortse settlement at ca. 3400 m a.s.l. (Figure 3 on the left of Photo 100 in the talweg).

As to the Phunki glacier joining from the orographic left side, this moraine complex is at the same time in the position of a Late Glacial medial moraine (Taglung Stage (II), Table 1) (Photo 103 ■; 84 ■ on the left of III). Here, over 100 m-thick material of ground-, medial- and end moraine is situated on an outcropping rock pedestal of schist. It contains large polymict, round-edged and erratic boulders of granite, gneiss, quartzite and metamorphite (Photo 98 ●; 99 ●,○; 101 ●). With regard to the reshaping of this material the following sequence of the glaciation history of the Imja Drangka and its tributary valleys can be suggested: (1) first, the High Glacial

Imja glacier here has deposited its ground moraine, whilst the Phunki tributary stream has joined as a subordinate side glacier; (2) during the Late Glacial (Stage I to II) between side- and main glacier a medial moraine has been developed from part of this ground moraine and (3) the Imja glacier has no longer passed through the Phunki Drangka, and the material of the medial moraine has been integrated into the end moraine of the Imja parent glacier.

This medial moraine can be identified by the limnic sediments preserved on its culmination (Photos 99 and 100:□; Figure 3). They are nearly horizontally layered: half to two/thirds (47– 65%) of them consist of sand and the second half, i.e. the remaining third consists of silt; clay partly reaches 1–3 %. The clay content points to the local proximity to clay-containing moraine matrix. Obviously it is moraine material washed out and removed on a small scale as it can be deposited in a small lake in an inset of medial moraine between two joining lateral moraines. The medial moraine lake must have been situated ca. 300 m above the adjacent talwegs. In the study area a comparable current lake development – here, however, a pure lateral lake is concerned – occurs in Gokyo, on the right side of the Ngozumpa glacier (Figure 3: Gokyo Tsho) and in 1955 was still in Gorak Shep (in 1982 it had already dried up) on the orographic right side next to the Khumbu glacier above the inflow of the Changri Shar glacier (see e.g. also Photo 59 ◇).

An end moraine of Stage III comparable with that of the Imja glacier has not been found in the Phunki Drangka. The oldest remaining end moraine of the Phunki glacier is the next-younger of the Sirkung Stage (IV) (Photos 97, 98 and 99: IV). The neoglacial to historical stages of this trough-shaped side valley are depicted in Photo 103.

In the confluence area of the Phunki- and Imja Drangka the postglacial fluvial reshaping and dislocation of moraine material by the Imja river, the discharge of which increases significantly during the summer-monsoon, are extremely intensive (Photo 102). Here, the main valley has narrowed to the form of a gorge and is marked by a decametre-deep incision into the Ice Age ground moraine, which has already partly started subglacially (Photos 98 and 99↓; 101▼).

With regard to the High Glacial glaciation of the Imja Drangka (Khola) and its side valleys from its confluence with the Khumbu Drangka up to the inflow of the Ngozumpa Drangka (Figure 3), it can be summarized that the connected, i.e. communicating, glacier level has dropped from ca. 5400 m a.s.l. (Figure 22) via 5300–5200 m (Figure 26) to 4500 (Figure 27) up to ca. 4400–4300 m. In this course the thickness of the Imja parent glacier has decreased from ca. 1400 m (Figure 26) to 800 m (Figure 27).

3.5. The highest former trim-lines and glacier thicknesses in the Ngozumpa Drangka and its tributary valleys from Gyachung Kang and Cho Oyu in the N up to its confluence with the Imja Drangka (Figure 3 between Nos. 4 and 9 and Panorama 148)

The upper catchment area of the Ngozumpa glacier consists of a contemporaneously still entirely glaciated valley head, which between Cho Oyu (No. 4) and Nup La (No. 63) is 10 km wide. During the last glacial period (Würm, Stage 0, Isotope Stage 3–2; Table 1) a glacier transfluence occurred over the at least 5860 m-high Nup La (Photo 106 No. 63) from the N-connected area of the S-Tibetan ice stream network (Kuhle 1985b Figure 2, I3). The connection of the ice to the Himalaya-N-side concerned has taken place through the W-Rongbuk glacier (Kuhle, 1988b Figure 2) (Figures 4 and 11). In the W-connected part of the valley source in question, the High Glacial accumulation of the glacier ice was autochthonous. Here, it had no additional inflow and was only dictated by the high viscosity of the very cold ice ca. 2500 m above the ELA and the minor incline of the valley bottom. Evidences of the glacier trim-line at that time are given by the roughened rock abrasions and remnants of glacigenically triangle-shaped slopes (Photo 106 ∩; Figure 3). The heaviest removal in source depressions of glacier valleys such as these takes place in the form of denudation by ice- and rock avalanches on the walls of crest fringes. The denudation base is the glacier surface below the walls. Whilst the upper wall areas are displaced backward by denudation, residual wall foot pedestals are created at places where the denudation breaks off (Kuhle, 1982, 53; 1983a: 132ff.). According to the higher glacier trim-line during the glacial period two rock terraces a time have been developed: a higher glacial one and a lower interglacial one. Avalanches which descended interglacially disperse the higher one into wall gorges and pillars situated in between. Accordingly, the height of the remaining rock pillars (Photo 106 the three ∩ below, between No. 7 and 66) marks the High Glacial glacier trim-line (– – –). It ran at 6600 (on the left below No. 7) to 6400 m a.s.l. (on the left below No. 66).

Generally, and accordingly in all parallel valleys situated more to the E, which have been treated above, during glacial times the glacier surface has been heightened least in the valley source area. Down-valley, approx. up to the valley cross-profile, where the glacier surface ran at the level of the snow-line, its heightening was most significant (cf. Photo 106 – – – with Photo 107 – – – and 108 – – –, ______; and all valley cross-profiles: e.g. Figure 20–27 in the Khumbu and Imja Drangka). Due to the progressive heightening down-valley, the glacier surface had a more minor relief than today, because the steep steps were levelled. For this reason the currently existing ice falls and glacier crevasses (cf. Photos 106 and 107:↓) were largely lacking during the Ice Age.

It is obvious that the faces of glacigenic flank abrasions (Photo 107⌒; 108⌒ below No. 67) are re-worked and roughened extremely fast. This is proved by the fact that even immediately above the current surface of the glacier margin smoothings no longer occur. With an increasing altitude above the ELA – which during the last glacial period lay ca. 1300 m below the rock faces concerned – the abrasions must have been developed by cold, i.e. glacier ice ca. −11 to −14 °C-cold. Therefore, the Ice Age glacier work here was more marked by exarations, detractions and detersions than by rock-smoothing polishings for which a meltwater film is needed. Fresh crumblings (Photo 108⇩) and debris cones (Photos 108 and 109△; Figure 3 on the left of Photo 110), however, testify to a secondary roughening. Since the time when the ice contact ceased, the crumblings have taken place so fast that not even blackenings by water running down the rocks could develop (Photo 109 ∩). In part the glacial-erosive influence of the subglacial meltwater can well be diagnosed. So e.g. on the same right rock flank below the 6066 m-peak (No. 67) where the neoglacial and Late Glacial polishings (Photo 110 ∩ above⇩) are much better developed than the historical ones (∩ below⇩). That the last ones can be no secondary roughening since the recent deglaciation, is proved by the ground moraine cover still preserved at many places ■. The better condition of the older polishings from the Late- to neoglacial polish processes is to be explained by the presence of subglacial meltwater between ice and rock. Due to a displaced drainage during the historical ice development, the intake of meltwater was obviously lacking.

The orographic right glacigenic flank forms with truncated spurs, i.e. glacigenically triangular-shaped slopes or -walls (Photo 111 below No. 9) and abrasion roundings (∩ and⌒) reach nearly up to the edge of the crest. Down-valley of the 6066 m-peak (Photo 111 on the left of No. 67) its ice and also that of the W-adjacent Lungsampa glacier branch has sharpened the crest. Due to glacigenic undercutting during the Late Glacial it has created a jagged crest formed by numerous separate glacial horns (Photo 111 below Photo 112). The characteristic reshaping at a right angle of the Ice Age trough valley flanks by the hanging glacier tongues of the Lungsampa 6066 m-peak E-glacier (south glacier tongue) (Photo 111 below No. 67) and Lungsampa 6066 m- peak E-glacier (north glacier tongue) (on the right of No. 67) is connected to the interglacial uplift of the snow-line. The younger, i.e. historical stages of these glaciers recorded by moraines (Photo 111 XII; 113 ′VII) and the corresponding snow-line are presented in Figure 19 and Table 3. The very youngest glacier retreat since 1955–1963 can be understood by a dead ice block (Photo 111●; 112 □ below; 113 □), the ice of which was still integrated within a connected glacier tongue capable of flowing from 1955 to 1963 (Table 1, XII). During the youngest neoglacial stage, the middle Dhaulagiri Stage, this tongue has overthrust the end moraine (Photo 113, ′VII) situated 1 km down the hanging valley. It dams up the contemporary Kyajumba Lake.

As is indicated by the Würmian glacier trim-line about 6000 m a.s.l. (Photo 111 and 113; ––– black) verified by remnants of ground moraine and, above, in particular by glacigenic abrasion forms, the glacial landscape with polish depressions and -thresholds and roches moutonnées (☗) of the uppermost E-section of the Ngozumpa Drangka and the Lungsampa 6066 m-peak E-glacier valley has been brought about by the ground scouring of the main glacier. It has filled the entire hollow forms of this relief and controlled the glacial erosion with its direction of flow. The interglacial glacier trim-line, which has dropped remarkably during the Holocene up to the present, subdivides the Ngozumpa glacier into 3–4 ice streams (Figures 3 and 19) forming a connected surface during the High Glacial. This has fallen away from Nup La (No. 63) from ca. 6300 to 6200 m (Photo 114 ––– white) via 6000 m (––– black) up to the Gyuba Tschomoche ridge situated 6–7 km apart, by merely 300 m to ca. 5900 m a.s.l. (Photo 113 from ––– white to ...; Figure 29).

The heightening of the Würmian glacier level in the source cauldron of the Ngozumpa Drangka below the crest fringe to 6400– 6600 m a.s.l. has been possible because of the ca. 1000–1300 m-thick ice filling of the middle valley section (Figures 28–30). This is spatially recognizable in Photos 115 and 125 (... below Nos. 4, 9 and 7). It was a back-damming process of ice accumulation which, due to the successive decrease of the velocity of ice discharge near to the surface, has led to an increase of the ice- and firn level below Gyachung Kang (No. 7) and the S-walls of its satellites. The roches moutonnées depicted in Figure 3 (below Nos. 9 and 7 between 4 and 15), are currently breaking through the ice surface as rock islands (Photo 106 ∩ below No. 9; 115 ▽; 119 ∩ on the right below No. 9; 120 ∩) have been created by the rough ground-scouring of cold ice with the participation of breaking-out and extracting processes, so that their rough lee-slopes visible today ought to have already been developed primarily.

Due to the increase of the glacier surfaces to ca. 6000 m (––– next to No. 67; Figure 28; Photo 116 ... next to No. 67) the western section of the Ngozumpa source depression SSE below Cho Oyu (No. 4), the currently, i.e. interglacially remaining glaciation of which accumulates in the Lungsampa valley glacier as a tributary stream of the Ngozumpa glacier (Figures 3 and 19; Photo 119 below Nos. 4–67; 120), was separated only by the glacial horn of the 6066 m-peak (Figure 3 No. 67) from the eastern ice discharge from the Ngozumpa source depression.

A catchment area also connected to the Lungsampa tributary stream is the currently only insignificantly glaciated Lhabtshan Drangka (Photos 116 and 117). From the High Würm up to the Late Glacial of the last glacial period (Stages 0–IV; Table 1) an ice transfluence has taken place across an at least 5570 m-high pass (No. 70 and Figure 28: 5700 m-point) via the neighbouring Sumna Drangka and the western Nangpa Drangka, i.e. upper Bote Koshi (Figure 3). The characteristically rounded mountain ridges close to the pass (Photo 116 ∩ black; 117 ∩ small on the right and left near to No. 70 and ∩ large below No. 70) point to a glacio-geomorphologically efficient ice flow in a W/E, i.e. E/W direction. A subordinated transfluence pass has led into the S-parallel Gyazumpa Drangka (←; Photo 116 ←). During the Late Glacial the encircling flow connected with it and the lateral erosion of the ice between the two transfluence passes and the entire transverse crest concerned between Sumna- and Ngozumpa Drangka have created several glacial horns (Figure 3 between No. 70 and Panorama 128; Photo 116 above, between ← and 70 →; 117 between No. 70 and the left margin).

The holocene to historical development of the Labtshan glacier, i.e. -glaciers (Lhabtshan E-glacier and Lhabtshan 5560 m-summit S-glacier) including the corresponding ELA-depression (Table 3; Figure 19) has been reconstructed in detail and supported by absolute datings (Photos 116–118; Table 1; 2 Nos. 7 and 8). Because of the Holocene end moraine series of the Lhaptshan glacier (Photos 116, 117 and 119: V) this local glacier development in the area of the lower Lhabtshan Drangka close to its confluence with the Ngozumpa Drangka, has led to a significant accumulation of the loose rock material and the moraines interpolated to approximately 400 m (Figure 28). These investigations are the subject of Section 3.6 (see below).

Beyond this neoglacial to historical glacier cover (Stages V–XII; Table 1) the reshaping of the glacigenic rock walls and valley flanks of the Lhaptshan Drangka by congelifraction with crumblings and the development of debris cones (Photos 116 and 117: △) has to be dated to ca. 13,000 years after deglaciation of the Late Glacial Sirkung Stage (IV).

Since the deglaciation of the glacier connection from the Lhabtshan Drangka, in the exit of the side valley lateral lakes have been formed, caused by the barrier of the Lungsampa main glacier branch with its orographic right lateral moraines (Photo 119 ○; Photo 121 below □). Just as in the side valley, so also in the main valley debris bodies have been built up due to crumblings during the deglaciation of the valley flanks ca. 13,000 years ago (△; Photo 120 △). Besides forms of debris cones they too show debris flows (Figure 3 half-left below Photo 112). In many places ground moraine has been buried in the core of these forms (Photo 120 ■).

The ground moraine remnants preserved in many topographically high and even steep positions (Photo 119 ■ small, below No. 15 up to the right below No. 57; 115 and 121: ■ black; 123 ■) together with abrasion roundings verify a Würmian glacier trim-line up to an altitude of ca. 5900 m a.s.l. (Photo 115 ... on the right; Photo 119 ...; 123 ... on the left; Figure 29).

Down the Ngozumpa Drangka over 100 m-thick accumulations of moraines have been observed in the glacier flow shadow of junctions of tributary valleys. They can mainly be classified as belonging to the Sirkung Stage (IV) (Figure 3 between the right and left of Panorama 128 up to Photo 146) and are supposed to be Late Glacial ground moraine bases or pedestal moraines of the Ngozumpa glacier and its tributaries (Photo 119 IV; 122 IV and III; 123 IV; 124 IV and III; 125 and 128: IV; 129 IV–III; 139 IV on the right; 144 IV). This idea is based on the suggestion that the High Würmian glacier has not yet had a ground moraine pedestal, because its ground scouring and deep erosion as a function of most important ice thickness must have been significant. Due to the uplift of the snow-line and step-by-step deglaciation, the ice thickness and the subglacial transport of material has decreased during the Late Glacial (Stages I–IV; Table 1), so that the ground moraine pedestal could successively develop. After deglaciation the fast fluvial cutting of the Ngozumpa river into this moraine pedestal has taken place. During the post-glacial advance in the neoglacial period, the Ngozumpa glacier followed this V-shaped valley in the ground moraine pedestal. Then, the much narrower holocene to past glacier has cut into the ground moraine material at a depth of over 100 m and built-up its own bed and lateral moraines.

The holocene to historical glacier history taking place in that dropped narrower glacier bed (Photos 119; 122, 123 and 131: VII; 124 ′VII; 125 VII and ′VII) is introduced against the background of its detailed absolute age dating in Section 3.6 (Photos 126 and 127).

In the S-parallel valley of the Lhabtshan Drangka, the Gyazumpa Drangka, also leading down to the E (Figure 3 on the left of Panorama 128; Figure 19), this Late Glacial genesis of pedestal moraine, its holocene cutting and excavation by the neoglacial and historical glacier advances can be found again in the section near to the talweg (Photo 128): on the orographic left side remnants of the ground moraine pedestal left behind by the dam- or pedestal glacier of the Sirkung Stage (Table 1), form a continuous ground moraine ledge testifying to a substantial thickness of the moraine material (the three IV from the right). On the orographic right side a pedestal moraine complex can be observed, too (IV on the very left). Neoglacial and historical end moraines are preserved from the middle and younger Dhaulagiri Stage (′VII and VII). Set into the level of the Late Glacial ground moraine pedestal, their positions show that the related two glacier tongues have been worked into this pedestal and that at the same time the Late Glacial ground moraine has partly been dislocated by them.

The polish lines of the glacigenic flank abrasions (∩) prove past glacier trim-lines at 5600–5800 m a.s.l. (...); the large-scale arrangements of the positions of the Würmian glacier trim-line in the W-contiguous Ngozumpa main valley are evidence of a glacier trim-line even at 5900 m a.s.l. (cf. Figure 29; Photo 122 ... on the very right; 123 ... on the left; 125 ... on the very left and right below No. 7). Accordingly, the 5493 m high transfluence pass (Photo 128 on the right next to □ and above and right of ∩; Figure 3 below No. 71) S of the 5927 m-peak (No. 71) has been overflowed with a glacier thickness of at least 300, but probably 400 m. In the E-opposite, orographic left side valley of the Ngozumpa Drangka, the Gyumbanare Drangka, the catchment area is so high that it is still completely glaciated and the Gyumbanare glacier is connected to the Ngozumpa trunk glacier (Figure 3 on the right of Photo 115; Photo 123 □ above). Here, too, the holocene glaciation of the side valley (VII and □ above) has cut into the partly preserved Late Glacial ground moraine pedestal (IV; Figure 3 IV on the right somewhat above Photo 115). In this case it is even immediately adjusted to the denudation base of the trunk glacier (□ below).

On its orographic left side the Donag Drangka (Photo 129), the S-parallel valley of the Gyazumpa Drangka, shows a ground moraine terrace derived from a ca. 300 m-high ground moraine pedestal, i.e. a pedestal moraine (IV–III). This ground moraine terrace also exists in the Ngozumpa main valley (Photo 122 and 124: IV): from there it runs continuously into the orographic right side valley concerned (Figure 3 below Panorama 124). This proves the synchronism of its development by the connected side- and main glacier. With regard to the material of its ground moraine, this ground moraine pedestal passing in an unbroken gradient curve upward into the ground moraine cover of the valley slope (Photos 122 and 124: III) has already been built up before the Sirkung Stage (Table 1 IV), i.e. during the Dhampu Stage (III) and the earlier Late Glacial stages. On the current terrace face, i.e. on the surface of the pedestal moraine base which was still intact during the Late Glacial, the glacier bottom was situated for the last time during the Sirkung Stage (IV). Afterwards the postglacial deglaciation and fluvial dissection of the pedestal moraine base (see above) has taken place. The C14-sample (Table 2 No. 6) taken from the surface of the pedestal (Photo 124 No. 6; Figure 19 No. 6) showed a minimum age of 2705 ± 235 YBP. This is a middle-neoglacial age. It cannot be related to the genesis of the pedestal ground moraine because the dated peat hummocks at 5230 m a.s.l. are situated close to the current upper limit of alpine turf and can only have been developed thousands of years after deglaciation. This was only possible during the much warmer climate in the middle Holocene.

How much warmer it was during the neoglacial period compared with the late Late Glacial is shown by the only insignificant glaciation of the Donag Drangka at that time (Photo 129 V; Figure 19). There, a merely 1.5 km-long wall foot glacier fed by avalanches has existed below the 5941 m-peak (No. 72). Its wealth of debris has led to a dumped end moraine (■), which after thawing has still contained permafrost and, accordingly, has become a rock glacier (Figure 3 on the right above No. 72). At the valley head of the Donag Drangka a roche moutonnée landscape is preserved (Figure 3 above No. 72; Photo 129 ∩ white, on the right above ■), created by the High Würmian to early Late Glacial glacier ground scouring. This ground scouring has taken place before the regressive covering of the valley bottom by the material of the ground moraine pedestal. The highest flank abrasions (∩ black and white above) prove a High Würmian ice level up to 5650–5700 m a.s.l. (...) and thus a ca. 250 m-thick ice transfluence across the polished 5486 m-pass at the valley head (◠ black on the left; Figure 3 above No. 72) into the contiguous Bote Koshi. Owing to this, at the time of the maximum glacier filling of this mountain relief, a valley glacier system has existed, communicating like an ice stream network and merely pierced by crests and summits over 5700 m in the form of glacial horns (Figure 3 e.g. No. 72).

The Gokyo Drangka is the southern parallel tributary valley of the Donag Drangka. Its neoglacial to historical glacier history is presented in Section 3.6 (see below). Here, the preservation of glacigenic abrasions has to be mentioned reaching up to the ca. 5500–5600 m-high spur summits (Photo 130 ∩ and ⊃ large). They testify to the Würmian ice level of the N-adjacent valley about 5600–5700 m (... bold; 122 ... on the right of No. 69; 124 ...). At the valley head a transfluence between Gokyo- and Donag Drangka has existed (Photo 130 ... fine). However, the roche moutonnée landscape there (∩ small; Figure 3 on the right of No. 72) has still been polished during the Holocene (cf. Figure 19). In the side valley exit of this valley, too, a terrace of a ground moraine pedestal (IV) has been preserved (Figure 3 on the right of Panorama 130, IV). Due to its ice level which in the area of the Gokyo Drangka was heightened to 5600 m a.s.l. and even more, the Ngozumpa parent glacier has been widened into the side valley by ca. 1 km to the W. With its orographic right ice margin (Photo 131 ...; 125 ... on the right) it has reached up to the summit superstructure of Pa Ri (No. 69) and undercut it. Correspondingly, the rock ridge running diagonally below, has been polished at a right angle and rounded (∩). On these rock roundings ground moraine remnants with and without erratic tourmaline-granite boulders have been left behind (Figure 3 on the right somewhat below Panorama 131).

Besides two very steep orographic left side valleys, which as eastern protrusions have been filled with ice by the Ice Age Ngozumpa parent glacier, the 3 km-long valley opposite the Gokyo Drangka, running from Kangchung (No. 57) down to the SW, has to be mentioned. At its valley head a ca. 5460 m-high Würmian transfluence pass covered with ground moraine is located, leading to the valley head of the Nyimagawa Drangka (Figure 3 on the left of No. 57). As confirmed by ground moraine and abrasion roundings, it has been overflowed by an ice at least 200 m-thick (Photo 125 ... on the right below No. 57). In this right side valley of the Ngozumpa Drangka, too, a late Late Glacial ground moraine pedestal has been preserved (Figure 3 on the right of Panorama 125, IV). It is ca. 260 m-high and topographically and glacio-gemorphologically corresponds with the rest of the ground moraine pedestals in the Ngozumpa Drangka and its tributary valleys already mentioned (Photo 125 IV black).

Along the orographic left main valley flank the mountain spurs of the intermediate valley ridges between those side valleys have been abraded back into glacigenically triangular-shaped slopes (Figure 3 between on the right below Photo 115 and on the right of Photo 127). Besides current crumblings, abrasion roundings are also partly preserved (Photo 125 ∩,↶,↷, between below Nos. 7 and 53; 132 ↶, ∩); ground moraine covers have also remained (Photo 125 ■; 132 III).

An approximately 2 km-wide further terrace of a ground moraine pedestal – here 320 m-high – forms an accumulative confluence step of the Nyimagawa Drangka to the Ngozumpa Drangka (Figure 3 on the right of Photo 132, IV; Photo 125 IV white; 139 IV on the right). It conserves the level of the glacier ground of the Ngozumpa parent glacier in the area of the inflow of the Nyimagawa glacier during the Sirkung Stage (IV). On this ground moraine pedestal forming the valley bottom of the Nyimagawa Drangka, several of the neoglacial tributary glaciers of the already ice-free Nyimagawa Drangka have discharged, so that their end moraines are situated upon it (Photo 133 V and ′VII; Figure 19).

In the approximately 11 km-long valley chamber between the current terminal of the Ngozumpa glacier and the inflow into the Imja Drangka (Figures 30 and 31), undisturbed High Würmian ground moraine covers are mainly preserved on the orographic left valley flank (Figure 3 on the right of the Panoramas 134–144; Figure 19 from above No. 4 up to the lower margin; Photo 138 ■; 142 the two ■ on the left; 144 ■ black; 145 the two ■ from the right; 146 ■; 148 ■ black). The Würm Age accumulations of ground moraine on the right Ngozumpa valley flank have been reshaped, i.e. dislocated by the Late Glacial hanging glaciers of the side valleys downward from the W (Photo 140 ■ black and white above; 145 ■ on the left; 148 ■ white on the right). A large part of the orographic right masses of ground moraine treated here, for the last time have been re-sedimentated in the form of lateral moraines of the Dhampu- and Sirkung Stages (Figure 19 from the left above No. 4 up to the lower margin; Photos 134, 135 and 138: IV; 139 the two IV on the left; 140 and 142: III; 143 IV and III). These tributary glacier tongues flanked by the lateral moraines have flowed into the Ngozumpa parent glacier with which they have built up a joint pedestal moraine basement. This ground moraine pedestal with its relicts develops terraces of pedestal moraines in each of these side valley exits (Figure 3 between Panorama 134 and Photo 103; Figure 30 WSW of the Ngozumpa river; Photo 134 ■ black; 139 the left two ■; 142 ■ below). In the exits of the orographic left side valleys, the Gyalagba- (or Tschom-) and Konar Drangka, pedestal moraine terraces are also located which have been developed in a similar way (Figure 3 on the right of Panorama 138 and on the right somewhat below Photo 103; Photo 142 IV on the left; 144 IV).

In the down-valley bevelled continuation of this pedestal moraine level which, genetically speaking, belongs together, the ground moraine surface of the Phortse settlement is situated (Figure 3 on the left of Panorama 148; Photo 138, 147 and 148: 0-III). Here, a several metres-thick ground moraine overlay on a terrace-like rock pedstal is concerned. During the maximum stage of the Würm Age (0; Table 1) and the Late Glacial Stages I–III the Ngozumpa glacier has integrated this rock pedestal into its ground moraine pedestal. As can be concluded from ELA-estimations, the Ngozumpa glacier tongue of Stage IV has just not reached this position any more, so that the Dhampu Stage (III) has caused a last reshaping of the ground moraines.

The Ngozumpa glacier is still a dam- or pedestal glacier with the ability to heighten its bed by the build-up of a pedestal ground moraine (Figure 3 on the right above Photo 133).

On the rock flanks above the remnants of the ground moraine cover preserved *in situ*, in the lower section of the Ngozumpa Drangka, glacigenic flank abrasions are partly preserved. They frequently occur on glacigenically back-polished triangle-shaped slopes (Figure 3 on the right and left of Panorama 134–145) (Photos 138, 144 and 145:↷, ∩,↶). The highest polish lines, which provide evidence of the High Würmian glacier level and in sections have been reshaped by those Late Glacial hanging glaciers, run from ca. 5500 down to 4600 m a.s.l. (Figure 31) (Photos 138, 143 and 145: ... 148 ... below and on the right of 74). Accordingly, the then glacier surface has lain here ca. 1800–900 m above the snow-line (ELA), i.e. it belonged to the glacier feeding area. The valley cross-profile shows a more or less clear trough form (Figures 30 and 31; Photo 143 profile line above the two ■). This also applies to the side valleys, as the Konar Drangka (Photo 44). At the same time a division into a wide, nearly trough-shaped form located above (Photo 138 in the area of ■) and a lower V-shaped one down to the talweg is obvious (somewhat above V; Photo 145↓; Figure 30). This shows the late Late Glacial to current fluvial dissection of the ground moraine pedestal, which probably has already started subglacially. During this dissection the rock pedestal of Phortse has also been cut into a form similar to a glacial gorge (‘Klamm’) (Photo 147). The potholes high up on the flanks of this glacial gorge point to the fact that this – at least partly – has already taken place subglacially (Figure 3 on the left of Photo 104).

Summing up, it has to be established that the High Würmian Ngozumpa glacier consisted of a parent glacier with numerous connected side glaciers (Figure 3). This dendritic valley glacier system has received a feeder from the S-Tibetan ice stream network of the Himalaya N-side over the 5985 (5860) m-high Nup La (No. 63). Additionally, its surface has communicated with the Ice Age Khumbu glacier system (3.2) over the ca. 5760 m-high Changri La transfluence pass (on the right below No. 15) and, indirectly, over three further transfluence passes from the Nyimagawa Drangka into the E-adjacent Tshola Drangka (between right of No. 57 and No. 53). During the High Würmian period (Stage 0) three ice-overflowed transfluence passes have existed to the W, producing the connection between the Ngozumpa- and Nangpa- i.e. Bote Koshi valley glacier system. They are located between the Nangpai Gosum-massif in the N (No. 5) and the 5941 m-peak (No. 72) in the S. This large number of transfluence passes is a typological characteristic of an ice stream network. For this reason, too, the idea seems to be justifiable to understand the Ngozumpa valley glacier system as one part of the S-Tibetan ice stream network. The ice surface of the Ngozumpa parent glacier which from Cho Oyu (No. 4) and Gyachung Kang (No. 7) up to the confluence with the Imja parent glacier (3.4) was ca. 30 km-long, has inclined from ca. 6600 to 4500–4400 m a.s.l. As the valley- and glacier cross-profiles 18–21 (Figures 28–31) show, the High Würmian ice thickness which must be assumed as reaching as far down as the rock ground of the valley bottom, has increased from the upper to the middle Ngozumpa parent glacier to ca. 1300 m (Figure 29) and at most even ca. 1400 m (Figure 30), and then decreased to 900 m close to the confluence with the Imja parent glacier (Figure 31). The glacier surface of this 30 km-extended Ngozumpa parent glacier was situated ca. 2500–700 altitude metres above the contemporaneous (Würmian) snow-line. In principle under constant conditions, the ice thickness should have increased, because the glacier surface was situated far above the ELA everywhere, i.e. with regard to the climate far within the glacier feeding area. This applies due to a positive mass balance. The incline of the valley bottom, however, has changed. Its steepening in the lower valley section has led to an accelerated movement of discharge and thus to that reduction of ice thickness down-valley.

The ice thickness of the modern Ngozumpa glacier amounts to ca. 300–500 m (Figure 29). By approximately the same value it has scraped itself into a correspondingly thick ground moraine pedestal (Figures 28 and 29). Down-valley from the current glacier terminal this ground moraine pedestal accumulated under the Ngozumpa glacier during the Late Glacial (Stage I–IV; Table 1) has been cut by the Ngozumpa river up to a depth of approximately 300 m (Figure 30).

3.6. Late Glacial-, neoglacial and historical glacier positions, snow-line depressions and absolute ages of medium-sized valley glaciers in the Ngozumpa Drangka (valley) on the south slope of the Cho Oyu Himalayas (see Tables 3 and 4; Figures 3 and 19)

The sequence of the holocene glacier positions in the area of the Ngozumpa Drangka and its side valleys is recorded in Table 3. The especially clearly developed end- and lateral moraines of these glacier positions are marked in Figure 19. In the Ngozumpa Drangka no glacier has come to an end during the High Würmian glaciation (Stage 0; Table 1). All side glaciers flowed into the Ngozumpa parent glacier, which has left the Ngozumpa Drangka (3.5) by flowing into the Imja parent glacier (3.4). This has still applied to the Late Glacial Stages I and II.

During the Late Glacial Stage III, the Dhampu Stage, only the East Khumbui Yul Lha glacier (Table 3 columns 1 and 2) (Photo 148 ○ on the right below No. 74) has built up an end moraine (Figure 19 III on the left lower margin). It is located at 3850 m a.s.l. (Table 3 column 5). The average altitude of the catchment area amounts to 5580 m a.s.l. (column 4), so that an orographical mathematical snow-line (ELA) at 4715 m a.s.l. (column 7) has been calculated for this E-exposed cirque glacier (columns 6 and 12). Compared with the current snow-line altitude at 5600 m a.s.l. (column 9) this means a snow-line depression of 885 m (column 10). The highest summit of the glacier catchment area is the 5761 m-high (column 3) Khumbui Yul Lha (Figure 3; Photo 148: No. 74). The absolute time limit of this glacier position has been settled by the glacio-gemorphological reference to a C14-age, obtained in the near surroundings, as being older than 4165 YB 1950 (Table 3 column 11) (see Table 2 No. 3; Figure 19: No. 3). During the Dhampu Stage (III) the East Khumbui Yul Lha glacier was 2.75 km-long (Table 3 column 8). The snow-line (ELA) has been calculated according to the formula: average altitude of the catchment area (m a.s.l.) (column 4) minus altitude of the ice margin (m a.s.l.) (column 5) divided through 2 plus altitude of the ice margin (m a.s.l.) (column 5), i.e.: $5580-3850=1730$; $1730{:}2=865$; $865+3850=4715$ m a.s.l. (column 7).

During the late Late Glacial Stage (IV) (Table 1), the Sirkung Stage, the Ngozumpa main glacier (Table 3) has reached down to 3580 m a.s.l. (column 5) and at the same time has approximately reached the exit of the Konar Drangka (column 1; Figure 19 on the left of IV close to the lower margin; Photo 138 between IV below and 0–III; 142 below ▼ and IV on the left; 145 in the area of the two □). The orographic snow-line (ELA) of that glacier has been calculated at 5440 m a.s.l. (Table 3 column 7). At that time the Konar glacier has reached down to 3720 m (Table 3 columns 1 and 5; Photo 144 IV; 142 IV on the left) and proves a S-exposed snow-line (ELA) at 4760 m a.s.l. (column 7). Accordingly, the difference of the snow-line between the two S-exposed glaciers amounts to 680 m. This provides evidence that the Late Glacial snow-line has fallen away approximately 700 m from the N, where the main feeding area of the Ngozumpa main glacier was situated, to the S, where that of the Konar glacier was located. Owing to the break-off of the summer monsoon during the High Würmian period (Stage 0) as a result of the complete build-up of the Tibetan inland ice (Kuhle, 1986e, 1987a, 1988a, 1989, 1998a, 2002b), this amount of falling away has been reduced to less than the half, i.e. to ca. 300 m. This amount has been taken as a base for the ELA-incline from N to S recorded in the summary of Section 3.5

The fourth Late Glacial ice margin position which has been evidenced, is that of the Dole glacier. During the Sirkung Stage (IV) (Table 1) its tongue end has reached down to 3980 m a.s.l. (Photo 142 IV on the right; Figure 3 on the right below Panorama 142 IV). The snow-line of this E-exposed, 4.2 km-long hanging valley glacier has run at 4765 m altitude (cf. Table 3). The classification as belonging to Stage IV results from an ELA-depression of 835 m (Table 3; cf. Table 1) and the position of this ice margin 250 altitude-metres below the next higher one, which with ca. 4165 YBP has been dated as an ice margin position of the oldest neoglacial period (Nauri-Stage V; see below) and set into the middle Holocene.

A further 120 ice margin positions in the Ngozumpa Drangka and its side valleys and the characteristics of their glaciers are noted in Table 3. The absolute datings, which have been arranged according to the glacio-geomorphologically substantiated and due to the calculation of snow-line depressions ensured relative chronology of those ice margin positions, can be found in Table 2 (Nos. 1–9).

A good 1 km up-valley of the Sirkung-Stage (IV)-ice margin position of the Dole glacier (see above) the locality is situated where C14-sample 3 has been taken on an end moraine (Figure 19 No. 3). It consists of glacial till with polymict gneiss- and metamorphic graywacke boulders. The dating concerns mud of acid alpine moor soil taken from a depth of 0.5 m. Its age amounts to 4165 ± 150 YB 1950 (cf. Table 2). This C14-age puts the ice margin into the neoglacial Nauri-Stage (V), thus classifying it as belonging to a glacier advance which has taken place in the Himalaya and all of High Asia between ca. 5500 and 4000 YBP (Kuhle, 1986g). The related E-exposed snow-line depression (ELA) of this – at that time 2.4 km-long-glacier amounted to 4890 m a.s.l. (cf. Table 3: Dole glacier, columns 6–8). Due to the extremely high ELA-depression of 710 m (column 10) a glacier surge induced by heavy monsoonal rains can be suggested to have caused this comparatively low ice margin position (cf. Table 1 Stage V: ELA-depression of 150–300 m on average in all of High Asia).

The sampling locality of C14-sample 1 is again further upward on an end moraine in the upper Dole Drangka (upper Dole hanging valley) at 4410 m a.s.l. (Figure 19 and Photo 141 No. 1). The dated soil is 2050 ± 105 YBP old and lies on moraine material with metamorphosed graywacke (Table 2, No. 1). Immediately adjacent in the tongue basin, a second dating has been carried out concerning peat, lying on gneissic gravels (Table 2, Figure 19 and Photo 141: No. 2), which with 2400 ± 140 YBP has confirmed a similar age. This age and the next higher ice margin position compared with Stage V (see above) classifies this end moraine as belonging to the neoglacial older Dhaulagiri-Stage (VI) (Table 3). The again next higher and thus next younger ice margin position of this valley is situated at 4680 m a.s.l. (Figure 19 ′VII above Sample 1) and so belongs to the youngest neoglacial stage, i.e. the middle Dhaulagiri Stage (′VII) (Table 3).

The sampling locality of C14-sample 4 is situated in the Machhermo Khola (Drangka), an orographic right side valley at 4440 m a.s.l. (Photo 135 and Figure 19: samples No. 4) connected to the Ngozumpa Drangka somewhat further up. By means of humus soil and peat, lying on end moraine material (Photo 136 No. 4) a C14-age of 2350 ± 295 YBP has been noted, which places this end moraine of the Machhermo glacier into the neoglacial to older Dhaulagiri-Stage (VI). The lowest ice margin lay ca. 40 m lower at 4400 m a.s.l. (Table 3). The next younger ice margin is located at 4560 m a.s.l. and thus has to be classified as being from the middle Dhaulagiri-Stage (Figure 19 ′VII on the left, somewhat above No. 4; Table 3). Again further upward, i.e. during the historical glacier stages (VII–X or recent), the Machhermo glacier has split into two glaciers, the South- and North Machhermo glacier (Table 3; Figure 19 VII on the left above No. 4).

Between these absolute datings of the ice margin positions of the Dole- and Machhermo glacier (Figure 19 Nos. 1–3 and 4), the South- and North Luza glaciers were situated in a similar position, so that the age of their stages can be chronologically extrapolated (Table 3).

The C14-dating locality 5 is in the orographic right lateral valley of the Ngozumpa main glacier, again further up the Ngozumpa Drangka (Figure 19 and Photo 124: No. 5). Here, at 4910 m a.s.l., the oldest soil cover on glaciofluvial lateral sands has been dated to 3345 ± 550 YBP (Table 2 No. 5; Photo 126 ● = white sample case below). The sand is younger than the lateral moraine, which flanks this lateral valley, and the ground cover is younger than the lateral sand. Accordingly, this right lateral moraine of the Ngozumpa glacier belongs to the older Dhaulagiri-Stage (VI) (Table 1; Figure 19 VI on the left below No. 5; Photo 121 and 128: VI). This dating makes clear that the neoglacial Ngozumpa glacier had already nearly the same width as the historical and contemporary ones and that the important difference in magnitude is due to the dimensional leap between the late Late Glacial Sirkung-Stage (IV) and Stage V or VI. Accordingly, the neoglacial Ngozumpa glacier body has eroded itself into the Late Glacial basement of pedestal moraine (Photo 124 and 125: IV) (see Section 3.5).

In some places of the orographic right lateral moraines close to the Ngozumpa glacier, on boulders the size of metres, lichens of Rhizocarpon geographicum 0.9–3.2 cm in diameter (Figure 19 lichen-diameter 0.9–3.2) have been found. As for the corresponding geomorphological altitude in the European Alps at a medium growth of 1 cm^2 within 60 years (information kindly supplied by the lichen-specialist G. Follmann, Museum of Natural History Kassel, Germany, 26/3/82) this would mean a lichenumetrical age of ca. 153–603 years ($r^2 \times 60 = 3.14159 \times 0.9^2 \times 60 = 3.14159 \times 0.81 \times 60 = 2.5446879 \times 60 = 152.681274$; $3.14159 \times$

$3.2 \times 60 = 10.053088 \times 60 = 603.18528$). This estimate would classify the lateral moraines concerned as belonging to the historical Stages X (younger Dhaulagiri-Stage) to VII (Figure 19 VII between No. 4 and on the right above No. 8 along the current Ngozumpa glacier; Photos 115, 119, 122, 125, 132 and 131: VII). However, up to now we are still waiting for the establishment of a chronologically calibrated lichenometric growth curve of the Himalaya S-slope.

The finding of Rhizocarpon geographicum lichens up to 25 cm in diameter is remarkable (Figure 19 lichen-diameter 25; Photo 127). The overgrown granite boulder photographed as an example is located in the orographic right Ngozumpa lateral valley, running between the second lateral moraine (seen from the glacier) and the valley slope along the outer slope of the lateral moraine. Because the growth of the lichens exponentially increases with an increasing extent, G. Follmann (in the meantime University of Cologne; friendly personal information in 1983) according to his comparative experiences supposes the age of this Rhizocarpon geographicum to be 3000–4000 years old. Thus, the calculation method (1 cm^2 per 60 years; see text of Photo 127) only applies to lichens of up to few centimetres in diameter. In view of this age estimate of the lichen-specialist, the moraine boulder with these very large specimens of Rhizocarpon geographicum has lain in the same position, i.e. without any movement, for 3000–4000 years. So, the lichen classifies the corresponding moraine – and this is also true with respect to geomorphology and chronology – as belonging to the older Dhaulagiri-Stage (VI) (Table 1) 2000–4000 years ago. This lichenumetrically-dated moraine ramp forms the continuation of the same lateral moraine 5 km down-valley (Figure 19 No. 5; see the same orographic right moraine 11 km up-valley: Photo 121 VI), the age of which has been C14-dated as being somewhat older than 3345 ± 550 YBP (see above). Thus, by means of the two absolute age-data a mutual confirmation has been found which corresponds to the geomorphological age-sequence, too.

The C14-dating locality 6 is also situated on the orographic right side of the Ngozumpa main valley glacier on the pedestal ground moraine terrace (Figure 19 and Photo 124: No. 6). The hummock peats at 5230 m a.s.l. yielded data for 2705 ± 235 YBP (Table 2 No. 6). This concerns a minimum age of the surface of the pedestal moraine basement superimposed on by them. Only during the middle holocene period was it warm enough to create hummock peats at this sea level. So, since the late Late Glacial deglaciation of this ground moraine surface of the Ngozumpa glacier of Stage IV, ca. 10 ka had to pass before alpine turf could develop (see Section 3.5).

The C14-dating locality 9 is situated in the Gokyo Drangka (Figure 19 and Table 2: No. 9; Photo 131 ⊗ 9) on the glaciofluvial alluvial debris fan (□; Figure 3 above Photo 131), i.e. the delta bedding into the Gokyo Tsho. The C14-age of the dated peats of hummocks of 1165 ± 110 YBP is evidence that the underlying gravels of the glaciofluvially reworked moraine have been sedimentated before this time, i.e. after the melting-back of the Stages V to ′VII of the E-Gokyo glacier. During the older Dhaulagiri-Stage (VI; 2400–2050 YBP, see above; Table 3; Table 1) the E-Gokyo glacier has still reached down to the position of the lake (Photo 131 ○) to lower than 4740 m a.s.l., so that the ELA must have run lower than 5170 m and the ELA-depression must have amounted to more than 280 m (Table 3 columns 5, 7 and 10). According to this dating the next-younger middle Dhaulagiri-Stage (′VII) of the E-Gokyo glacier must have been older than 1165, too, and due to the datings in the S-parallel valleys younger than 2050 YBP (Table 3).

The C14-dating localities 7 and 8 are situated in the Lhabtshan Drangka (Figure 19 and Table 2: Nos. 7 and 8; Photo 117 ⊗ 7 and 8; 118 ▲ 7 and 8) in the orographic left lateral valley of the Lhabtshan E-glacier and at the same time in the position of the tongue basin of the Lhabtshan 5560 m-summit south glacier at 5350 m a.s.l. (Figure 3 below Panorama 117–119; Table 3). The datings of root wood from Rhodiola yielded an age of 290 ± 70 and 440 ± 80 YBP (before 1950). Since this time,

Table 4. Average snow-line depression of medium-sized valley glaciers in the Ngozumpa valley (south slope of Cho Oyu) from the Late-Glacial Dhampu-Stage (III) to the recent Stage X (see Tables 1–3)

Stade (1)	Exposure (in order of importance) (2)	Average snow-line altitude (m a.s.l.) (3)	Average snow-line depression (m) (4)	Average glacier length (km) (5)	Number of glaciers taken into account (6)	Minimum age before 1950 (years) (7)
Dhampu III	E	4715	815	2.75	1	Older than 4165
Sirkung IV	E, S	4763	767	5.05	2	Older than 4165
Nauri V	E, S, SW	4970	560	2.81	7	4165
Older Dhaulagiri VI	E, S, W, SW	5073	457	3.50	10	2050–2400
Middle Dhaulagiri ‘VII	E, SW, SE, NE, S, W	5253	277	3.10	19	Younger than 2050
Younger Dhaulagiri VII	S, SE, E, NE, N, W	5383	147	2.17	18	440
VIII	E, S, NE, W, SE, NW	5431	99	1.98	22	320
IX	E, NW, NE, S, W, SE	5453	77	1.74	12	Younger than 320
X	S, E	5478	52	1.57	2	80–30?
Recent	E, S, N, NE, SE, W, NW	5530	0	1.53	30	30–0
					Total 123	

Table 5. Peaks and saddles in the research area

No.	Peak	Altitude (m a.s.l.)
1	Mt. Everest	8872 (8848)
2	Lhotse	8501
3	Makalu	8481
4	Cho Oyu	8202
5	Nangpai Gosum	7352
6	Changtse (Bei Peak)	7583
7	Gyachung Kang	7922
8	Nuptse	7879
9	Ngozumpa Kang	7806
10	Shar Tse	7502
11	Nangpai Gosum	7352
12	Chamlang	7290
13	Baruntse	7220
14	Pumori	7165 (7145)
15	7020 m-peak	7020
16	Karyolung	6611
17	Nupla	5885
18	6907 m-peak	6907
19	Chumbu	6870
20	Amai Dablang	6856
21	6853 m-peak	6853
22	6830 m-peak	6830
23	6825 m-peak	6825
24	Drag Karob	6801
25	Kyashar	6770
26	Pigpherago Shar	6718
27	Kang Taiga	6779
28	ca. 6750 m-peak	ca. 6750
29	Cho Polu	6734
30	6730 m-peak (Baruntse SE-satellite)	6730
31	6720 m-peak	6720
32	Kang Karob	6705
33	Khumbutse	6697
34	Panayo Tuppa	6696
35	Rim Ri	6677
36	Tramserku	6608
37	Iswa Peak	ca. 6600
38	6571 m-peak	6571
39	6550 m-peak	6550
40	Taboche	6367
41	6510 m-peak	6510
42	6480 m-peak	6480
43	ca. 6450 m-peak	ca. 6450
44	6830 m-peak 'Chonku Chuli'	6830
45	Peak 3	6477
46	Shipton La	4135 (4127)
47	Iswa La	5340
48	Ekrate Dada	6213
49	Chang La	7066
50	Lho La	6026
51	Rapui La	6548
52	Mt. Everest (West Ridge)	7309 (7205)
53	Jobo Lhaptshan	6440
54	Lingtren	6749
55	6145 m-peak	6145
56	6119 m-peak	6119

Table 5. Continued

No	Peak	Altitude (m a.s.l.)
57	Kangchung	6103
58	6238 m-peak	6238
59	6430 m-peak	6430
60	Kongde Ri	6187
61	6571 m-peak	6571
62	Nangpa La (Khumbu La)	5716
63	Nup La	5985 or 5860
64	Pumori La	6146
65	Lingtren La	6150 or 6126
66	6845 m-peak	6845
67	6066 m-peak	6066
68	Kyajo Ri	6186
69	Pa Ri (6073 m-peak)	6073
70	5570 m-saddle	5570
71	5927 m-peak	5927
72	5941 m-peak	5941
73	Kusum Kanguru	6369
74	Khumbui Yul Lha	5761
75	5719 m-peak	5719
76	6296 m-peak	6296
77	6907 m-peak	6907
78	Pangbug Ri	6716
79	Menlung La	5883
80	Kang Korob	6705
81	Drag Korob (or Drangnag Ri)	6801
82	5890 m-pass	5890
83	Tangi Ragi Tau	6940
84	Trashi Labtsa	5755
85	Pigpherago Shar	6718
86	Panayo Tuppa	6696
87	Teng Kangpoche	6500
88	6180 m-peak	6180
89	5967 m-peak	5967
90	5949 m-peak	5949
91	5970 m-peak	5970
92	Kabsale	5583
93	Numbur	6959
94	6797 m-peak	6797
95	5650 m-col	5650
96	6589 m-peak	6589
97	6362 m-peak	6362
98	6425 m-peak	6425
99	5977 m-peak	5977
100	6477 m-peak	6477
101	Jobo Garu	7181
102	ca. 6000 m-tower	ca. 6000
103	Dragkar Go	6793
104	6263 m-peak	6263
105	6508 m-peak	6508

plus the time needed for plant settlement, this small tongue basin must have been devoid of ice. Between the melting-back of the Lhabtshan 5560 m-summit S-glacier tongue and this development of vegetation, the lateral fan (Photo 117 between VI and ⊗ 7 and 8; Table 2 Nos. 7 and 8) in the orographic left lateral valley of the Lhaptshan E-glacier has additionally been sedimented. Before, the tongue end of the Lhabtshan 5560 m-summit S-glacier might have filled the tongue basin as far down as 5290 m a.s.l. and on the orographic right side it might have reached down to here, i.e. to 5350 m a.s.l. As to the timing, the younger Dhaulagiri-Stage (VII) could be taken in consideration here, i.e. the time between 1700 and 440 or 355 YBP (Table 1). However, the calculated

ELA-depression of 130 m (Table 3 column 10) would be more convincing with regard to the next-older, middle Dhaulagiri-Stage (′VII) (cf. Table 1) which has taken place ca. 2000–1700 YBP.

How very rapidly, i.e. within which short period of time a geomorphologic reshaping by weathering takes place at this altitude with a permanent alternation between freezing and thawing, becomes obvious through the upper Lhabtshan Drangka. During the neoglacial Nauri-Stage (V) the fjell-like mountain ridges with a bedrock surface of Lower Tibetan gneisses of many varieties (6b in Nepal Geological Map 125,000; 1985: Sheet No. 71L-D) were still covered by glacier ice with a thickness of many decametres (Photo 116 ∩ black; 117 ∩ on the right below No. 70; Figure 19) and have been abraded into the form of roches-moutonnées by glacigenic ground scouring (Figure 3 between No. 70 and Panorama 117). During the last 4000–5000 years since the deglaciation of the Nauri-Stage ice cover the rock faces have been modified into boulder fields, so that the smoothings have been roughened. Corresponding observations have been made in the uppermost catchment area of the Lhabtshan 5560 m-summit S-glacier (see above) melting down since at most 1700 to at least ca. 400 YBP. Here, too, the at that time glacier-covered rock faces in the cirque (Figure 3 below Panorama 119) have been dispersed into metre-sized, edged boulders weathered *in situ* (Photo 117 boulders on the right in the foreground). A corresponding dispersion of outcropping gneiss faces smoothed by glacier polishing is known of the inland ice areas of Scandinavia and therefore belongs to the preserved store of glacial key-forms. In terms of this character of key-forms, the existence of roughenings due to physical weathering of strikingly rounded mountain ridges such as these ought to be stressed in our research area, too (see e.g. Photo 121 ∩ white above).

A representative example of the unbroken sequence of the late Late Glacial to historical glacier positions between ca. 13,500 (Stage IV) and 300–180 YBP (Stage IX) supplies e.g. the southernmost orographic left side valley of the Nyimagawa Drangka (Figure 3 on the left of No. 53). Below the W-wall of Jobo Lhabtshan (No. 53) the Late Glacial, neoglacial to historical moraines IV, V,′VII, VII–IX have been laid down in an increasing nearness to the Jobo Lhabtshan W-glacier (Photo 133; Figure 19). The current glacier tongue of this side valley ends at 5120 m a.s.l.

Section 3.6 has to be summarized with reference to Tables 2 and 3. Table 3 shows 123 ice margin positions of time-specific glacier entities (Figure 19). According to relative geomorphological datings, snow-line depressions and absolute age determinations (Table 2) they have been classified as belonging to the 10 glacier stages developed within the Ngozumpa Drangka (Stage III to recent; recent = XI and XII after Table 1). In addition, the absolutely dated ice margin positions supply a system of reference as to the glacier positions of the parallel side valleys situated in between without absolute age data, as e.g. the Gyazumpa Drangka and Donag Drangka (Photo 128 IV, VI, VII and ′VII; 129 III, IV and V). This system of reference interpolates the absolute ages of glaciers of the same ELA- depression at the same exposition. Special examples as to the classification of glacier positions with their ice margin positions, snow-line depressions and C14-ages have been introduced in order to explain the method. Further details of the glacier history since the Dhampu-Stage (III) can be inferred from Table 3 under consideration of Table 2 and Figures 3 and 19.

Table 4 summarizes the individual observations and calculation results by arithmetical mean values. The average snow-line altitudes, average snow-line depressions and minimum ages before 1950 presented, which apply to this investigation area of the Himalaya S-slope, are added to the large-scale data in Table 1. This table is based on datings from the whole of High Asia.

3.7. The highest former trim-lines and glacier thicknesses in the Imja Drangka between the junction with the Ngozumpa Drangka up to the confluence of the Imja Drangka and the Nangpo Tsangpo Drangka, i.e. Bote Koshi (Figure 3 between Photo 102 and below 84)

Before discussing the ground moraines reaching the highest positions on the valley flanks, a futile attempt of C14-dating on the end moraine near Tengboche (Photo 152 ■ below No. 20; see Table 2 No. 14) has to be mentioned. Here, a wood-sample taken from 1.5 m below the surface of overlying glaciofluvial sand, 350 m above the Imja river, has been dated as being younger than 1955. Geomorphologically dated, the end moraine belongs to the Late Glacial Dhampu-Stage (III, Table 1). Strictly speaking, the glaciofluvial sand ought to be of a similar age, because without an attached glacier ice a catchment area for the discharge of the necessary water is lacking on the moraine. Obviously, recent slide movements have established here a connection between a young piece of wood and much older sediments. This is one of the numerous examples of the relief- and monsoon-dependent false datings in the Himalaya due to secondary removal.

On the orographic right side down-valley of the confluence of Ngozumpa Drangka and Imja Drangka, the ground moraine reaches up to 4170 m a.s.l. (Photo 105 and 149) and somewhat further down- valley even up to 4300 m (Figure 32; Photo 51 ■ small). The ground moraine contains polymict, in part far-travelled boulders, among them erratic tourmaline-granite boulders on outcropping mica augen-gneiss.

The fine material matrix shows moraine-typical, relatively great clay portions of ca. 7–10% (Figures 52 and 60); the cumulative curves of the grain sizes present a bimodal, i.e. inclusive of the boulder- to pebble-sized skeletal portions a characteristic, trimodal course (Figures 52 and 60) (cf. Dreimanis and Vagners, 1971). This corresponds to the characteristic of the grain size distribution of moraines, as for the last time again introduced by Bennet and Glaser (1996, p. 158). Ca. 50–51% of the quartz grains are glacially crushed (Figure 37 Nos. 28 and 29). Due to the admixture of the erratic components it has to be ruled out that sharp-edged grains developed by fresh weathering *in situ* of the outcropping rock are concerned. The approximately similar portions of fluvially polished grains point to Late Glacial (Stage I; Table 1) subglacial work of the meltwater and thus secondary reshaping. In the High Würmian (Stage 0) this process was impossible, because the snow-line (ELA) ran at least 200–500 m below the localities of ground moraines discussed.

Here, the glacigenic abrasions of the rock forms, like rock roundings, reach up to a polish line about 4300–4400 m a.s.l. (Photo 149–152). Down-slope, the ground moraines described increase in thickness (Photo 150 and 152 ■ from left above to right below) so that they, near to the valley bottom, pass into remnants of a ground moraine pedestal (Photo 151 ■ large; Figure 3 above Photo 102). Due to the local development of gullies by the water of rain and melting snow, these covers of ground moraine have been incised since deglaciation (Photo 151 mainly on the right of ■ small; 152 on the right below ■ on the very left).

The orographic left valley flank shows ground moraine covers (Figure 3 on the left of No. 36 and on the left diagonally above No. 36) up to altitudes of 4200–4300 m a.s.l. (Photo 152 ■ on the left below No. 27; 157 ■ on the left below No. 73 black; 156 ■ on the left below No. 73; Figure 32 on the right below the 4500 m-point). Below, these overlays of ground moraine are interrupted in an areal and linear manner by down-slope hanging glacier beds, and below the cirques in the Tramserku WNW-flank (Photo 156 ○ below No. 26; 157 ○ on the left below No. 36; Figure 3 diagonally left below No. 36) also by slope ravines. In particular, however, their remnants have been preserved on protruding spur positions (■ below No. 73 white; Photo 152 second ■ from the left below No. 27). The related remnants of flank polishing (Figure 3 on the left diagonally above No. 36) and the abrasion level of the Würmian Imja glacier running about 4300 m, confirm the abrasion level of the orographic right flank (Photo 152 ... on the very right; 156 ... on the very left; 157_____ below Nos. 20–36; Figure 32 as down-valley continuation of Figures 27 and 31).

At the place where the orographic right valley flank of the section of the lower Imja Drangka, discussed here, reaches the valley exit of the Khumjung Drangka, a roche-moutonnée-like form has remained with a very flat scour- and a steep lee slope (Figure 3 on the left above Photo 154; Photo 154). Below the lee slope debris slopes due to crumblings have been created since deglaciation (△). The Khunde–Khumjung Drangka (Figure 59 between III and IV; Photo 151 between III and IV) is a hanging tributary valley, which during the Würmian period was filled by the local Khumbui Yul Lha S-glacier (Photo 155 on the left below No. 74 up to the left margin), as evidenced by its moraine mantling (Figure 59 below and on the right and left of Khunde). Two cirques served as catchment areas of this glacier. During the High Glacial Würmian period (Stage 0), this Khunde–Khumjung side glacier was completely integrated within the Imja glacier as an orographic right protrusion with one and the same glacier level (Photo ... 155 on the right below No. 83 and on the right below No. 74; 151 ...). At that time the outcropping rock pedestal in the underlying bed between Khunde and Namche has been covered by a more or less concordant ground moraine layer (Figure 59 moraine above – – – –). This has been sedimentologically evidenced (Figure 61) by a trimodal course of the grain-size curve, an extremely high clay portion and a sorting coefficient of 3.21. The morphoscopic analysis proves the lodgement till character of the sediment by more than 94% glacially crushed quartz grains in a transported material, i.e. a material which has not been developed *in situ* (Figure 37 No. 13). At that time the ice was connected with the Kyajo Drangka via the ca. 4200 m-high rock crest. Among others, evidence of this has been provided by the existence of the moraine cover (Photo 155 ▼; Figure 3: 24/03/03/1). The sample material shows a bimodal course of the grain sizes and contains clay. It has a sorting coefficient of 3.24 and, besides just 89% sharply edged quartz grains, still presents a fully 11% fluvially polished quartz grains, which at this crest position are only understandable in terms of deposition by subglacial glacier meltwater (Figure 63; Figure 37 No. 30). During the gradual lowering of the ice level, interrupted by Late Glacial advances of the Stages I–IV (Table 1), the Khunde-Khumjung side glacier has increasingly developed into an independent ice stream accumulating local, thick covers of ground moraine and then also end moraines (Figure 59 II,III and IV; Photo 151 and 155: III and IV). At the same time the direction of its advancing glacier tongue has changed from facing S toward Syampoche – so that the flow direction was transverse to that of the Khunde-Khumjung Drangka - up to facing E in the longitudinal direction of this morainic hanging valley of Khunde and Khumjung. During this development, the end moraine of the Late Glacial Taglung Stage (II) of this local glacier was situated (Figure 3 II above Photo 158) in the position of the Syampoche settlement. Later, its tongue basin has been filled up to its inner slope by the outer slope of the end moraine of the next-younger Dhampu Stage (III) (Figure 3 III above 13/03/03/2; Photo 151 and 155: III) (Figure 59 II and III). Due to this process of moraine attachment, the position of the front moraine near Syampoche has only been preserved as a convex bend of slope with glaciofluvial and glacio- lacrustine deposits of meltwater on the side facing toward the mountains (Figure 59 II). The determination of the minimum age of these deposits, which geomorphologically belong to the Late Glacial, has been carried out by means of two pieces of wood, dug from 130 cm depth (Figure 3, Sample 12), and yielding a C14-age of younger than

1955 (Table 2 No. 12). This proves the obviously very heavy morphodynamics close to the surface at this periglacial altitude level. In geomorphological terms, the Dhampu-Stage (III) front moraine of the Khunde–Khumjung side glacier, i.e. local Khumbui Yul Lha S-glacier is rather clear (Photos 151 and 155 III; Figure 3 above 13/03/03/2 and on the left of 13/03/03/1; III) and has been evidenced sedimentologically. The decametre-thick area of the inner slope of the front moraine (Figure 62) where the sample has been taken, presents a matrix with 16% clay and a trimodal course of the grain size curve with a So of 4.26 and ca. 90% glacially crushed quartz grains (Figure 37 No. 14).

During these Stages II and III, the Taglung- and the Dhampu Stage (Table 1), the tongue end of the Khunde-Khumjung side glacier has turned to the E. Perhaps it has even just met the Imja parent glacier during Stage II, because during Stage III this has no longer reached the inflow of the side valley concerned. Due to the uplift of the ELA, the tongue of the side valley, too, will not have reached down deep enough. During the last Late Glacial Stage, the Sirkung Stage (IV), the Khunde-Khumjung side glacier, i.e. Khumbui Yul Lha S-glacier, no longer flowed through the bottom of the current Khumjung Drangka valley form, but has already deposited its more or less markedly preserved end moraines on the N-side of the valley (Figure 3 IV on the left above Panorama 155; Photo 155, 151 and 154: IV; Figure 59 IV). This means, that the Khumbui Yul Lha S-glacier of this stage was no longer a valley glacier, but only a hanging glacier. Below the outlet of the end moraines, i.e. the positions of the former glacier mouth, cone sanders continue, which have been – and are still – formed into debris flow fans (Photo 155 ▽; Figure 3 on the left of Panorama 155). Further below, on the valley bottom of the Khumjung Drangka, the past glacier meltwater has accumulated glaciolimnic sand in the tongue basin of Stage III, in which a moraine lake had been developed (Figure 3 above 13/03/03/2; Figure 59 below Khunde). On the outer slope of its end- or lateral moraine (Figure 3, Sample No. 13; Photo 155 on the left of IV) at 4030 m a.s.l., 0.5 m below the surface, a piece of wood has been C14-dated to 210 ± 50 YBP (Table 2 No. 13). This means a minimum age of the moraine, which in the youngest case would classify the accompanying glacier as belonging to the historic Stage VIII, ca. 400–300 years ago (cf. Table 1). At that time, however, the snow-line depression was only ca. 50 m compared with today. Despite its altitudes about 5200–5700 m a.s.l., the catchment area of the Khumbui Yul Lha S-flank shows no current glaciation worth mentioning (Figure 3 below and on the right below No. 74; Photo 155 at ○ on the left and right below No. 74 are cirque bottoms covered with snow, but without a glacier). Thus, an ELA-depression of ca. 700 m would be necessary to render a glacier possible, which could have built up the end moraine of the minimum age. This is the snow-line depression of the Late Glacial Stage IV, ca. 13,500–13,000 YBP (Table 1).

There are two explanatory models for the glaciolimnic sands on the ground moraine terrace near the Trashinga settlement, 420 m above the contemporary talweg of the Imja Drangka (Photo 153; Figure 3 Photo 153; Photo 151 ■ large): (1) during Stage III they have been sedimentated in a tongue basin lake – dammed up by the end moraines of Stage II – in the Late Glacial tongue basin of Stage II of the Imja glacier; or 2. this lake, in which the sands have been sedimentated, has been dammed up by the Bote Koshi- i.e. Nangpo Tsangpo glacier. The latter case would mean, that – if the Bote Koshi, i.e. Nangpo Tsangpo glacier has passed the exit of the Imja Drangka with a thickness of 850 m, i.e. has closed it 850 m above the current talwegs about a good 2800 m a.s.l., when the Imja glacier had already cleared the confluence area up to the locality of the lake sediments – the Bote Koshi- i.e. Nangpo Tsangpo glacier must have had a larger catchment area than the Imja glacier. These occurrences must have taken place during Stage III. The larger catchment area can be suggested as being a confirmation of the very thick ice transfluence from Tibet across the Nangpa La into the Bote Koshi (Odell, 1925; Kuhle, 1998c, 1999b, 2001b, 2002a).

The glaciogenic and glaciolimnic accumulation complex in the confluence area of the Imja Drangka and Nangpo Tsangpo, i.e. lower Bote Koshi, is a polygenetic moraine complex with the character of ground- and medial moraines in the inset between the two valleys (Figure 3 Panorama 156, 157, 159; Figure 59 Namche). This observation obtained according to its geomorphology is confirmed in detail by the grain size- and morphoscopic analyses (Figures 64–71; Figure 37 Nos. 8–12 and 46). Thus, the matrix found on the orographic right side of the Imja Drangka (Figure 3: 07/04/03/1; Photo 157 ■ foreground on the left), which originates from the deposit classified as being from the Late Glacial Ghasa-Stage (I; Table 1), is typical of moraine (Figure 64; 37 No. 46). The clay peak with 7%, which is inconsistent with the alternative hypothesis of a rock avalanche, as well as the bimodal course of the grain size curve and the portion of 90.6% glacially crushed quartz grains, provide evidence of this. Moreover, the macroscopic analysis of the condition of the sediment and the boulders contained (see Photo 157) is proof enough. The chronological classification of this ground moraine as belonging to Stage I clearly results from the altitude level above the Imja Drangka talweg, i.e. the end moraine of Stage II (cf. Photo 157 I and II).

In many places (Photo 156 the two ▼ from the left; Figure 50 from I up to Namche) of this basement of pedestal ground moraine and later medial moraine inset, fluvial to limnic (lacrustine) sediments are evident (Photo 158). In these positions, situated ca. 360–700 m above the talwegs of the Imja Drangka and Nangpo Tsangpo, they can only be understood as glaciofluvial to glaciolimnic (lacrustine) sediments, deposited between the two joint valley glaciers in the form of marginal developments by meltwater, as e.g. lateral sander- and medial moraine lakes. Without these glaciers, an up-damming of the sedimentologically very young, diagenetically not yet solidified lake sediments and lake formations would be impossible in these positions, which due to the steep relief are topographically unfavourable (Kuhle, 1987a 407). The three samples taken from the glaciofluvial and glaciolimnic sediment covers, which have been chosen as representative for this area (Figure 3: 10/11/82/1 and /2; 11/03/03/1; Figures 65–67), show a slighter or stronger degree of washing-out from the surrounding morainic material. In general, the washing-out of the clay content increases (Figures 67 and 66) and the sorting coefficient decreases from 3.45 (Figure 66) up to 1.51 (Figure 67). The morainic origin of these fluvial, i.e. lacrustine (limnic) sediments and, accordingly, their glacio-specific character, is morphoscopically verifiable by the high portion of a good 90% glacially crushed quartz grains (Figure 37 No. 8), because due to the fact that valley fill is concerned, a corresponding weathering *in situ* has to be ruled out right from the beginning. The interplay of glaciofluvial activity and renewed use of the quartz grains by the transport of the glacier, typical of ground- and lateral moraine areas far below the snow-line, can be recognized by the fact, that a large portion of the fluvially treated grains has been crushed again (Figure 37 No. 8, remarks). Up to the present, a certain aeolian reshaping by catabatic winds is effective in this valley confluence near the Namche Bazar settlement, so that a quartz grain portion of 0.1% is dull (aeolian). Additionally, a further locality of glaciofluvial, i.e. glacio-lacrustine sands W above Namche Bazar has to be mentioned (Figure 3, Sample 11; Table 2 No. 11; Photo 159 on the right above the left ▼). They also lie on moraine (lodgement till). At a digging-depth of 0.7 m, a piece of wood has been dated there as being younger than 1955 YBP. Obviously, the recent to current movement of the ground is so strong, that reliable absolute datings are not obtainable. However, in geomorphological terms it is trivial that these sediments must be markedly older than 1955. They might be of Late Glacial age, i.e. from ca. 17,000 to 13,500 YBP because classified glacio-historically they belong to the Ghasa- to Dhampu-Stage (I–III; Table 1) of the Nangpo Tsangpo- i.e. Bhote Koshi glacier.

All the four samples of non-glaciofluvial or non-glaciolimnic material in the accumulation inset between Imja Drangka and Nangpo Tsangpo, which with regard to their spatial distribution and their characteristics are representative (Figure 3: 11/03/03/2 to /5; Figure 68–71; Photo 156 third to fifth ▼ from the left; 159 ■ on the left in the foreground and ▼), show the characteristics of morainic matrix. Bimodal (Figures 69–71) and even trimodal (Figure 68) grain size cumulative curves of the matrix are concerned here. The clay portions are significant and lie between ca. 10 and even 15%, whilst the sorting coefficients are situated between 4.12 and even 8.66%. A good 70–96% of the quartz grains of the medium sand fraction analysed are glacially crushed. They are mixed with erratic boulders, so that weathering *in situ* has to be ruled out. In the remaining small portions of lustrous grains, the normal, slight reshaping due to meltwater of moraines below the snow-line (ELA) can be observed. The macroscopic condition of the young clasts is unambiguously morainic anyway (Photo 158 and 160 ■). They show the characteristics of lateral-, medial- and end moraines with local indications of rock avalanche moraines (Photo 158 ■ white), but also of very tightly packed ground moraines (Photo 160) with crush resistances up to 8 kg/cm^2 even in a moistened condition. The tourmaline-granite boulders contained (○) are erratic and have travelled over a distance of at least 12.5–16.5 km from the bedrock near the Dingpoche settlement (cf. Nepal Geological Map 1:125,000 (1985): Sheet No. 72I-B).

To sum up, the question as to the glacier-historical development of the glacigenic accumulations in the inset of the confluence of Imja Drangka and Nangpo Tsangpo has to be answered, considering the sedimentology and geomorphology as well as the arrangement of their positions with regard to the maximum glacier trim-line reconstructed (Photos 156 and 159 ...). Three stages of development have to be differentiated:

(1) during the highest Würmian position of the glacier level (Stage 0) in this medium to lower altitudes of the valley talwegs, i.e. valley grounds below 3000 m a.s.l., the same has taken place what had happened in the upper valley areas during the Late Glacial period (cf. Sections 3.2; 3.3; 3.5), that is to say, the build-up of subglacial heightenings of ground moraines up to basements of pedestal moraines at a thickness of several hundred metres beneath the ice of the valley glacier (Figure 32). This subglacial, very progressive occurrence of moraines as a condition for the development of pedestal moraines is only possible several hundred metres below the snow-line. Accordingly, up-valley this process can only have taken place during the Late Glacial, but not during the Würmian period. This means, that during the High Würmian it could have only been rendered possible below, i.e. ca. 400–800 m below the ELA. In this manner, characteristic of ice dynamics, the Imja- and Bote Koshi glacier have enlarged their cross-section by up-lifting, filling the narrowest gorge areas near the talweg (Figure 3 see valley form between Photo 101 and 84) with ground moraine, and thus have reduced the flow friction. The 300 m-high terrace of a ground moraine pedestal on which the Trashinga settlement is situated (Figure 3 above Photo 102), as a remainder of this subglacial forming (Photo 151 ■ large; 152 second ■ from the right below; Figure 32), is proof of this moraine pedestal. Corresponding Würmian remnants of ground moraine pedestals, modified during the Late Glacial, are preserved at the same altitude about 3520 m a.s.l. near the Namche settlement (Figure 3 on the left of Photo 160 and on the right of Panorama 159; Figure 59 I Namche). This primary level of pedestal ground moraine has also been marked with 'I' in the Photos 156, 157, 159.

(2) during the early Late Glacial, approx. during Ghasa-Stage (I), the subglacial meltwater erosion, which increased with the rising snow-line, has caused the two valley glaciers to sink into this ground moraine pedestal. Because this was accompanied by a necessary reduction of the glaciers' width, the Würmian lateral remnants of the ground moraine pedestal have turned into Late Glacial lateral moraines. For this reason, the preserved secondary lateral moraines, which existed during the Ghasa-Stage, have been marked with 'I' (Photos 156, 157 and 159: I; Figure 59 I; Figure 3 I on the left above and I on the right below Photo 160). As for the Bhote Koshi-, i.e. Nangpo Tsangpo glacier this was still valid during the Late Glacial Stage II, whilst during the Taglung Stage (II) the tongue end of the Imja glacier was already situated above the confluence with the Bote Koshi glacier (see above). The glaciofluvial and glaciolacrustine (limnic) sands originate from paraglacial developments of lateral sanders, which the meltwater has deposited as still water sediments in the two lateral valleys beside the two glaciers and in their insets (see above).

(3) the contemporary surface forms preserved around Namche are no longer able to render these still water sedimentation possible, because the crests of the lateral moraines and, accordingly, also their outer slopes have been destroyed and wasted away, so that the primary forms of the lateral valleys as a condition for glaciofluvial and glaciolimnic sedimentation are no longer preserved. However, due to these sands they must have undoubtedly existed (cf. Figure 59). Correspondingly, the entire moraine valley in which the Namche Bazar settlement is situated, is a secondary, i.e. post-Late Glacial hollow form. Only with the melting down and -out of the Bhote Koshi-, i.e. Nangpo Tsangpo glacier, which was an abutment and a relative erosion base, could it develop. However, syngenetically and later on, this development of a moraine valley has taken place very fast by regressive erosion. To this point e.g. moraine boulders of granite and gneiss, the size of a hut, spread over the slopes (Photo 159 on the right and left above ↓). They do not lie in a primarily glacigenic position on the moraine slope, but, because of backward-shifting of the slope due to denudation of the fine components, have residually come to the slope surface, i.e. have been secondarily exposed. The striking width of the valley form (Photo 156 between I black and I white; Photo 159 from the left to right margin), could have been caused by the original inlay of a wide Late Glacial dead ice complex and the slidings and settlings accompanying its thawing-out.

Summing up Section 3.7, a Würmian Imja glacier trim-line at 4300 m a.s.l. (Figure 32) has to be indicated. It proves a maximum ice thickness of 1200 m down to the rock ground of the trough valley. This may apply at most to the early Würmian period. During the Late Würmian period, however, the glacier has been heightened on a ground moraine pedestal by ca. 300 m (Figure 32). Accordingly, at that time the thickness of the Imja glacier amounted to ca. 900 m. A confluence with the lower Bhote Koshi-, i.e. Nangpo Tsangpo glacier has taken place, for which in the area of the confluence the same ice level as for the Imja glacier – running at 4200 m a.s.l. there – has been verified (cf. Figure 36 with Profile 26, situated ca. 6 km up the Bote Koshi). Due to the ice level at 4300–4200 m altitude, this confluence area was very wide during the maximum glaciation. From the foot of the Khumbui Yul Lha (No. 14) up to down-valley of Namche (Figure 59) it reached a N/S-extension of ca. 5 km (Figure 3 from above Panorama 152 up to the lower margin of the map) and from the exit of the Kyajo Drangka up to the W-flank of the Tramserku (No. 36) a W/E-extension of even a good 7 km (Figure 3 from the left of 11.3.03/4 up to the middle between Photo 84 and No. 36). This means, that during Stage 0 (Table 1) the whole confluence inset with the positions of the Khunde, Khumjung and Namche Bazar settlements has been covered with the ice of the two valley glaciers.

The Würmian orographic snow-line in the confluence area has run at ca. 3600–3700 m. Accordingly, the glacier surface in the confluence area of the Imja- and Bote Koshi glacier was situated 600–500 m above the snow-line.

3.8. The highest former trim-lines and glacier thicknesses in the Bote Koshi-, i.e. Nangpo Tsangpo Drangka and its tributary valleys from the Himalaya main crest with Cho Oyu and the Nangpa La as a transfluence pass from Tibet in the N up to its confluence with the Imja Drangka in the SSE (Figure 3 between No. 4, 62, 100 and 102 and on the right below Panorama 159)

The Bote Koshi Drangka begins at the water shed of the High Himalaya between Tibet and the Himalaya S-slope on the Nangpa- or Khumbu La (Figure 3 and Photo 163; 168; 169: No. 62). This is a 5716 m-high, currently still glaciated pass, from which the Kyetrak- (or Gyabrag-) glacier flows down to the N, to Tibet, and the Nangpa glacier to the S, into the Himalaya S-slope (Photo 163 XI and XII on the left below No. 62; Photo 164 □). The Himalaya N-side with the current to Ice Age glaciation of the Kyetrak Chu has been reconstructed in detail (Kuhle, 1999b, 2001b, 2002a) (cf. Figure 11). The investigations resulted in the observation, that during the Würmian ice age (Stage 0) an outlet glacier of the S-Tibetan inland ice, i.e. ice stream network (I3) (Figure 2 Section 1), has flowed to the S across the Nangpa La, a transfluence pass, and into the research area (Figure 3) concerned. At that time the flow direction of the Kyetrak glacier was not to the N – as it is nowadays – but, due to the development of the inland ice, it was the reverse, i.e. to the S. Accordingly, that outlet glacier has overflowed the Nangpa La and, as Bote Koshi glacier, has received further influx from the local Himalaya tributary valley glaciers. The subject of the expedition 2003 (Figure 1 No. 4) was to find out in which way and up to which thickness this has taken place and which dimensions the Bote Koshi glacier has had. This is presented in the following.

The modern Nangpa-, Lunag- and Sumna glaciers form a dendritic valley glacier system, the glacier tongue surfaces of which are currently situated between 5716 and 4760 m a.s.l. (Figure 3 No. 62 and Profile 23 (Figure 33); Photos 161, 162 and 164): □ black). The area of the valley bottoms on both sides of these ice streams is filled with recent and historical moraines (XII–VII; cf. Table 1), neoglacial moraines (V = Nauri Stage) and remnants of a late Late Glacial ground moraine pedestal of the Sirkung Stage (IV) (Photo 161 X and IV; 162 VII–X,X,V,IV; 163 XII,XI,X,V,IV; 164 XI–XII,X). In many places the basal slopes of the valley flanks show debris cones and -slopes (Photos 161, 162 and 164: △; 163 △ small), heaped up in the lateral valleys of the valley glaciers since the Late Glacial to neoglacial deglaciation. They have often buried and reshaped the older ground moraine material (Photo 161 ■ on the very left and very right; 162 ■ with the exception of ■ below No. 102 and right down below No. 103). On the one hand these cones and slopes consist of the debris of crumblings from the glacigenically oversteepened trough flanks (Figure 3 on the right and on the right above No. 75; on the right and on the right below No. 77; on the right above No. 76; on the right below No. 5; on the left below No. 99), here formed in massive gneiss; on the other hand of ground moraine material dislocated slope-downwards. At some places, so e.g. below the transfluence pass to the Ngozumpa Drangka, the 5570 m-saddle (No. 70; Figure 3), the Ice Age glacigenic slope with ground moraine overlay has been reshaped into a periglacial slope during the Holocene, levelled by frost weathering and solifluction. It is marked by outcropping rock remnants in the shape of rock towers and -pinnacles (Photo 161 ⏶;162 ▲ white). They have been – and are still – undercut by frost cliffs, so that they remain steep. Finally, they vanish completely and, due to the intensive subtropical frost weathering, become integrated into the surface of the debris slope. Down-valley of the current glacier terminals, glaciofluvially accumulated gravels of alluvial- and debris flow fans are the characteristic fillings of the valley bottom (Photo 163 △ large; 168 and 169 △; Figure 3 above Panorama 163). At some places remnants of ground moraine have been preserved on the trough slopes up to altitudes of ca. 5700 m a.s.l. (Photo 161 ■ below No. 81, on the right below No. 80), 5570 m (Figure 33; Photos 161 and 162 ■ on the very right), 5500 m (Photo 163 ■; 168 and 169:■ on the right of No. 62) and 5450 m (Photo 164 ■). They are situated ca. 500 (Photos 168 and 169 ■ on the right of No. 62) to 700 m above the valley bottom.

In part mantled by ground moraine, but also continuing up the valley slopes, more or less well-preserved, round-polished hills (large roches moutonnées) and flank abrasions have been preserved (Figure 3 on the right below No. 77; on the right above and exactly above No. 75; on the left above, on the left below and exactly below No. 76; on the left of Nos. 70, 71 and 99 and above and below No. 99; Photos 161–164⊃,∩,⊂). In many places they are located on truncated spurs and glacigenically polished triangular-shaped slopes (Figure 3 below, on the right and on the right below No. 77; on the right of No. 100; at No. 76 and below; above and on the right of No. 75; on the left of No. 70 and 99). Provided that the valley flanks are formed by mountain flanks higher than 6000 m, which during the postglacial and the holocene period up to the present have shown an auto-glaciation, as e.g. the 6296 m-high peak (Photo 161 and Figure 3: No. 76), then those High Würmian flank polishings have been especially intensively subdivided by rills of rock fall and avalanches and in part even destroyed (Photo 161 ⇩). The Würmian upper limits of abrasion and polishing naturally are preserved only sporadically and weakly (Photos 161–163 ..., – – –; 164 ...; 168 and 169 ... on the right of No. 62). In addition to the postglacial reworking at this altitude of most intensive frost weathering, the length of time for the treatment by flank polishing becomes shorter and shorter with the increasing height of the flanks. The High- to Late Glacial deglaciation first clears the uppermost sections of the valley flanks, so that they are exposed to the reworking described. Thus, the preservation of the abrasion up to the abrasion- and polish line becomes rougher and rougher. Owing to this, the discrepancy of the smoothing to the non-polished area at the polish line may be reduced beyond recognition. Good examples have also been observed for the case, that the High Würmian ice level has reached above lower valley flanks, i.e. mountains (Photo 161 ... below No. 98 and on the left below No. 101; 163 – – – on the left of No. 62). Here one would expect a rounded forming of the transfluence pass. As for the case of the two examples provided here, a development such as this has been overcompensated by an undercutting on both sides (taking place in the two adjacent valleys) and a sharpening and tapering by the Early- and Late Glacial valley glaciers flowing down parallel to each other. For this reason sharpened, jagged crests and glacial horns have been developed (Photo 161 ... below No. 98 and on the left below No. 101; Figure 3 below No. 76; on the right of No. 96; at, above and on the left above No. 75).

The upper limits of abrasion and polishing and, correspondingly, the Würmian (Stage 0) glacier trimline, run between ca. 6100 and 6200 m (Photo 161 – – – and ... on the right below No. 102; 162 ... on the right below No. 102; – – – below No. 76 and on the right of No. 5; 163 – – – and ... below No. 76; 164 ...) via ca. 6000 m a.s.l. (Figure 33; Photo 162 ... on the left above and below No. 71; 168 and 169: ... on the right of No. 62), down to ca. 5900–5800 m (Photo 161 and 162 ... on the right below No. 99; 163 ... on the left below No. 99). Accordingly, the related glacier thickness from the rock ground up to the polish lines in the corresponding parallel valleys of the upper Bote Koshi, i.e. Nangpa Drangka, amounted on average to 1350 m (see Figure 3 Profile 23; cf. Figure 33). In accordance with the increasing deglaciation from the High Würmian Glacial (Stage 0) up to the Late Glacial glaciation of the Sirkung Stage (IV), a ca. 100–300 m-thick ground moraine pedestal has been built-up under the more or less connected parts of the ice stream network, on which the separate valley glacier streams have flowed down in the end (Photo 161–163 IV; Figure 33). The thickness of this pedestal increases down-valley (cf. Photo 161 IV with Photo 163 IV on the left below No. 4 and on the right below No. 99).

In correspondence with the altitudes of the ice level, several transfluences have existed during the High Würmian period. They have taken place for instance on the cross-profile of the Ice Age Nangpa glacier (Figure 33; Figure 3 Profile 23), communicating across the 5570 m-saddle (No. 70; Photo 162) and the adjacent up to ca. 6000 m-high mountain ridges of the intermediate valley ridge (Figure 33: 5927 m-peak; Photo 162 No. 71), i.e. they had a continuously connected ice level. The thicknesses of the transfluences amounted to somewhat more than 400 m and, at some places, have left behind clear abrasion roundings (Photo 162 ∩ on the very right). Transfluences have also existed towards the W, to the Pangbug-, Dingjung- or Chhule glacier branches (Figure 3 between Nos. 96 and 75; see several of the corresponding ice level- and transfluence localities in Photo 161 ... on the left below No. 101 and below No. 98; 162 ... on the left below No. 101; Figure 33: 5777 m-peak). Here, however, they have taken place through narrow notches and obviously with an only insignificant velocity of flow, because they have left behind no clear roundings comparable with the orographic left side of the Nangpa Drangka. Where the thickness of the overflowing ice was ca. 600 m, as e.g. on a 5420 m-high summit between Sumna Drangka and its southernmost orographic left side valley, a perfectly formed, ca. 500 m-high roche moutonnée, i.e. glacially streamlined hill, has been developed under the transfluence (Photo 161 ∩ white, large, somewhat on the left below No. 101; Figure 3 on the left, somewhat below of Panorama 162).

The orographic left side of the valley chamber connected down-valley, beside and below the current glacier tongue end of the Nangpa-Lunag glacier (Figure 3 between Nos. 75 and 72), is marked by 200- to almost 400 m-high terraces of a ground moraine pedestal (Figure 3 IV above Photo 164; Photo 163 the first and second IV from the right). Just as in the neighbouring Ngozumpa valley (see Section 3.5), the holocene (neoglacial) to historical (see Table 1) advances of the Nangpa glacier (Photo 163 V,X,XI,XII) have eroded themselves into this late Late Glacial ground moraine pedestal (Photo 163 IV). During the younger Dhaulagiri Stage (VII) the tongue of the Nangpa glacier has still reached 2.5 km further down than nowadays, i.e. up to the Sengpo alpine pasture (Photos 168 and 169 VII; Figure 3 VII on the right of Panorama 163). 1955–1963 the tongue basin of this historical advance (VII) was still filled with dead ice (cf. Khumbu Himal 1:50,000, Schneider, E., 1978). Again down-valley and somewhat higher up the valley flanks, a lateral to end moraine ledge is preserved, classified as belonging to the oldest neoglacial Stage, the Nauri Stage (V; Table 1) (Photos 163, 168 and 169): V). During this stage a confluence of Nangpa- and Chhule glacier has taken place. The lowest joint position of the glacier tongue terminal is 5.5 km away from the current Nangpa glacier (Photos 163 and 164: XII; 168 X on the right) and 6 km away from the Dingjung glacier (Photo 165 IX; 169 X on the left), the modern glacier, which flows down the lowest in the Chhule Drangka (Figure 3 Photo 175; Photo 168 V on the left below No. 104; 169 V below Nos. 79 and 89; 171 V; 172 V below No. 80). Whether this moraine ledge is an overthrust moraine or an older ground moraine pedestal, into which the glacier of Stage V has eroded itself, is an open question. At two localities samplings of sediment have been taken here: first (Figure 74; Figure 3: 31.3.2003/1; Photo 169 +; Figure 37 and No. 35) up-valley of the Chhule alpine pasture. The analysis of the grain sizes and the morphoscopic analysis prove without doubt, that moraine is concerned. At the same time the clay portion, which with regard to moraine matrix is not too high, argues in favour of a glaciofluvial reshaping close to the surface. A relatively insignificant So = 2.48, too, points to a secondary sorting of the material. The second sample (Figure 75; Figure 3:31.3.2003/2; Photo 169 →; see Figure 37 No. 36), taken from the same lateral moraine on the orographic left side, is unambiguously moraine matrix, too. However, it is less glaciofluvially reworked, despite its having been taken from a similar depth near to the surface. Correspondingly, the clay portion as well as the sorting coefficient (So) is higher.

In this connection, the comparison with High- to Late Glacial ground moraine, also situated on the orographic left side, which in the late Late Glacial (Sirkung Stage IV) has been deposited, i.e. glacigenically moved for the last time, suggests itself. In the one case it has been additionally reshaped later by activities of debris flow cones and the corresponding re-deposition (Figure 72; Figure 3: 1.4.2003/1; Photo 168+; see Figure 37 No. 37). In the other case (Figure 73; Figure 3: 1.4.2003/2; Photo 169 ↓; see Figure 37 No. 38) the reshaping by ground moraine, which must have taken place by solifluction and fluvial denudation near to the surface, is less than that one (Figure 72) taken from a great depth in the area of debris flow activities. The So is similar, but the clay portion in Figure 73 is double the amount of Figure 72 and 13% more quartz grains are crushed in this matrix (Figure 37 No. 38) than in sample Figure 72 (No. 37). The insignificant reworking even of the sample in the debris flow (Figure 72) can be realized by the only very slight rounding of the relatively few (17.9%) fluvially reworked grains.

In the Bote Koshi valley section concerned, the orographic left lateral moraine ledge of the neoglacial Nauri Stage (V), probably developed from Late Glacial ground moraine, shows a flat lateral depression (Photo 170). It has been filled with a glaciofluvial gravel band, i.e. a lateral sander. At the same time, moraine substrate has also been glaciofluvially reshaped. The youngest (neoglacial to current) rock falls have taken place on to the level of the lateral depression and that of the glaciofluvial surface.

Up to which important extent morainic substrate has been dislocated and glaciofluvially, i.e. fluvially modified or – as far as single components are concerned – even completely reshaped in the area of this neoglacial tongue basin, is shown up-valley by a perfectly rounded granite gravel on the ground moraine (Photo 175) in front of the end moraine position of the Nauri Stage (Photo 171 V somewhat on the left below No. 80).

Beside the late Late Glacial remnants of a ground moraine pedestal on the orographic left side, which have already been mentioned, a remnant of a pedestal such as this of the Sirkung Stage (Photo 169 IV on the left below No. 75; 171 IV below No. 75), has been preserved on the orographic right side up to the valley inset between Chhule- and Nangpo Drangka. This shows that the then Chhule glacier component has also flowed on a corresponding ground moraine pedestal. Due to their position, remnants of ground moraine or of inner slopes of lateral moraine situated still higher upwards, are to be classified as belonging to the next-older Dhampu Stage (Photos 168 and 169: III). The highest, i.e. High Würmian (Stage 0) glacier level, diagnosable by flank abrasions (Photo 168 ∩ below Nos. 75 and 77◠; 170 ∩; 173◠) and an upper limit of abrasion, runs about 5800 m a.s.l. (Photo 169 ... below Nos. 75 and 72). Obviously, the 5941 m-peak (No. 72) was a nunatak, slightly towering above the ice surface (Photo 173 ... below No. 72); during the early Late Glacial (Stage I–II) the same has applied to the 5719 m-peak (No. 75). Both the mountains are glacial horns (Figure 3 Nos. 72, 75).

3.8.1. The current and historical to High Würmian glacier filling of the Chhule Drangka as an orographic right tributary valley of the Bote Koshi Drangka

Today the glaciation of the Chhule Drangka is divided into three separate, 4–9 km-long valley glaciers: the Pangbug- (Photo 167 □ white), the Dingjung- (Photo 165 XI) and the Chhule glacier (Photo 166). The latter is an outlet glacier tongue of the Drolum Bau (-glacier) (Figure 3). As has been described (3.8), five transfluences have existed between the High Würmian upper Nangpa-Lunag ice stream network, adjacent to the NE, and the Pangbug glacier component of that time (Figure 3 between Nos. 96 and 75). On the abraded confluence inset between the Pangbug- and Dingjung glacier valley, ground moraine of the late Late Glacial Sirkung Stage lies up to an altitude about 5600–5400 m a.s.l. (Photo 167 IV; 165 ■ on the left below No. 78; 172 ■ below No. 78). In both the source valleys the glacigenic flank abrasions reach still higher up; on the flanks of the 6989 m-peak (No. 96) and Pangbuk Ri (No. 78) they can be observed up to altitudes of 6400–6200 m a.s.l. (Photo 167 ∩, ◠). The High Würmian glacier trim-line, running at a correspondingly high altitude (...; Photo 165 ... on the left below No. 78), mediates to a transfluence across the still glaciated Menlung La (No. 79; 5883 m) into the W-adjacent ice stream network of the Rolwaling Himal (Figure 2 No. 3; Figure 4 and 11 No. 79), thus providing evidence of this transfluence. A further continuous ice transfluence has taken place across a 6130 m-high notch and the Dinjung La (5877 m) between Kang Korob (No. 80) and Drag Korob (No. 81) (Photo 165).

Down the Chhule Drangka, also on the orographic right, a glacigenic abrasion slope of a back-polished mountain spur, covered with ground moraine and reaching up to ca. 5400 m, is situated in the intermediate valley inset of the junction of the current Chhule glacier valley (Photo 165 ■ on the right below No. 98). Below, a ground moraine complex of the Sirkung Stage (Photo 165 IV below No. 98) starts with the usual important thickness (Photo 165 IV below No. 98). It is a remnant of a ground moraine pedestal, on the surface of which, ca. 250–300 m above the valley floor (□), the then valley glacier component of the Chhule glacier has joined the Chhule main valley glacier. Nowadays, the remnant of the ground moraine pedestal is cut by the meltwater stream of the currently small Chhule glacier; part of its material is re-sedimentated in a historical front moraine (Photo 166 X). Down-valley accumulations (Photo 165 IV on the very left) are continuations of the remnant of the ground moraine pedestal discussed (IV below No. 98). The rock abrasions, reaching a further 700–800 altitude-metres beyond the back-polished face of the mountain spur (Photo 166 and 165: ◝, ∩, ◠) prove a High Würmian (Stage 0) Chhulu glacier level about 6200–6100 m a.s.l. (... on the right below Nos. 98 to 105; Photo 166 – – –; Photos 168 and 169 ... below No. 98).

In the cross-profile at the exit of the Chhule Drangka and its junction with the Nangpo-, i.e. Bote Koshi Drangka, the two valley flanks are formed by glacigenically triangle-shaped slopes (Photo 172 ◓ below No. 80) with flank abrasions (Photos 168 and 169: ◠ on the right somewhat above No. 79) up to 5700–5500 m. They show more or less thick covers of ground moraine (Photo 171 ■ on the left below No. 80 and on the right below No. 96; 169 ■ on the right of No. 79 and on the right below No. 89) up to at least 5200 m a.s.l. (Figure 3 between Nos. 75 and 89). Thus, the High Würmian glacier level, which was continuously approx. equally high in this confluence of a tributary valley, has had a level about 5700–5000 m a.s.l. (Photos 168 and 169: ... at No. 75 and on the right of No. 89). The last value applies to the parent glacier immediately down-valley of that confluence (Figure 34).

3.8.2. Continuation of the reconstruction of the High Würmian glacier filling of the Bote Koshi Drangka from the Chhule Drangka confluence downwards

On the orographic left side, above a 400 to at least 500 m-high valley terrace, the Bote Koshi Drangka widens in the form of an indentation 3 km to the E (Figure 3 on the left somewhat above No. 90; Photo 173 ′VII to IV somewhat to the right and left below No. 72).

The bottom of this valley indentation, i.e. valley terrace, consists of a terrace-shaped remnant of a ground moraine pedestal, belonging to the late Late Glacial Sirkung Stage (Figure 3 IV below Panorama 171 and 172; Photo 171 IV on the very left and ■ on the very right; 172 IV on the very left and on the very right and left lower corner, first ■ from the left; 174 IV below and on the left below No. 90). This remnant of a moraine pedestal is a continuation of the ground moraine terraces described up-valley (3.8 and 3.8.1; Photo 173 IV on the very left). It consists of a clayey matrix with (among others) round-edged, polymict boulders up to several metres in length (Photo 171 ○). At two localities samples have been taken from the matrix (Figure 3, samples 29.3.03/1 and 30.3.03/1). Both the samples, Figures 76 and 77 (Figure 37 No. 33 u.34), show a morainic character with a high (Figure 76) to very high (Figure 77) clay portion of 8–17% and a sorting coefficient of ca. 4–5.5. The morphoscopic analyses confirm this field investigation with portions of at least 96% to not quite 98% of crushed quartz grains (Figure 37 Nos. 33 and 34). As is proved by the embedded crystalline boulders, transported horizontally, this is erratic matrix, i.e. the matrix is not freshly weathered, but the grains are glacially crushed. Due to the glaciofluvial reshaping during the process of thawing-out of the ice, the existing, but insignificant portions of fluvially polished (lustrous) quartz grains are understandable.

To this ground moraine terrace, neoglacial (Nauri Stage, middle and older Dhaulagiri Stage, Table 1) glaciers have been adjusted as high valley- and cirque glaciers of at most 4 km in length (Photo 173 and Figure 3: V, ′VII; Photo 172 VI). Small hanging- and wall foot glaciers exist on the nearly 6000 m-high mountain flanks of the 5941 m-peak (No. 72) and the 5949 m-peak (No. 90) (Photo 172 below No. 90 and ▲ on the left below No. 90; 173 on the right below No. 72) up to these days. Additionally, a rock glacier has been mapped, developed in neoglacial to historical moraines (Figure 3 on the left above No. 90).

Up (Figure 3 Profiles 24 and 25) and down from this eastern valley indentation (Profile 25) the Bote Koshi cross-profiles present fully developed trough forms up to 5500, i.e. 5000 m a.s.l. (Figures 34 and 35; Photo 169 on the left of No. 89; 174 and 176: below and on the right and left of No. 75; 191). The orographic right slopes of the intermediate valley chamber with their flank polishing and ground moraine cover (Photo 172 ∩ and ■ from the right below No. 98 up to the right below No. 60) are divided by cirque forms, wall gorges and debris flow fans (Photo 169 and 174: ○ on the left below No. 89; 171 ▲; 174 ▽ on the left below No. 89 and on the left below No. 60). The summits, towering several hundred metres above the High Würmian ice level concerned, which has fallen away from ca. 5500 to 5000 m a.s.l. (Photos 169, 171, 172, 174: ... on both sides below No. 89), have been sharpened into glacial horns (Photo 169 No. 89; 171 No. 89 and 104; Figure 3). On the orographic left side the exemplary preservation of a back-polished truncated mountain spur can be observed. Its rounding has been developed by flank abrasion of the Ice Age Bote Koshi glacier, which was effective up to 5300 m a.s.l. Despite the superficial weathering of the coarse boulders in the outcropping mica gneiss (6b: Nepal Geological Map 1: 125,000, 1985: Sheet No. 72I-B) since the deglaciation, as it is known from the Scandinavian fjell-landscapes, the rounding is clearly recognizable (Photos 173 and 174: ☗). Apart from that, this valley flank has been glacigenically modified at a small scale by interglacial cirque forms (Photo 172 between △ on the very left and below No. 91), so that only small areas show Ice Age morainic overlays and remnants of abrasions (Photo 172 ■ and below ... below No. 90). On the bottom of this valley chamber the geomorphological change since the deglaciation becomes obvious through the box-shaped, glaciofluvial, i.e. fluvial excavation of ground moraine by the Nangpa-, i.e. Bote Koshi river (Photos 174, 176 and 191:□) and the band-shaped gravel accumulation of glaciofluvial terraces in the meantime (Photo 174 on the right and left of □; Figure 3 above Panorama 176 and on the left above 191). In addition, the debris cones and -slopes, debris flow fans and the active development of gullies within and on the moraine material provide evidence of this fundamental geomorphologic change of the regime (Photo 174△,⇓; 176 and 191:▽; 171▲). In these cases remnants of ground moraine covers and pedestal moraine bases have been removed into accumulation forms such as these and, in some places, covered by them (e.g. Figure 34, the right half of the profile).

About 3 km down-valley of the large terrace of a ground moraine pedestal (Figure 3 Panorama 171), a further pedestal remnant is located on the orographic left, too. According to its height more than 500 m above the valley bottom, it can also be classified as belonging to the Sirkung Stage (Figure 3 on the left of No. 91; Photo 184 IV on the right above; 174 IV on the right; 177 and 188: IV in the foreground). On the surface of the ground moraine pedestal polymictic boulders are situated up to metres in size, in part erratic. They consist of eight types of rock, among which are different gneiss varieties, granites, quartzites in different colours and phyllites, developed from silt- and sand stones. They are edged, round-edged and facetted (x; Photo 177 ▲). The matrix sample 3.4.03/1 (Figures 78 and 37 No. 40; Photo 177 IV large in the foreground) indicates, that moraine material is concerned. This is mainly proved by the high clay content of ca. 13%, the sorting coefficient of at least 3 and the very high portion of ca. 96% glacially crushed quartz grains. The remaining, fluvially polished grains point to a sedimentation below or at the level of the snow-line (ELA) and thus during the late Late Glacial (Sirkung Stage IV). The ELA must have already been clearly uplifted against the Würmian Maximum, i.e. by ca. 600 m (cf. Table 1). Local neoglacial to historical hanging glaciers have glacigenically reshaped the terrace of the ground moraine pedestal. They have eroded their tongue basins into it and lateral- and end moraines have been attached (Photos 177 and 184: V). Finally, these tongue basins have been covered by glaciofluvial gravel plains, alluvial fans and debris cones (Photo 177□, ▽; Figure 3 on the left somewhat below No. 68). The validity of this remnant of a ground moraine pedestal increases due to its association with further remnants of a ground moraine pedestal in this valley chamber. Something like this is situated on the opposite orographical right side (Photo 191 IV below No. 89; Figure 3: 26.3.03/1). The sample of fine material matrix taken there (Photo 188 ↓) (Figure 80; see Figure 37 No. 31) once more shows the typical characteristics of moraine with a clay peak and the unambiguous, morphoscopic characteristic feature of moraines with 95% glacially crushed quartz grains in erratic diamictite. The remaining 5% of very well fluvially rounded grains, as well as the sorting coefficient of only 2.2, show a subglacial reshaping by meltwater below the ELA. A further ground moraine remnant, the surface of which has been sub- and postglacially modified (Figure 3: 2.4.2003/1; Photo 184 above ■ on the right below; 191 above ■ white) also presents a typical, clay-containing matrix (11%) and 93% glacially crushed quartz grains (Figure 79; see Figure 37 No. 39). The matrix of the terrace of the ground moraine pedestal on the orographic right side in the inset of the Langmoche Drangka junction correspondingly appears (Figure 3: 27.3.2003/1; Photo 178 IV white on the left in the foreground; 184 IV on the right above ∩; 188 IV white small; 191 above IV white). Here, approx. 400 m above the Bote Koshi talweg, the matrix even shows 15% clay and the So reaches 4.6 (Figure 81); 93% of the quartz grains of the erratic matrix are glacially crushed (Figure 37 No. 32). The fact, that afterwards many of the fluvially polished quartz grains have been crushed again, i.e. that crushed edges occur beside the polished roundings, provides evidence of their initially glacigenic transport in the ground moraine, the reworking by meltwater and finally the renewed glacigenic transport. Owing to this, subglacial conditions with the existence of meltwater, i.e. below the snow-line (ELA), are evidenced. Accordingly, the snow-line must have run somewhat above 4380 m a.s.l., which means ca. 700 m above the High Würmian ELA about 3700–3800 m. The remaining ELA-depression of 600–800 m against today has been established for the late Late Glacial Sirkung Stage (IV).

Polymictic boulders, in part erratic, up to hut-size (Photo 179 ○ white), edged, round-edged and facetted (Photo 182), non-weathered (on the right side of the person), slightly weathered (Photo 179 ○; 181 ○) and heavily weathered (Photo 180 ○) are integrated into the fine matrix and lie on the ground moraine terrace at 4380–4390 m a.s.l., too. They consist of e.g. crystalline schists (Photo 178 ○ white from below No. 73 up to below No. 83), granites (Photo 182) and gneiss varieties (augen-gneisses, banded gneisses; Photos 179 and 180:○; 182; Figure 3 on the right of Photo 185 and Pro. 25; Figure 35). The augen-gneiss boulder which, due to frost weathering, but also hydration is extremely angular and has been strongly roughened on its surface (Photo 180 ○), gives the impression of a markedly old age in this position. However, the condition of its surface cannot be reduced mainly to the duration of its position, but to the hydrothermal decomposition preparing it. This has already taken place in the bedrock and has prejudged the roughening by splintering-off and granular disintegration of the crystals. The boulders, slightly or not at all weathered, which are situated immediately adjacent in the same geomorphological position and are completely exposed (Photo 179 ○; 182), must have the same age of deposit. Their hydrothermal decay in the bedrock has been less or the process of their removal due to glacier transport was different, etc. This difference with regard to the character of the boulders on one and the same accumulation already disproves the possibility of determining the age of moraines by the dating of the boulder surfaces.

Corresponding with the ground moraine pedestals on the orographic left side reshaped by local hanging glaciers of the holocene to historical period (see above), the forms of the High Würmian to Late Glacial flank abrasions in this region have been interrupted, i.e. modified by cirques and cirque steps (Photo 184 ○,○; 178 and 183:○ black from below of No. 90 up to below No. 92; Figure 3 from the left of No. 68 up to left of No. 92 and on the left below No. 92). On both sides of the cirque steps and cirques truncated spurs (Photo 184 ▲), which have been abraded back up to approx. the same altitude, as well as flank abrasions and ground moraine covers (Photo 178 ∩ and ■ from the right below No. 91 up to on the right below No. 92; 177 ∩ and ■ on the left of No. 92; ∩ and ■ from the right below No. 68 up to on the right below No. 92; 191 ∩ and ■ black, on the right of No. 89) a continuous High Würmian (Stage 0) Bote Koshi glacier level (Photo 177 ––– and ... on the very right; 178 ... on the left below No. 90 up to on the right below No. 92). On average this ice level has run about 5300–5000 m a.s.l. (Figure 35). Its counterpart is on the orographic right valley side, where truncated spurs have also been preserved as glacigenically triangle-shaped spurs up to at least 5000 m (Figure 3 on the right of No. 89 up to Photo 185; Photo 179▲; 188▲ from below No. 88 up to the right margin; 177▲ from below No. 86 up to below No. 89; 178▲ large; 191▲; 183▲ on the left below No. 4).

On the orographic right side of this valley section, on both sides of Profile 25 (see Figure 3), two tributary valleys join the Bote Koshi Drangka. These are the short Chhuitingpo Drangka (Figure 3 above Pro. 25; Photo 188 on the right somewhat above ↓) and the much larger Langmoche Drangka (Figure 3 below Pro. 25; Photo 178 and 181: right halves; 183 left half).

The Chhuitingpo Drangka is a 3.5 km-long, trough-shaped hanging valley, cloaked by moraine. From the direction of the steep step of its valley exit, its trough ground has been cut by backward erosion. This might have already been subglacially effective during the Late

Glacial, as can be deduced from the snow-line altitude at that time. Where the Chhuitingpo Drangka joins the main valley, the current, erosionally V-shaped form is narrow like a glacial gorge. It also cuts moraine material, transported from the hanging valley on to the ground moraine pedestal of the main valley (Photo 191 IV below No. 89; 188 ↓; Figure 3 IV below 26.3.03/1). Across its ca. 4950 m-high source saddle, a transfluence pass covered with moraine situated in the W, the valley has received ice from the upper Langmoche Drangka (Figure 3 below No. 89) during the High Würmian period (Stage 0). As is evidenced by the ground moraines on its valley flanks (Photo 188 ■ below and on the left below No. 88), the orographic right side of the Chhuitingpo Drangka was completely filled with ice during this maximum glaciation phase. The Chhuitingpo side glacier and the Bote Koshi parent glacier have had a uniform ice level.

3.8.3. The dimensions of the High Würmian Langmoche glacier component as the orographic right inflow of the Bote Koshi parent glacier (Figure 3 from No. 89 via No. 104, 97, 83, 82 up to 88)

The upper catchment area of the 11.5 km-long Langmoche Drangka is fringed by five almost 6000–7000 m-high summits and their crests and satellites (Photo 181 Nos. 88, 83, 97; 183 and 186: Nos. 88, 83, 97, 104; Figure 3 Nos. 88, 83, 97, 104, 89). Today, 10 hanging glaciers flow down from the valley head, the six northernmost of which are called the Chhuitingpo glacier (Photo 186 below No. 97 and 104; Figure 3 on the right of No. 82 and 97, between No. 104 and 89). The longest is the a good 4 km-long Langmoche glacier, reaching from the 6940 m-high Tangi Ragi Tau NE-flank (Photo 181 and 188: below No. 83) down to the valley bottom at 4400 m a.s.l. (Figure 3 XII on the left below Pro. 25). In the forefields of these 10 glaciers the current and historical (Glacier Stages XII–X; see Table 1) as well as neoglacial (Glacier Stage ′VII to V) ice margin positions have been mapped (Figure 3 XII, XI, X, ′VII, VI, V between Nos. 104 to 89 and No. 83 to Panorama 186; Photo 186 X). According to its largest catchment area, the Langmoche glacier has reached down the lowest in the neoglacial (holocene) Nauri Stage, i.e. up to the junction of the valley with the Bote Koshi Drangka at ca. 4100–4200 m a.s.l. (Figure 3 V below Photo 192; Photos 178, 189, 192 and 194: V; 181 V large; 183 V white). Due to the accumulation geomorphology on the valley bottom, the Langmoche Drangka has been reshaped by glaciofluvial gravel accumulation (Photo 181 □) and debris flow fans (△) into a trough-shaped valley (box-profile; Figure 3 below Pro 25; Photo 181⇩ large). At the same time the lateral erosion caused by the outburst of the moraine lake of the Langmoche glacier, the Dig-Tsho outburst on August 5th, 1985, has modified and widened the valley bottom (Photo 192 □). But the breaking away of the valley flanks and the subsequent slidings of the moraine material with the development of debris cones since the deglaciation, have also in part buried the Ice Age trough form (◡ large) developed in the rock (Photo 181 ▼). The decrease of the ELA by 150–300 m during the Nauri Stage (V, Table 1) and the small hanging glaciers with their tongue basins (Figure 3 V on the right and on the right above No. 88; Photo 181 V on the right below No. 60 up to below No. 88; 183 V on the left; 182 on the right and left below Nos. 88, 186; 187 and 188: IV) have removed a large part of the orographic right ground moraine pedestal of the late Late Glacial Sirkung Stage (Figure 3 IV on the right above No. 88; Photos 178 and 188: IV black; 181 and 182: IV small; 183 IV black and white large; 186 and 187: IV) and modified into insets of tongue basins, i.e. forms of lateral- and end moraines. However, due to these remnants a continuous level can still be recognized, corresponding with the larger remnants of ground moraine pedestals of that time on the orographic left valley side (Figure 3 IV on the right side above Panorama 181; Photo 182 IV large; 183 IV small; 188 IV small, white). At the same time, the flank areas of the tributary valley concerned also belong to the orographic right flank of the Bote Koshi Drangka. Accordingly, the relation to these remnants of the ground moraine pedestal provides evidence of a Late Glacial system of tributary- and main valley glaciers, still connected during Stage IV.

Matrix-sample Figure 82 (see also Figure 37 No. 41) has been taken on the orographic right side at the exit of the Langmoche Drangka, on the outer slope of the neoglacial moraine of the Nauri Stage (Figure 3: 4.4.03/1; Photo 189 ↓), a large part of which consists of dislocated, late Late Glacial ground moraine of the Sirkung Stage (Table 1). The large clay portion, the bimodal course of the grain size cumulative curve and 89% glacially crushed quartz grains prove the fresh moraine character, which, as it is typical of end moraines, has been slightly reworked by the glacier meltwater. In this connection the comparison with the older sample of ground moraine matrix Figure 83 (see also Figure 37 No. 42), which in petrophic terms has been built up in the same way, is expressive. It has also been taken in the junction area of the side valley, but ca. 100 m higher, from the non-reshaped ground moraine cover of the Sirkung Stage (IV) (Figure 3: 5.4.2003/1; Photo 189 ↑). Here, the removal by a neoglacial glacier under the influence of meltwater is lacking. Accordingly, the clay content is 4% higher and the portion of fluvially polished quartz grains is ca. 4% less. It reaches 7.4% against 11.2%. At this locality only the comparatively insignificant subglacial work of the meltwater was effective.

Due to glacigenic rock abrasions and truncated spurs in the form of glacigenically triangle-shaped slopes and roche-moutonnée-like forms in the position of a mountain ridge (Figure 3 between on the right of No. 104 and 83 as well as above and on the right of No. 88) the maximum Würmian ice level (Stage 0) of the Langmoche Drangka can be reconstructed at an altitude between 6200 and, at the valley exit, 5000 m a.s.l. (Photo 178 and 181: ... from below No. 82 up to on the left below 88, 182 ...; 183 ... below No. 104 up to the left margin; 186 ... from the right below No. 104 up to on the left below 83, 187 ...; 188 ... on the right below No. 83 up to below 93). Due to the classic, glacigenically triangle-shaped slope (Photo 178 and 181:▲ large and ... on the very right; 191▲ and ... on the left; 183▲ and ... on the left of No. 4; Figure 35; Figure 3 Photo 185) a level about 5000 m altitude at the valley exit, i.e. in the confluence area with the Bote Koshi parent glacier, is also evidenced on the orographic left side. In correspondence with the ice level, at least three transfluence passes have existed from N to S: the northernmost, which has connected the ice surface of the Chhulu- with that of the Langmoche glacier (Figure 3 between Nos. 104 and 89; Photo 186 ←) and the westernmost (Photo 181 and 186:↑; Figure 3 No. 82), which has connected the Drolum Bau substream, already belonging to the W-adjacent Rolwaling glacier system (Figure 2 No. 3; Figures 4 and 11: on the left of No. 82), with the Bote Koshi glacier system. The southernmost was situated between Langmoche- and Arabtsen glacier (Figure 3 on the right of No. 88). Across the 5890 m-high transfluence pass (No. 82) an ice thickness of at least 300 m must have existed.

3.8.4. Continuation of the reconstruction of the High Würmian glacier filling of the Bote Koshi Drangka from the junction of the Langmoche- up to that of the Arabtsen glacier

A highest sample of ground moraine matrix (Figure 84 and Figure 37 No. 43) in the confluence area of the Langmoche glacier and the parent glacier has been taken on the orographic right side at 4550 m a.s.l. (Figure 3: 5.4.2003/2; Photo 183 IV white). The sampling locality is ca. 650 m above the valley bottom of the Bote Koshi Drangka. The clay portion of at least 20% is extremely high. This is already evidenced by the decreasing amount of meltwater in dependence on the altitude. In the same direction points the diminution of the fluvially polished quartz grains to only 4.2% against the samples Figures 83 and 82, which have been taken 350–450 m lower. The rest of the 95.8% quartz grains is glacially crushed. The sorting coefficient even reaches the extreme value of 7.96! The sorting coefficients of comparable matrix samples, taken from a lower position, show values about 4.1–4.11. Up to 4600 m a.s.l. (Photo 193 ■ black) the High- to Late Glacial (Stage 0–III or IV, Table 1) moraine material concerned contains 1–3 m-long, round-edged, slightly rounded and edged polymictic boulders of metamorphites, granites (○ black; Photo 183 ↑↑) and gneisses (183⇓ Photo 193 ○ white). Granites and gneisses are erratic. Down to the valley bottom, the completely covering ground moraine increases in thickness and becomes a ground moraine pedestal terrace.

Because down-valley, near the Thame Teng alpine pasture, this moraine terrace has an only insignificant altitude above sea-level and a great relative height of 400 m above the valley bottom, it has more likely to be classified as belonging to the Late Glacial Dhampu Stage (Table 1) than to the younger Sirkung Stage (Photo 189 III). The Bote Koshi glacier tongue of the Sirkung Stage has already come to an end 5.5 km down-valley at ca. 3300 m a.s.l., that is still upward of the main-valley from the Kyajo Drangka junction (Figure 3 Photo 208; Photo 193 below III; 203 below ■ on the right below III; 204 below ▼). According to the minor distance to its ice margin, its ground moraine pedestal had a height of only ca. 100–200 m at Thame Og (Photos 205, 206 and 210: IV), but not of nearly 400 m.

Downslope, the ground moraine cover concerned has been increasingly split-up by holocene to historical slope rills and -small depressions (Photo 188 below ■ on the left below No. 93). On the remaining moraine ribs between these rills and slide depressions several large moraine boulders are situated, which have been secondarily exposed and cleared by denudation (Photo 190 the two □ from the right). Beyond, on the orographic left valley slopes, remnants of a ground moraine cover (Photo 193 ■ on the right) occur as debris-cone-like, residual debris bodies (Iturrizaga, 1999, pp. 244–246; 245 Point c); 246 Figure 42 on the left below). This is due to the dissection by slope gullies (△). The valley bottom shows a glaciofluvial gravel cover (Figure 3 above Photo 194; Photo 190 □ on the left; 194 and 195: □), which at some places undercuts Late Glacial ground moraine material (Photos 194 and 195: ■) and in many places covers it. On this trough valley bottom current debris flow fans are adjusted from ground moraine, superficially dislocated downslope (Photo 195 △ white on the left).

Above the ground moraine covers on the orographic right slope, i.e. at more than 4600 m a.s.l. (see above), abrasion forms have been preserved. They occur as the upper tips of back-polished rock spurs or -ribs. Their lower slope areas plunge below the moraine material, growing thicker toward below (Photo 183▲ large; 188▲ below Nos. 93–87; Photo 195 ◥; Figure 3 between Panoramas 193 and 198). Roche-moutonnée-like roundings of abrasion (Figure 3 on the left and below of Panorama 178; Photo 187 ∩ on the left) provide evidence of a High Würmian ice level about 5000 m a.s.l. (Photo 187 ... on the left; 195 ... on the right of No. 87).

During the late Late Glacial Sirkung Stage (IV Table 1) the Kabsale-SW-hanging glacier has still reached the Bote Koshi parent glacier from an orographic left hanging- and side valley formed like a tube cirque (Photo 198 ○ below No. 92). At the same time it has overthrust a 170 m-high ground moraine pedestal (IV) across which it has flowed into the parent glacier (Photo 199 IV small). During the Nauri Stage the cirque (●) and the ground moraine pedestal have undergone a holocene reshaping by a last, somewhat heavier cirque glaciation (Figure 3 V on the left below No. 92). This was especially due to the meltwater and debris flow activities below the glacier mouth (Figure 3 on the right above Photo 201).

3.8.5. The High Würmian glacier filling of the Arabtsen Drangka, its junction with the Bote Koshi-, i.e. Nangpo Tsangpo parent glacier and the course of this glacier, inclusive of the junction with the Ice Age Kyajo glacier (Figure 3 between No. 83–85 and below No. 74 on the right of Pro. 26)

The approximately 12 km-long Arabtsen Drangka (Figure 3 above No. 85 up to Photo 202) has two small, orographic left side valleys. The more westward, higher one, is a good 3 km-long hanging side valley, connected by a confluence step (Photo 197 ∩ left half and ▼ white). At the heads of the main- and side valleys, current glaciers are situated in a NE- and S-exposition, the modern ice margins, historical and neoglacial (holocene see Table 1) moraines of which have been mapped (Photos 196 and 197: above X,X–XI,X–XII,VII and V, i.e. only V; Figure 3 between No. 86 and 88 and on the right below 88). The 6 km-long Thengpo glacier (Photo 196 above X) reaches down to the valley bottom at ca. 4300 m a.s.l.

The valley bottom consists of an historical glacier mouth gravel floor (□), which, according to the C14-sample No. 10 (Table 2), has been dated to 320 ± 130 YBP (Photo 196 ↓). This dating proves, that since the historical Stage IX the Thengpo glacier tongue end can no longer have overthrust the sample locality, but has remained in a nearly stable position up to these days. The reason for this stability can be seen in the topography of the glacier catchment area, the walls of which fall steeply away (below and on the right below No. 86; Figure 3 above No. 86). The climatic change, i.e. in this case the warming-up, has led to an uplift of the snow-line. However, due to the steepness of the wall section, in which the uplift of the snow-line has taken place, the connected loss in accumulation area (catchment area) was very small. It has remained so small that the only result was a decrease in ice thickness at the tongue end, but no back-melting of the glacier worth mentioning. The accumulation area ratio (AAR) of the Thengpo glacier remained unchanged (Kuhle, 1986h, 1987c, 1988f, 2004b).

The valley bottom is flanked by active debris flow cones and -fans (Photo 196 ∇ black) made up of dislocated, coarse-blocky (○) moraine material. This comes from the Late Glacial remnants of the ground moraine pedestal of the Sirkung Stage (Photos 196 and 197: IV). At some places of the moraine slopes, neoglacial moraine ledges of the Nauri Stage (V) are also preserved. They, too, can locally be diagnosed as material of a ground moraine pedestal (Photo 196 ■ white; 197 V). Here again the inherent law is confirmed that during the younger advances the narrower glaciers erode into the older ground moraine pedestals (Sections 3.2 and 3.5). It is remarkable, that the three current, comparably small glacier tongue ends are dam glaciers, i.e. that they flow down on a ground moraine pedestal (Figure 3 below No. 88 and above 87; Photo 196 on the right of X). The covers of surface moraine (on the right above X), which also correspond, are determined by the glaciers' feeding through ice avalanches and the debris which at the same time is torn out of the steep wall.

Part of the abrasion forms preserved in the flat rock area (∩ below No. 88; Photo 197 ∩) has been mapped as roches moutonnées (Figure 3 below and on the right below No. 88). In an upward direction they pass into glacigenic remnants of abrasion on the steep walls (Photo 196⊃,∩ below No. 86–85) and glacigenically triangle-shaped slopes on truncated spurs (Photo 197▲), so that a High Würmian ice level at 6200 (Photo 196 −−− below No. 85; 197 ... on the very left) to 5700 m a.s.l. (... on the very right) is evidenced in the side valleys and at the valley head of the Arabtsen Drangka. Despite numerous Late Glacial to postglacial crumblings (Photo 198 ➘,⇩ black) on the rock roundings (∩,⊃ on the left,⊂; Photo 199 ∩,⊃ large and⊂ large;⊃,∩ small on the right; ▲ white; Figure 3 above, below and on the right of Panorama 198), the downward continuation of the upper abrasion limits can be observed without any difficulty on both the valley flanks. During the Würmian period (Stage 0, Table 1) the glacier trim-line has run from ca. 5800 m (... on the right) down to 4700 m a.s.l. (... on the left below No. 60; Photo 193 ... on the right).

During the Nauri Stage (Table 1 V), the High- to Late Glacial ground moraine material, still preserved in part on the slopes or dislocated down-slope (Photo 198 ■ on the very left and very right; 199 IV large, the three ■ from the right) has been reshaped into a tongue basin and pushed together to end moraines (Photos 198, 199 and 195: V; 180 V above; 181 V on the left below No. 60 small) by the neoglacial Arabtsen glacier on the valley ground.

On the orographic right outer slope of the end moraine, large boulders (Photo 195 ○ white) up to the size of a hut (○ black) consisting of local gneiss (6b) are situated. This tongue basin with its fringing moraines has been pushed up to the confluence with the Bote Koshi main valley, i.e. down to 3800 m (Figure 3 on the right of Panorama 199). It is the settlement area of Thame Og. In order to flow down up to here, the Thengpo glacier needed an ELA-depression of ca. 250 m (current height of the glacier tongue end = 4300 m a.s.l. (see above), past height of the glacier tongue end = 3800 m; 4300–3800 m = 500 m; 500 m: 2 = 250 m). This corresponds with the snow-line depression of the Nauri Stage (see Table 1 V). At the same time, the tongue basin concerned has been thrust across a remnant of a ground moraine pedestal of the Sirkung Stage (IV) (Photos 200, 205, 206 and 210: see V above IV). The level of this remnant of a ground moraine pedestal terrace corresponds with the ground moraine pedestal terrace on the orographic left main valley side at the exit of the Kabsale SW-hose cirque

(Schlauchkar) (Photo 195 IV large; 198 IV; 199 IV small). Accordingly, in this valley section, too, the phases of the glacier-historical development are confirmed as follows: (1) High Würmian maximum glacier thickness with ground scouring down to the rock ground of the side- and main valley; this becomes obvious in the cross-profiles of the Bote Koshi Drangka recorded above and below the confluence area concerned (Figures 35 and 36). (2) Late Glacial development of dam glaciers with a heavy ground moraine accumulation (Figure 36), up to the point of a several hundred metres thick development of ground moraine pedestals (Figure 35). (3) Due to denudation and erosion the ground moraine pedestals have been removed since the Late Glacial to postglacial deglaciation. Part of their remnants has been overthrust and modified during the neoglacial glacier advances – here during the Nauri Stage (Table 1,V).

Near the root of the orographic left lateral moraine of the Nauri Stage (V), in the area of a marginal reshaping during the neoglacial period (Photo 199 ↓; Figures 3, 6.4.03/1), a sample of the matrix of a ground moraine pedestal of the Sirkung Stage (IV) has been taken (Figure 85; 37 No. 44) between large, edged to round-edged granite- and gneiss boulders. As is confirmed by the clay content of more than 7% and 82% glacially crushed quartz grains, without doubt matrix of ground moraine is involved here. The ca. 18% fluvially polished quartz grains, as well as the slight reworking of several broken edges of the grains and the comparably minor So of 2.45, show the reshaping of the sediment by the ice margin of the Arabtsen glacier, which has taken place with the participation of meltwater during the Nauri Stage (V), somewhat above the lowest ice margin of that time.

In the area of the glacier mouth of the neoglacial Arabtsen side valley glacier, the terrace of a late Late Glacial ground moraine pedestal (Photo 199 ■ large, half-right below No. 92), located in the underlying bed of the tongue basin, has been – and is still – regressively cut by the Arabtsen river in the direction from its inflow into the Bote Koshi river (▼ white; Photo 200 below V and on the left above ⇩).

Therefore, the glacial gorge stretch of the Bote Koshi, which here above this confluence (Photo 201), in the very resistant, because very thickly-bedded, massive-crystalline rock could only develop by cavitation corrasion under the influence of hydrostatically confined water, has to be explained as subglacial formation. It could only develop in the Late Glacial because, for the necessary amount of meltwater below the glacier, a snow-line altitude of at least 4000 m a.s.l. was needed. During the High Würmian period (Stage 0) the ELA has run here at ca. 3600–3800 m.

The orographic left flank polishing of the main valley, a few decametres above the talweg, in the confluence area of the Arabtsen Drangka (Photo 202 ∩ large), ought to belong to the High Glacial, i.e. to the period, when the abrasions of the most important ice stream have reached down to the rock ground. As has been described, the remnants of potholes and related forms of subglacial meltwater erosion (▼; Figure 3: on the right above Photo 203) have to be placed into a period with an again uplifted snow-line, i.e. into the Late Glacial. Due to the synchronicity of the two processes it can be suggested that this has taken place syngenetically with the adjacent accumulation of the ground moraine pedestal on the right valley side, developed at exactly the same altitude (Photo 202 ■; 200 IV; 203 on the right below No. 73). This is to say, that at this locality the subglacial meltwater river has cut itself between the moraine pedestal and the rock face along the left valley flank (Photo 198 between ■ below ⇩ white and ⇩ white). In this local-genetic connection an also subglacial, but vertical meltwater form has to mentioned (⇩ white; 202 ⇩; 199 ∇ white). Beside its very sharply inset tube-form, which suggests cavitation corrasion due to very rapidly flowing water, the absence of a subaerial catchment area is an indicator of a genesis by water supply through an intraglacial tube system.

The High Würmian glaciation of the main valley section of the Bote Koshi Drangka – which from here up to the confluence with the Imja Drangka is also called Nangpo Tsangpo Drangka – up to the junction with the Kyajo Drangka, can be diagnosed with the help of ground moraine covers (Photo 200 ■ foreground; 204 ■; 205 the first five ■ from the right and the first from the left; 206 ■ large and white; Figure 3 between Photos 200, 204 and Panorama 205). The matrix of these moraine covers, containing edged to facetted boulders up to some metres in size, has been analysed by spot samples (Figure 86; 37 No. 45 Figure 3: 6.4.2003/2; Photo 203 below ■ white on the left; 204 ↑). Due to the clay content, the bimodal course of the cumulative curve and at least 93% of glacially crushed quartz grains, it shows all characteristics of moraine. The sorting coefficient of 2.0, as well as 6.5% lustrous quartz grains, suggest an already subglacial reworking by meltwater; the loss in ignition (LOI) of 3.22% at a depth of 1.3 m speaks in favour of a down-slope holocene to historical reshaping by solifluction. The ground moraine covers and the abrasion roundings up to a polish line about 4350–4400 m a.s.l. above (Figure 36; Photo 199 ... on the right below Nos. 73; 200 and 205: ... on the left; 206 ... on the left and right; 210 ... on the left and the two ... on the right) prove a correspondingly high glacier trim-line in this valley chamber below the junction of the Arabtsen side glacier during the Würmian ice age (Stage 0 = Isotope Stage 3–2). From a corresponding longitudinal perspective of the valley the significantly glacigenic trough character is clearly diagnosable (Photo 193; 205).

At the junction of the Kyajo side glacier, its lateral- and end moraines have reached the Nangpo Tsangpo Drangka and in part blocked it (Figure 3 on the right of Photo 208; Photos 193, 203; 204 and 210: III). These moraines reach down to 3200 m a.s.l.; the current terminal of the Kyajo glacier is at 5400 m (Figure 3 on the right below No. 91), so that a snow-line depression (ELA- depr.) of ca. 1050 m has been calculated (5400–3300 = 2100; 2100:2 = 1050). Due to the average ELA-depression of 1100 m calculated for the whole of High Asia, this ice margin position should be classified as belonging to the early Late Glacial Ghasa Stage (I) (see Table 1). But because this glacier was situated in a S-, i.e. windward position of the Himalaya main crest, from which the ELA-depression must have profited, the classification into the Dhampu Stage (III) seems to be appropriate. During this stage the side glacier has flowed into the still existing Nangpo Tsangpo parent glacier. However, the end moraines preserved here must have been sedimentated during a renewed, short advance in the course of the melting process of the Dhampu Stage (III), in which the merely 10 km- long, steep Kyajo side glacier of comparably minor thickness has participated, but not the huge Bote Koshi-Nangpo Tsangpo parent- and outlet glacier, which, with regard to its reactions to the climate, was sluggish, because of its connection with the Tibetan ice. Accordingly, the parent glacier had already melted down to a thickness of just 100 m, when, during a short advance, the Kyajo glacier has thrust itself across the parent glacier. Its sharply drawn moraines (Photos 193 and 210: III) point to a short advance such as this, which might have been a surge. This sequence of sedimentation and its relative dating according to the ELA-depressions additionally shows that during the late Late Glacial Sirkung Stage (IV) the glacier terminal of the parent glacier must have been situated in the valley chamber above the Kyajo Drangka, because the ELA had been uplifted by ca. 100–200 m against the Dhampu Stage (III) (Table 1). Here, a tongue-basin-like widening of the valley is preserved (Photos 204 and 206: □), so that the tongue end of the Bote Koshi–Nangpo Tsangpo glacier, which has still passed the Arabtsen Drangka (see above), must have come to an end here (Photo 204 ▼; Figure 3: Photo 208). Clearly isolated end moraines have not been preserved.

The correspondingly old late Late Glacial moraine material of Stage IV (Sirkung Stage) is located about 4000 m a.s.l. in the Kyajo Drangka on a junction threshold (Photo 209 IV; Figure 3 IV on the left below No. 74) via which the trough valley (Photos 208 and 209: ∪) falls 400 altitude-metres away, down to its junction with the Nangpo Tsangpo valley. This junction threshold can be interpreted as a glacigenic confluence step, by the height of which the much thicker and more rapidly flowing main valley glacier has deepened itself against the hanging valley during the repeated pleniglacials of the pleistocene ice age period. For the last time this process has taken place during the High Würmian period. The rock ramp of the step, consisting of gneiss, shows glacigenic forms of ground polishing as e.g. roches moutonnées (∩) and an extraordinarily smooth rock ground. During Stage III it was situated below the snow-line, so that its subglacial flushing by meltwater, i.e. the water film, must have led to an additional reduction of the ground scouring of the glacier. Thus, the surge, which might have overthrust the moraines of the Dhampu Stage (Photo 210 III), could have experienced its topographic-climatic preparation. Dynamics of surges and ice-slides of this type are known e.g. from the glacier surge of the Alalin glacier tongue in the European Alps on August 30th, 1965, and from glacier slides and -surges in the Bell-Mountains (Glockenberge) in NW Norway. But also without surges, the oscillations of the Kyajo side glacier must have had much more deflections, i.e. advances at a shorter frequency, than the parent glacier. This is due – as compared with the Bote Koshi main valley glacier, which additionally was an outlet glacier of the Tibetan ice – to its very small mass.

On the orographic right confluence spur of the Kyajo- and the Nangpo Tsangpo Drangka, a polishing of the rock spur covered with lateral moraine material is evident (Photo 210 II and ∩ above), which genetically corresponds with the Late Glacial depression of the glacier level. According to the glacial chronology described (see above) it belongs to the Taglung Stage (II Table 2).

On the steep trough flanks of the Kyajo Drangka glacigenically triangle-shaped slopes are preserved (Photo 208▲; 210▲ large; Figure 3: between on the right below No. 91 and Panorama 210) from near to the valley head up to the valley exit. These, as well as the neighbouring slope areas, are sporadically covered with decametres-thick remnants of ground moraine up to 3900 m a.s.l. (Photos 207 and 208:■; 204 second highest ■). At places, where the ground moraine is extremely thick, even iron-shaped remnants of ground moraine ramps (Photo 207 ■ on the right side) with boulders up to the size of a hut or a house (▼,▲ white) are preserved. These are relicts of former lateral moraines, even set off against the valley flank by a saddle (◗), which is a remnant of a lateral valley. In the area of the valley exit, the highest flank abrasions (Photo 204⊃ white; 207 ∩,⊃; 208⊃,⊂; 209⊃,∩ on the right), naturally corresponding with those of the main valley (Photo 210 ∩ on the right) reach up to ca. 4300 m a.s.l. They provide evidence of the High Würmian glacier trim-line (Photo 208 ...; 210 the two ... from the right). Immediately in the confluence area, the ice level of this Stage 0 (Table 1) has dropped to ca. 4240 m (Photo 198 ... on the right; 199 ... below Nos. 27–36; 203 ... below No. 36; 204 the two ... from the left; 207 −−−). Beside the abrasion roundings described, reaching up to 4240 m a.s.l., the ground moraine matrix, which has been analysed (Figure 63; 37 No. 30; Photo 207 ▼ black), proves an ice transfluence into the E-adjacent valley chamber of Khumjung (Figure 3: on the right of 24.3.03/1; see also Photo 155 ▼) (Section 3.7) up to this altitude. Even more than by the morainic character of the sediment, the ice thickness is evidenced by the portion of at least 11% fluvially polished quartz grains. In this crest-position they are only understandable by subglacial meltwater activities, because up here an alternative does not exist, i.e. no stream could have flowed here.

Summing up sub-Section 3.8.5, a High Würmian glacier trim-line of the Bote Koshi-, i.e. Nangpo Tsangpo parent glacier has to be indicated, which has dropped from ca. 4700 m in the junction area of the Arabtsen tributary glacier, via 4350–4400 m in the area of cross-profile 26 (Figure 36; Figure 3 Pro. 26) to ca. 4240 m a.s.l. down-valley of the junction of the Kyajo tributary glacier. The levels of the two tributary glaciers were adjusted to this trim-line. At a Würmian orographic altitude of the snow-line (ELA) of ca. 3700–3800 m a.s.l. in the precipitation shadow of the 6187 m-high Kongde Ri-massif (No. 60), this glacier surface of the Bote Koshi-Nangpo Tsangpo valley glacier system was situated 1000–440 m above the snow-line. During the late Late Glacial Sirkung Stage (IV, Table 1), the terminal of the parent glacier was located immediately up-valley of the junction of the Kyajo Drangka(Figure 3 IV at Photo 206). During the ablation phase of the Nangpo Tsangpo parent glacier at the time of the Dhampu Stage (III), the Kyajo tributary glacier has experienced a short, surge-like advance, in which the parent glacier has not been involved.

3.8.6. Glacigenic features, highest former trim-lines and glacier thicknesses of the Bote Koshi-, i.e. Nangpo Tsangpo Drangka from the Kyajo Drangka up to the confluence with the Imja Drangka, the source of the Dudh Koshi Nadi (Figure 3 between Photo 209 and on the right below Panorama 159)

The glaciogeomorphology, as well as the sedimentology of the orographic left flank of the valley chamber E of the junction of the Kyajo Drangka, has already been treated in connection with the lower Imja Drangka in the confluence area with the Nangpo Tsangpo Drangka (see end of Section 3.7). The analysis of the right flank is still pending. The trough cross-profile of Figure 36 continues but in the upper part of the valley flank along this valley chamber. Here, the valley bottom has been cut by a glacial gorge, which has been subglacially developed in the outcropping gneiss (Photo 211 ⇩). This glacial gorge already sets in above the junction of the Kyajo Drangka (Photo 210 ⇩) and continues in an increasing depth down the main valley up to the Imja Drangka confluence (Figure 3 from Photo 206 up to on the right below Panorama 159). Above the working edge of the incision of the glacial gorge, remnants of ground moraine are preserved on the remnants of the trough ground which have been left as a ledge (Photo 211 ■ on the left above and below ⇩). Provided that they reach a thickness of decametres (■ on the left below ⇩), remnants of a Late Glacial ground moraine pedestal are concerned. These ground moraines contain granite- and gneiss boulders metres in size (○ white) and continue as a cover on the orographic left side up to ca. 3750 m a.s.l. (Figure 3 above Panorama 211). Down-valley they pass into the ground moraine accumulations near the Syampoche and Namche settlements (Figure 59; Photos 156, 157, 159: I). On the orographic right valley flank the remnants of the ground moraine cover extend up to ca. 4100 m (■ above on the right). The glacigenically triangle-shaped slopes (▲) and abrasion roundings (◠, ∩) reach a height of 4200 m a.s.l. (Photo 156◠,∩; 157∩ below and on the left and right below No. 60; Photo 159▲ below No. 60). The unity of this orographic right flank polishing is interrupted by three cirques, i.e. tube cirques with an elongation in a downward direction, that is to say glacigenic hanging valleys (Photo 211 ○ black; 151, 156, 157, 159: ○ below No. 60; Figure 3 above and on the right of No. 60). Even so, a continuous upper abrasion limit can be verified. It runs between ca. 4400 m (Figure 36 right half of Profile 26) and 4200 m a.s.l. (Photos 156 and 159: from the right ... to left below No. 60; 157 ... from the right margin to left below No. 60; 211 on the right). This abrasion limit partially bulges about 50–150 altitude metres in an upward direction, so that it reaches an altitude of at most 4300 m there (Photo 156 ... on the left below No. 60). This is due to the ground polishing of the local glaciation, which from the valley glacier margin extends upward on the flat slope faces (Kongde alpine pasture) above the ELA. The NE-exposed bottoms of the tube cirques (Photo 157 ○ below No. 60; Figure 3 above and on the right above No. 60) reach down to ca. 3800 m a.s.l., i.e. they must still have been glaciated at a time, when the surface of the Nangpo Tsangpo parent glacier had melted down to at least this level. During the Late Glacial this was not before the Dhampu Stage (III Table 1). At this time the orographic snow-line has run here at about 4400 m (5000–3800 = 1200; 1200:2 = 600; 600 + 3800 = 4400), i.e. there was a depression of ca. 700 m against the current orographic snow-line, running in these cirques about 5100 m. Accordingly, at that time the Nangpo Tsangpo glacier must still have had a surface height of ca. 600 m above the current talweg, in order to limit the bottom of the tube cirque towards below at 3800 m a.s.l. As is confirmed by the moraine findings in the opposite exit of the Kyajo Drangka (Section 3.8.5), actually this was the case for the last time during the early Dhampu Stage (III). During the High Würmian glacier position, only the areas with higher back-walls of cirques and the highest cirque bottoms above 4400–4200 m a.s.l. have supplied the parent glacier with local ice, because during Stage 0 (Table 1) the cirque glaciers were adjusted to a valley glacier level, heightened to 4200 m (see above).

It is a realistic assumption that the surface of the Bote Koshi-, i.e. Nangpo Tsangpo parent glacier of the Dhampu Stage (III) under discussion, which has flowed down on a ground moraine pedestal of an unknown thickness from these cirque bottoms up to the confluence with the Imja parent glacier, i.e. on a horizontal distance of ca. 4 km, has dropped about ca. 100–150 m from 3800 to ca. 3650 m a.s.l. This is a confirmation of the hypothesis suggested (Section 3.7), that the glacio-limnic sands on the ground moraine terrace near the Trashinga settlement about 3650 m a.s.l. (Photo 153; Figure 3 Photo 153; Photo 151 ■ large) have been accumulated in a dammed-up glacier lake by the Bote Koshi-, i.e. Nangpo Tsangpo glacier.

3.8.7. Summary of Section 3.8

The approximately 40 km-long High Würmian (Stage 0 Table 1) Bote Koshi-Nangpo Tsangpo parent glacier was a S-Tibetan outlet glacier, which at the transfluence pass from Tibet into the S-slope of the Himalaya W of Cho Oyu (No. 4),that is the Nangpa La (No. 62), has had a 500–600 m higher ice level than today. Its surface lay about 6300–6200 m a.s.l. It has been supplied by altogether seven larger local Himalaya valley glaciers (Figure 3). Within the first 12 km S of Nangpa La (Figure 3 No. 62 up to Pro. 23) its ice level has fallen away to ca. 6200 m a.s.l. (Figure 33) and its ice thickness has grown from an estimated 800–900 m at the transfluence pass to ca. 1400 m (Figure 33). Further 9 (Figure 34) and then 8 km (Figure 35) down the Bote Koshi it has kept its thickness about 1300 m (Figure 34 and 35). 5.5 km up-valley of its confluence with the Imja parent glacier (Figure 3 Pro. 26) it was still ca. 1100 m thick (Figure 36). Ice transfluences have existed to the E, to the Ngozumpa-but also to the W, to the Rolwaling-valley glacier system (Figures 3, 4, 11). The Würmian snow-line has increased from SSE to NNW from ca. 3600–3700 to 4000 m, so that the glacier's surface, which has dropped from NNW to SSE from ca. 6300 to 4200 m a.s.l. (Figure 33–36), in the NNW was situated ca. 2300 m and in the SSE still ca. 600–500 m above the ELA. As has been suggested according to the most important ice thickness which has existed and according to the trough valley forms, but also in theory, during the High Glacial the Bote Koshi-Nangpo Tsangpo glacier has abraded the valley down to the rock ground. During the step by step Late Glacial uplift of the ELA (Stages I–IV, Table 1) and the connected decrease of the ice level (from above to below), the glacier thickness has been diminished, too, from the direction of the valley ground (from below to above) by the gradual built-up of a ground moraine pedestal (Figures 33–36). During the Sirkung Stage (IV) the thickness of this ground moraine pedestal has reached 500 m at a maximum at an altitude of the talweg about 4400 m a.s.l. in the middle course of the valley. During the Dhampu Stage (III Table 1) the Nangpo Tsangpo glacier has passed and closed the already ice- free inflow of the Imja Drangka with a surface level about 3650 m a.s.l. The fact that the Nangpo Tsangpo glacier has flowed lower down, has to be explained by the comparably more significant influx of ice from Tibet.

3.9. Reconstruction of the lowest parent glacier tongue (Dudh Koshi glacier) and its thickness from the confluence of the Imja- and Bote Koshi-Nangpo Tsangpo glacier up to its lowest Würmian ice margin in the Dudh Koshi Nadi (Figure 4 from Photo 212 via Pro. 28 up to below Pro. 33; Figure 11 from the right of No. 17 toward below (S) up to the terminal of the valley glacier near the Inkhu Khola junction)

The glacier level about 4200–4100 m a.s.l. and the corresponding ice thickness at the root of the tongue of the Dudh Koshi parent glacier, necessarily derives from the reconstructed glacier levels of the two tributary streams, which have joined in it, the Imja- (Photo 212) and the Bote Koshi-Nangpo Tsangpo glacier (Section 3.8) (Figure 3 Photo 212 and 213), because an over 1000 m-thick glacier does not break off vertically or just steeply, but keeps its thickness minus an insignificant incline of the surface. On the orographic right side the valley shoulder of the Kongde Ri alpine pasture has been reached here by the Dudh Koshi glacier level (Photo 157 ... on the left below No. 60) The local-autochthonous ice cover, which somewhat above has been verified according to abrasions (Photo 156 above ... on the very left below No. 60), testifies to a local High Würmian (Stage 0) ELA in an E-exposition about 4000 m a.s.l. at maximum or even a little lower. In correspondence with more large-scale indications of the snow-line above cirques levels, in this area of the Himalaya S-slope it has rather run about 3600–3700 m a.s.l. (Section 2.4.7).

The two valley glacier tributary streams have flowed together into a narrow, slightly concavely polished-out Dudh Koshi valley (Photo 157: on the right below No. 73), which can be described as a glacigenically V-shaped valley, i.e. a trough-shaped glacial gorge (Kuhle, 1982, 1983a) (Figure 52). The reason for this divergence from the classic trough form is the subglacial meltwater erosion below the High- to Late Glacial snow-line, which, due to hydrostatic pressure and the corresponding cavitation erosion, must have been especially effective below the ice. It has cut the trough ground like a glacial gorge (Photos 212 and 213; Figure 11 on the right of No. 17). The potholes at the upper root of the Dudh Koshi Nadi (Photo 213) are proof of this past process. Accordingly, terrain edges can be found on the valley flanks (Photo 214 ▷◁), below which the rock slopes become markedly steeper, so that a narrow lower V-shaped, i.e. gorge-profile is set into the rock bottom of a very wide, extended upper trough profile (▢). On these upper, flatter parts of the slope, remnants of ground moraine are preserved (Figure 52 left half of the profile), whilst the lower slopes are too steep. Late Glacial remnants of moraine and remnants of a gravel cover on inner banks, consisting of removed and washed moraine (Figure 52; Photos 214, 215, 216: □) are predominant on the valley ground. This applies in particular to the exit of the orographic left, steep Kyashar Khola trough valley (Figures 4 and 11 above No. 73), from which the

Kyashar glacier, currently ending at 4350 m a.s.l., has transported decametre-thick moraine material to the parent glacier as late as the Late Glacial.

The glacigenic flank polishings reach up to 4000 m a.s.l. (Ͻ,∩,⌒). Owing to this, in the valley chamber up to the Bengkar-and Toktok settlements a ca. 1200 m-thick ice filling has been evidenced up to a glacier level at 4000 m (Figure 52). Naturally, since the deglaciation the glaciofluvial and fluvial reworking of the glaciogeomorphology close to the talweg is most intensive (Photos 215 and 218). However, already ca. 150 m above the talweg, forms of roches moutonnées with glacier polishings are preserved without any damages (Photo 117; Figure 11 on the right below No. 17). Between the valley chambers of the Toktok-and Ghat settlements the cross-profile of the Dudh Koshi Nadi keeps its character of a glacigenically V-shaped valley with flank abrasions (Photo 218Ͻ,⌒) and interposed trough cross-profiles (Photos 218, 222 and 227: U). On the upper slopes minor-thick ground moraine covers can also be recognized (Photo 218 ■ on the right) and remnants of a ground moraine pedestal are in the valley ground (■ below U; Photo 222: 0 black) (Figure 11 on the right of No. 16). In this valley section the subglacial meltwater activity is demonstrated by remnants of potholes (Photo 219). The masses of rock avalanches near Ghat are typical of glacigenic crumblings from the orographic left valley flank, left behind over-steepened by glacigenic flank abrasions (Figure 11 on the left of No. 73).

According to remnants of a ground moraine pedestal terrace seen down-valley, an oldest ground moraine pedestal, classified as belonging to the Late High Würmian Dudh Koshi glacier, can be observed from the valley chamber N of Ghat. On the orographic right remnant of a pedestal terrace, the Sano Gumela settlement is located (Photo 222: 0 black). At the same level of a ground moraine pedestal the orographic left Thado Koshi glacier, flowing out of the Thado Koshi which has been filled with ice up to 3500–3600 m a.s.l. (Photo 220 ...), has joined the main valley. This is verified by the remnant of a ground moraine pedestal at its junction (Photo 222: 0 white). During the two older Late Glacial stages, the Ghasa Stage and the Taglung Stage (see I and II, Table 1) the down-melted, minor-thick Dudh Koshi parent glacier has reworked this ground moraine pedestal and in part removed it (Photo 222 II). The tongue of the Taglung Stage has flowed down to ca. 2500 m a.s.l. and there, ca. 1.5–3 km down-valley of the Thado Koshi Khola junction, it has worked a tongue basin form into the Würmian ground moraine pedestal (Photo 227 II). Concomitant with this – in the course of the corresponding advance of the glacier tongue – end moraines, i.e. front moraines with the characteristics of push moraines (Photo 221), have also been overthrust (Figure 11 II on the left below No. 73).

Among other things, flatly-embedded glaciolimnic sands have been compressed (Figure 4: 10.11.82/3), showing a predominance of 66% in the fine sand (Figure 87). This very good sorting points to an originally flatly-deposited sedimentation and proves, that the corresponding steeply bended layer (Photo 221↘) does not concern a primary bedding but a compression.

During the maximum Würmian glacier position in the valley cross- profile of this ice margin position of the Taglung Stage (II) (Figure 53), the glacier trim-line of the Dudh Koshi glacier has reached up to ca. 3500 m a.s.l. (Photo 224 ... on the right below No. 16; 228 second ... from the left). This is indicated by glacigenic flank abrasions (Photo 124Ͻ, on the left below No. 17; 227 and 228: secondϽ from the left). At this time, i.e. at the end of the High Würmian period, the 200–400 m-high ground moraine pedestal (Photo 227 the two 0 above; 223; 224 ■ large, 0–I; 225) has been built up below the Dudh Koshi glacier, here a good 1000 m below the ELA. This means that during the Early- to High Würmian the glacier has reached down to the rock ground, filling the valley receptacle up to the talweg as presented in Profile 29 (Figure 53). Then, during the later phase of the Würm-glaciation, the subglacial ground moraine pedestal has been built-up, increasingly filling the valley from below to above up to a height of 200–400 m. At this time the glacier has flowed on a raised bottom, which, at a level with a constant altitude, has meant a decrease in thickness. The morphoscopic analysis (Figure 4: 8.4.03/1), showing 93% glacially crushed quartz grains in the matrix of the loose-rock-pedestal, interspersed with erratic material, is a clear indication of its glacial genesis (Figure 37 No. 47). The 7% fluvially polished quartz grains, the insignificant sorting coefficient of 1.58 (Figure 88) and the obviously reduced clay content of ca. 4% (Figure 88) point to a certain influence of meltwater with regard to the sedimentation and removal below the Dudh Koshi glacier tongue. This corresponds with a genesis of the ground moraine pedestal more than 1000 m below the synchronous snow-line.

Somewhat above the level of the end moraine surface of Stage II and below the highest Würmian level of pedestal ground moraine, a level of a ground moraine pedestal is situated, which systematically has to be classified as being from the oldest Late Glacial Stage, the Ghasa Stage (I; Table 1) (Photo 222 ■). As has already been mentioned, due to the corresponding advance of a now narrower glacier a removal of the Würmian ground moraine pedestal has taken place in the centre of the valley bottom. This removal and reworking has reached up to the remnant of the ground moraine pedestal 700–600 m N of the Lumding Khola-junction (Photos 229–231:■ I), i.e. up to still ca. 1 km beyond the pedestal remnant on which the Surke settlement is located (Photos 227, 228 and 230: 0–I). Owing to this, during the Ghasa Stage (I) the end of the Dudh Koshi parent glacier must have been situated in the gorge-stretch near the Lumding Khola-junction at ca. 1800 m a.s.l. (Figure 11 on the right below No. 16;

Photos 229 and 230: on the left of ■ I below▲). Front moraines, which would admit a more precise information, are lacking.

The lateral- and end moraines of the oldest Late Glacial advance – that is during the Ghasa Stage – of the Handi Khola glacier, the southernmost orographic left tributary glacier (Photos 226, 228, 231: I; Figure 11 somewhat on the left below No. 73), are adjusted to the Würmian ground moraine pedestal of the Dudh Koshi main valley (Photo 226 0; 228 and 231: 0 above). Therefore, the chronological classification is obligatory, because the Gonglha and Kalo Himal, which have formed the cirque-like catchment area of the W-exposed glacier, show an average altitude of merely ca. 5400 m a.s.l. So that the Handi Khola glacier could flow down to ca. 2400 m a.s.l., an orographic snow-line running about 3900 m a.s.l. (5400–2400 = 3000; 3000:2 = 1500; 2400 + 1500 = 3900) was needed. This means as a rule, at least 200 m higher than the High Würmian (Stage 0) snow-line (cf. Table 1) about 3600–3700 m a.s.l. (Section 2.4.7).

On the orographic right side, behind the right lateral- to end moraine ramp of the Handi Khola glacier, the surface of the ground moraine pedestal of the Würmian parent glacier (Dudh Koshi glacier) stretches, which here, in the area of the Lukla settlement, has been slightly glaciofluvially remoulded, i.e. truncated and covered by a layer of debris flow and gravels (Photo 224 0–I). This was a result of the meltwater, flowing down from the right lateral valley of this tributary glacier. A digging (Photo 225) has proved that the pedestal ground moraine of the Dudh Koshi dam-glacier pedestal outcrops in the underground. At this level of a ground moraine pedestal the High Würmian (Stage 0) Handi Khola glacier, joining the Dudh Koshi parent glacier, has naturally syngenetically contributed ground moraine material to this pedestal. Accordingly, the joint ground moraine pedestal in the area of the tributary valley junction in the surrounding of Lukla has been heightened by a further ca. 150–200 m up to ca. 2840 m a.s.l. compared with the surface of the ground moraine pedestal up the main valley near the Chaurikharka settlement. The trim-line of the High Würmian Handi Khola tributary glacier has run rather steeply from 4000 to 3800 m a.s.l. (Photo 226 ___) down to the trim-line of the main valley glacier at 3200 m (... on the right).

Samples of the Late Glacial (Ghasa Stage (I)) lateral- and ground moraines of the Handi Khola glacier reaching down to 2400 m have been taken on the orographic right side (Figure 89). Due to the laboratory analyses they have been verified according to e.g. 31% clay and a sorting coefficient of 6.9 and 96.9% glacially crushed quartz grains in their matrix (Figure 37 No. 7). The altitude of 2400 m a.s.l. as for the end of the Handi Khola glacier during Ghasa Stage (I) is only an approximate value. This concerns its basal height with regard to its inflow into the Dudh Koshi parent glacier during this stage (Photo 231 below I black; 227 below 0 on the right). However, because no further end moraines of this tributary glacier exist up the main valley, an empirical correction of this approximate value is not possible. Accordingly, in this confluence area the Dudh Koshi parent glacier of Ghasa Stage (I) still had a thickness of ca. 500 m minus its ca. 150–200-thick ground moraine pedestal in the underlying bed. This is consistent with its terminal 2–3 km down-valley in the confluence area of the Lumding Khola (see above).

Just as the Handi Khola glacier has still joined the parent glacier during the High Würmian glaciation (Stage 0, Last Ice Age), besides the orographic left Thado Koshi glacier (see above) also the orographic right Toktok Khola tributary glacier has flowed into the Dudh Koshi parent stream until as late as Ghasa Stage (I). As a climatic necessity this is already evident because of its SE-exposition at an average altitude of the catchment area about 5600 m in the Nupla SE-flank (No. 17, 5885 m) (Photo 224 below No. 17; Figure 11 on the right below No. 17). From the Lumding Danda (Figure 53), the 3900–4500 m-high catchment area of the Gumela- and Kamsyawa Khola, small hanging glaciers and firn shields have reached a confluence, i.e. the contact with the surface of the Dudh Koshi parent glacier (Photo 224 on the left below No. 17; Figure 11 half-right below No. 17) only during the High Würmian period.

3.9.1. The glaciogemorphological indicators of the lower 17–20 km of the Würmian Dudh Koshi parent glacier tongue between Handi Khola- (Lukla) and Inkhu Khola junction (Figure 4 from above of Pro. 30 up the glacier terminal)

The orographic left main valley flank, where samples have been taken from the Handi Khola junction down the main valley up to Profile 30 (Figure 4) shows a more or less sporadic cover of ground moraine up to an altitude of ca. 2650–2790 m a.s.l. (Photo 229 ■ black on the left; 231 ■ on the very left). This observation in the field is confirmed by laboratory analyses (Figure 91; Figure 37 No. 5) from 2630 m a.s.l., i.e. 900 m above the Dudh Koshi river. The fine matrix has a trimodal course of the grain size cumulative curve. It contains 22% clay and has an extremely high sorting coefficient of 11.81; 61% of the quartz grains are glacially crushed. In addition, the analyses of the transition to the ground moraine pedestal in this valley flank area verify the field investigations by a trimodal course of the grain size cumulative curve, a clay content of 33%, a sorting coefficient of even 13.21 and 99.5% crushed quartz grains, which, because the samples have been taken from a depth of 3 m and with an admixture of components transported in the longitudinal direction of the valley, can only be glacially crushed (Figure 92; Figure 37 No. 4). All further sediment-samples, dug at 2380–2490 m a.s.l., without doubt point to moraine material, too. This is depicted in Figures 93–95 and confirmed by the morphoscopic analyses (Figure 37 No. 1–3). The ground moraine values which – compared with those in a decakilometre-distance up-valley – without exception show very high sorting coefficients and clay portions, are a function of the increasing trituration of moraine in connection with the distance of their transport. They ought to be taken as a further confirmation of their typical glacial character.

In the same section of the valley flanks, up to 700 m above the Dudh Koshi river in the hanging layer of moraine, glaciolimnic to glaciofluvial material up to 700 m above the Dudh Koshi river has been analysed in the laboratory (Figure 90; Figure 37 No. 6). This is washed substrate (57% coarse silt), made up of local moraine material (still 8% clay and 95% crushed quartz grains), i.e. merely 4.7% fluvially polished quartz grains point to only a short water transport. This transport must have taken place in an orographic left lateral valley between a valley slope mantled with ground moraine and the glacier margin. Glaciolimnic, i.e. glaciofluvial, material such as this has been found on the orographic left valley slope up to ca. 2700 m a.s.l. (Photos 227, 229, 231: □). Due to the material's vertical distribution on the slope, a successive lowering of the lateral valley accompanied with the melting of the glacier margin is probable. Owing to this, a High Würmian to Late Glacial development of the lateral valley from the maximum of Stage 0 up to Ghasa Stage I (cf. Table 1) has to be suggested.

Due to the ground moraines described, which locally also occur on the orographic right side (Photo 230 ■ white on the right; 231 ■ white on the right below No. 16) and glaciolimnic lateral formations, but also because of the interspersed glacigenic flank abrasions on both valley slopes (Photos 227,228,231:◠ on the right; 229,230:◝; 227, 228:◝ on the left; 229◠; 230, 231: ∩) up to altitudes of 2800–2700 m a.s.l., a glacier trim-line about 2700 m a.s.l. has been evidenced in Profile 30 (Figure 53) (Photo 226 ... on the left; 229 and 230 ...; 231___ on the right and below No. 16 below). The flank abrasions in the Lumding Khola up to its exit (Photo ◝131 white) prove, that the Lumding Khola glacier has joined the here still ca. 1000 m-thick Dudh Koshi parent glacier at least during the maximum Würmian glaciation (Stage 0). Between Profiles 30 and 31 (see Figure 4) the flank abrasions continue on both valley slopes (Photos 232 and 233:◝,∩,◠) from an abrasion limit at 2700 m a.s.l. (Figure 54; Photo 232 the two ... on the right) up to below the confluences of the Khari- and Deku Khola up to altitudes of 2250 m a.s.l. (Figure 55; Photo 232 ... on the left; 233 ...; Figure 11). On the orographic right side a subglacial meltwater tube is preserved on the rock face (Photo 233 ↓; Figure 11 above Deku K.). Mainly on the orographic left side metre- to decametre-thick remnants of ground moraine (Photos 232 and 233:■) with up to 3 m-long rounded gneiss boulders (○) have remained between ca. 200 and 450 above the talweg. From the Khari Khola an orographic left lateral kame has been heaped up against the down-melting tongue of the Dudh Koshi glacier (□ white). The subglacial meltwater erosion of the Dudh Koshi main glacier, which up to here – over a distance of approx. 20 km – has flowed below the snow-line, has led to a two-part valley cross-profile. A narrow, gorge-like valley profile (below ▢) has been set into a wide, trough-like one (Photo 232 ▢). Currently the further development of this glacial gorge section (⇓) is insignificant, because it does not take place subglacially, i.e. under hydrostatic pressure. During the last phase of the High Würmian ice filling the gorge-like lower profile in a down-valley elongation of the ground moraine pedestal (Photos 227–231 0 and 0–I) was completely filled with ground moraine under the glacier. However, this loose material has been quickly removed after the deglaciation. From the Deku Khola junction down the main valley, washed sediments have been found, still containing clay and silt (Figure 55). They might be glacio-fluvially, i.e. fluvially removed moraine.

From an ice thickness of ca. 850 m in Profile 31 (Figure 55), at an altitude of the valley bottom of 1400–1300 m a.s.l., a ca. 12–15 km long continuation of the Dudh Koshi glacier tongue up to the Inkhu Khola junction has been extrapolated (Figure 4 ? below Pro. 33). The extrapolation is mediated by Profiles 32 and 33 (Figures 56, 57) located in between, on which concave bends of the slope have been interpreted as abrasion limits which, due to a consistent decrease in glacier thickness via ca. 700 and 650 m and a decrease in the altitude of the glacier surface via ca. 1750 and 1600 m a.s.l. would be plausible. A reliable proof of the High Würmian glacier thickness down-valley from Profile 31 was not possible. The postglacial monsoonal, fluvial reshaping is bound to have been essential. However, according to the extrapolated findings of the author, a lowest ice margin at ca. 900 (880) m a.s.l. E of the Bakhor settlement (27°28′30″ N/86°43′20″ E) seems to be probable.

3.9.2. Summary of Section 3.9

The High Würmian (Stage 0) Dudh Koshi parent glacier tongue, which from the confluence of the Imja- and Nangpo Tsangpo (Bote Koshi-) glacier was 38 km-long, has flowed down to ca. 900 m a.s.l. The glacier terminal was situated near the Inkhu Khola- junction (27°28′30″ N/86°43′20″ E; Figures 4 and 11). This lowest ice margin position is an extrapolation from glaciogemorphological indicators, verifying in detail a decrease in ice thickness of the Dudh Koshi glacier from ca. 1300 m (Figure 52), via 1200 m (Figure 53) and 1000 m (Figure 54) to ca. 850 m (Figure 55) in the junction area of the Deku Khola (Figure 4 Pro. 31; Figure 11) (Kuhle, 1986g, 1987a, 1988a, p. 587, 1999b, 2001c, pp. 389–391). At the Deku Khola the altitude of the valley ground amounts to only ca. 1500 m a.s.l. The ice thickness of 850 m has existed 12–15 km up-valley of the extrapolated lowest ice margin positions. Down to the Khari Khola inflow, the Dudh Koshi Nadi shows sections of a trough-like form (Figures 52–54), i.e. of a trough-shaped glacial gorge. This is typical of steep Himalayan cross-valleys, created by glaciers with a strong, decakilometre-long subglacial meltwater erosion, which have flowed down far below the ELA

(Figure 11 on the left below No. 73 up to Deku K.). The Dudh Koshi parent glacier tongue has received an inflow by two orographic right and three left, mostly short and steep tributary glaciers. A longer tributary glacier was the 18 km-extended Lumding Khola glacier, which as the lowest tributary stream has joined the parent glacier from the still glaciated right tributary valley of the same name (Figure 11 on the right of No. 16; Photo 131 below No. 16). During the Late Glacial Dhampu Stage (III, Table 1), the tongue-end of the parent glacier has passed the Kyashar Khola-junction by ca. 1.5 km and reached ca. 2750 m a.s.l. (Figure 4 above Pro. 28, cf. Figure 11: III on the right somewhat below No. 17). During the Taglung Stage (II) the end of the parent glacier was situated ca. 2 km down-valley from the Thado Koshi Khola-junction about 2500 m a.s.l. (Figure 4 in Pro. 29; cf. Figure 11: II above Deku K.) and during the oldest Late Glacial Stage, the Ghasa Stage (I), the tongue end has approx. reached the Lumding Khola-junction at 1800 m a.s.l. (Figure 4 in Pro. 30; cf. Figure 11: I above Deku K.).

According to the cross-profiles 28–33 (Figures 52–57) the High Würmian (Stage I) Dudh Koshi parent glacier has filled and polished the valley receptacle as far as the rock ground. During the last High Würmian phase the glacier tongue has not yet melted back, but a ca. 200 to 400 m-high ground moraine pedestal has been built up below the ice, on which the valley glacier tongue has flowed down. In the upper valley chambers of the Dudh Koshi Nadi (Figure 4 from above Pro. 28 to Pro. 30) it has been polished down, i.e. partly removed by the three Late Glacial advances mentioned above. Due to post-glacial fluvial dynamics in the area of the talweg it has been partly to completely evacuated. First this evacuation has taken place in the lower valley sections and at last also in the upper ones.

4. Reference to and discussion of the existing approaches and the methods applied

Heuberger, who in 1956 has published a short study on a section of the research area, has repeatedly retracted his findings and ice margin positions; so e.g. on the 'German Geographers' Day' in Göttingen, 1979. (Quotation: "Diese Moränen erfreuen sich inzwischen einer anderen Genese".). Accordingly, his opinion stated here, probably cannot be considered as still valid. However, originally he has suggested (1956, 356) an Ice Age ice margin position at ca. 2500 m a.s.l. in the Dudh Koshi Nadi S of the Ghat settlement, providing evidence by erratics described ca. 400 m above the talweg. Fushimi (1978, p. 76, Figure 10) draws the map of an Ice Age Khumbu valley glacier system, which with the Dudh Koshi glacier has reached up to S of the Lukla settlement. Near Lukla it was still 400 m-thick. He proves this thickness by ground moraine mapped near Lukla (ibid. p. 73, Figure 6). Empirical findings and proofs of this valley glacier system are not provided in his 7-page presentation. Heuberger and Weingartner (1985, p. 79) reconstruct the "maximum extension of the last main-glaciation" in the Dudh Koshi Nadi down-valley of the Ghat settlement – this time even below 2400 m a.s.l. It is not proved or explained why the ice margin position described at the same time is the lowest one. The formulated result has not been obtained by the glaciogemorphological arrangement of the positions, but by pedological investigations and related comparisons with the Alps. Heuberger (1986, p. 29/30) confirms this opinion in a 2-page study without any new observations and calls the glaciation "Youngest main glaciation or Tega glaciation". Bäumler et al. (1991) corroborate the suggestion of Heuberger and Weingartner (1985), but they provide no new geomorphological evidences. The authors are not interested in the proof of a maximum past ice extension, but in the relative synchronous classification of the findings of Heuberger and Weingartner. In addition, on the basis of soil weathering analysis (Bäumler et al. 1991, p. 240), they postulate "that the ice of the last main glaciation never reached Lukla" at 2800 m a.s.l., ca. 400 m above the Dudh Koshi talweg. Unfortunately, the climate-dependent soil development is an indicator which is not very appropriate as for the dating of Quaternary sediments or even moraines in the mountains in general, and especially in the monsoonal-tropical Himalayas. A possibility of calibrating the soil development in the Himalaya, which would admit a comparison, does not exist. The small-scale change of the petrographic compositions of moraine surfaces in the mountains, the small-scale climate change according to the altitude and the change of the topographically dependent amount of precipitation on the moraine bottoms, but also catabatic winds and special conditions near to glaciers and ice faces as well as this complicated spacious change against the background of the extreme vertical shiftings of the climatic altitude levels during the last 20,000 years with shifts of the snow-line by 1500 m, naturally do not render possible an acceptable statement as to the duration of the development of slow and integral processes like weathering and soil development of moraines (cf. especially Wagner, 2005). This exemplarily applies to the soil development in the Dudh Koshi Nadi in the Handi Khola-junction on the luff side of the Himalaya.

Finally the study of König (2001) on the Late Glacial glaciation of the lower Bote Koshi Nadi and its four tributary valleys has to be discussed (ibid. p. 452 Figure 1). Besides important geomorphological observations, it provides considerations as to the relativity of Late Glacial ELA-depressions and the extension of glaciers. In the context of our researches it has to be stressed that the Late Glacial snow-line depression of 900 m compared with the current snow-line, established by König (ibid. p.453/454), due to the findings introduced in Section 3.8.3-6, in this section of the valley area has also been calculated and thus confirmed by the author for the late Late Glacial, the Sirkung-(IV) and the Dhampu Stage (III) (Table 1).

5. Summary of the field- and laboratory data as to the Last Ice Age glaciation (Würmian, Stage 0, Table 1) and the Late Glacial glaciation (Stages I–IV) of the Khumbu- and Khumbakarna Himalaya (Figure 2/1, 3, 4, 11, 19) concerning the altitudes of their glacier levels, their ice thicknesses and the snow-line depressions as indicators of the past climate (Sections 1–4)

5.1. The glaciogeomorphologically reconstructed former glacier extensions, altitudes of the ice levels, glacier thicknesses and glacier types of the past ice stream network (Figures 2,3, 4, 11 and Figures 7–10, 12–16, 20–36, 52–57 with the valley cross-profiles Pro. 1–26 and 28–33)

Field- and laboratory findings have been interpreted according to their three-dimensional arrangement of the positions in the relief of the research area (see Section 1.1). They show 100 more than 6000–8000 m-high summits, from which five are higher than 7900 m (Table 5). With respect to the Würmian ice thicknesses overlying the relief, they can be understood on the basis of 32 valley cross-profiles. Their localities are depicted in Figures 3 and 4. The outline of the ice surface reconstructed here with the length of the valley glacier components can be found in Figures 4 and 11. The position of this outline of the ice surface in the whole Himalayan arc and on the S-margin of Tibet marks Section 1 in Figure 2.

In the research area between and inclusive of the Bote Koshi Nadi in the W and the Arun Nadi in the E, a 120 km-wide valley glacier system has been situated, which toward the S has joined in two parent glaciers, the Dudh Koshi main glacier and the Arun glacier. The N/S-extension of the High Würmian (Stage 0, Isotope Stages 4–2) Dudh Koshi main glacier from the Himalaya main crest up to its lowest ice margin at ca. 900 m a.s.l. (Section 3.9.2) was ca. 67–70 km. The N/S-extension of the Arun glacier from its catchment area of the Barun glacier W of Makalu up to its glacier tongue end at ca. 500 (450) m a.s.l. (Sections 2.4.5 and 2.4.7) was also ca. 67 km; its extension from S-Tibet, down from the Himalaya break-through S of the Kada settlement (Figure 4) even amounted to ca. 80 km. At that time the most important ice thicknesses in the catchment areas and tributary valleys of the two parent glaciers amounted to 1300–1450 m (Pro. 4, Figure 10; Pro. 5, Figure 12; Pro. 13, Figure 23; Pro. 16,Figure 26; Pro. 19, Figure 29; Pro. 20, Figure 30; Pro. 23, Figure 33; Pro. 24, Figure 34; Pro. 28, Figure 52). These ice thicknesses and surface raisings of the glacier feeding areas up to more than 6000 and 6400 m a.s.l. at maximum (Pro. 1, Figure 7) have led to numerous ice transfluences, so e.g. across the 6220 m-high pass between Barun Nadi and Imja Khola situated between Cho Polu (No. 29) and Shar Tse (Peak 38) (No. 10), across the 6190 m-transfluence pass between Cho Polu and Baruntse (No. 13) (Figure 3) more to the S etc. . Three further transfluence passes with an altitude about 6100 m, connected with the Barun Nadi on the orographic right side, have led to the W-adjacent Lower Barun glacier branch and a further one across the 6135 m-high West Col into the connected Hunku Drangka (Sections 2.1–2.1.4). Corresponding ice transfluences have taken place further westward between Imja Drangka and Khumbu Drangka (Section 3.3), between Khumbu Drangka and Ngozumpa Drangka, in part mediated by subordinated valleys located in between, as the Tschola- and Nyimagawa Drangka (Sections 3.2 and 3.5), between Ngozumpa Drangka and Bote Koshi Nadi (Sections 3.5 and 3.8), mediated by the Sumna Drangka located in between, as well as over to the Chhule and Langmoche Drangka (Section 3.8.1 and 3.8.3). At the same time, the ice level of the investigation area was connected to the neighbouring mountain groups and their ice- stream-network-like valley glaciation. Ice transfluences have existed into the NE-adjacent Kangschung Nadi, E of Mt. Everest (Figure 3 between No. 10 and 3; Figure 4) (Section 2.1.3) and on the W-margin between Rolwaling Himal and Bote Koshi Drangka (Section 3.8.1 and 3.8.3.) (Figure 2, No. 1; Figures 3,4 and 11). Consequently, in the Khumbu-Khumbakarna Himalaya an extended valley glacier system has existed, flowing down to the S, with transfluences and accompanying ice domes and -cupolas on the area between Rolwaling and Bote Koshi Drangka, the area between Bote Koshi- and Ngozumpa Drangka, the area between Ngozumpa- and Khumbu Drangka, the area between Khumbu- and upper Imja Drangka and between the upper Imja- and upper Barun Drangka with a Lower Barun Drangka- smaller cupola. The sizes of these little ice domes increase with the average altitude of the relief to the N, toward the Himalaya main crest. Besides the W/E-transfluences, ice transfluences between the Himalaya N-side, i.e. S-Tibet, and the investigation area have also been evidenced. So between the Rongbuk- and the Khumbu glacier valley (Section 3.1) (Photos 53 and 54), the W-Rongbuk- and the Ngozumpa glacier valley (Section 3.5) and finally also between the Kyetrak- and the Nangpa glacier valley across the 5716 m-high Nangpa La (Figure 3 No. 62) (Sections 3.7 and 3.8). Without exception the N/S-transfluence areas had the character of ice cupolas. Currently, nearly all Würmian transfluence passes are locally glaciated.

Accordingly, the Würmian maximum glaciation of the research area has shown the characteristics of an ice-stream-network-like valley glacier system, which was a part of the ice stream network of the Himalaya (Figure 2). Due to the extending basal face of the transfluence areas, the cover with ice cupolas has also increased toward the N, and also the character of an ice stream network, i.e. toward the S it passes into a valley glacier system. The valley glacier, which from the N across the Nangpa La has flowed into the Himalaya S-slope, into the Bote Koshi Drangka, shows the characteristics of an outlet glacier from the S-margin of the Tibetan ice (Sections 3.7 and 3.8).

The high summits, towering up to 2000 m above the névé areas of the ice stream network between 7000 and 6000 m, have been situated with their steep faces ca. 2000–5000 altitude-metres above the High Glacial snow-line (Section 5.3 and Figure 17). The consequence was that there were permafrost (pergelid) conditions with constant temperatures between −15 to −45 °C, so that no melting process has enabled the snow to adhere. Owing to this, no flank glaciations with ice balconies have been developed, but – as in the Antarctic – cold, dry rock faces have risen above those névé areas (Kuhle, 1986i, j) (see Photos 53, 54; 106–108).

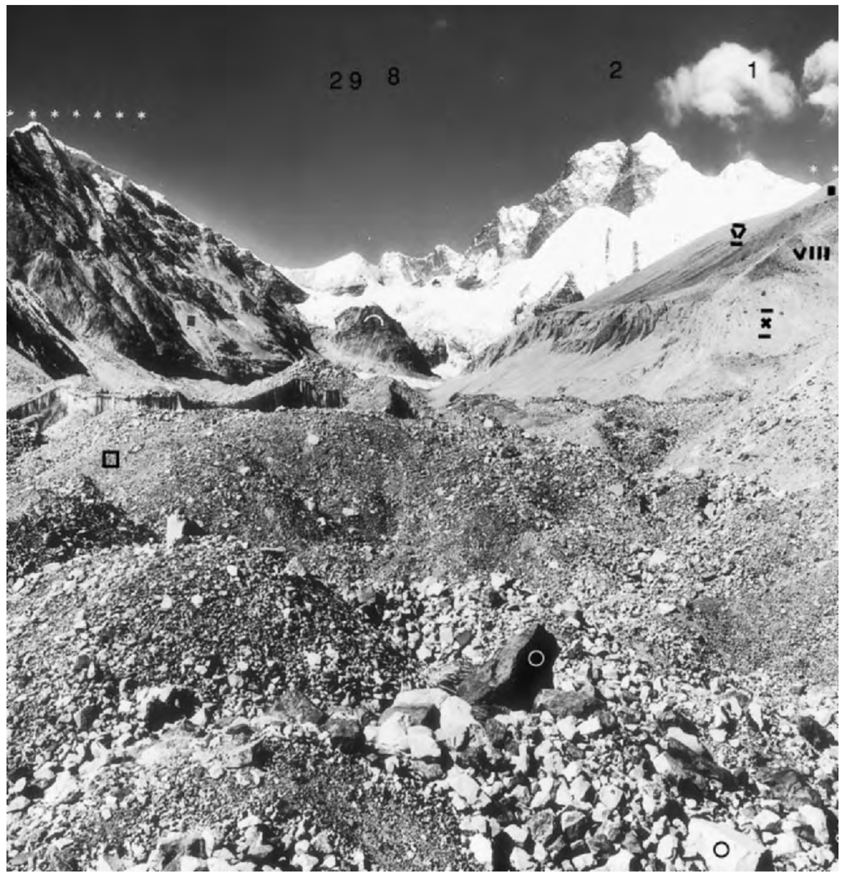
5.2. Thirteen glacier stages and their distances since the last maximum glaciation as well as neoglacial to historical 14C-datings as indicators of the Würmian to historical glacier history

Table 1 indicates the 13 glacier stages (Stages XII–0) which in this investigation area, in accordance with other investigation areas in High Asia, have been reconstructed by means of ice margin positions between the current glacier tongues and the lowest past glacier terminals (Figures 3,11 and 19). Table 3 shows 123 Late Glacial-, Neoglacial- and Historical glacier positions from the Late Glacial Dhampu Stage (III) up to Stage X, as well as their snow-line depressions and absolute ages for the section of the area on the S-slope of the Cho Oyu Himalayas (Ngozumpa valley) (Figure 19). Table 4 summarizes the average snow-line depressions of these medium-sized valley glaciers in the Ngozumpa valley from Stage III to Stage X (Figure 19) (cf. with Table 1, which summarizes the whole of High Asia). In the investigation area absolute age data have been obtained as far as back into the Holocene, i.e. up to a Neoglacial Age (Stage V) (Table 2). According to ELA-depressions, the four Late Glacial Stages IV–I and also the High Würmian Stage 0 (Table 1) evidenced, have been classified by analogy with 14C- and TL-data from neighbouring areas of S-Tibet and High Asia (Kuhle, 1998a).

The summarizing question, to what extent the glacier history of the investigation area or of the whole of High Asia is combined with the global climate development, has to be answered as follows: The worldwide comparison shows a strikingly precise glacier synchronism, also with respect to the extent of the glacier variations. As to their reconstruction of the ice stream network of the approx. 100,000 km^2 extended Ice Age glaciation of the Alps, Penck and Brückner (1901–1909) have diagnosed a snow-line depression about 1200 m for the Last Ice Age (Isotope Stage 4–2). Similar values not only apply to other mountains of Europe, but e.g. also to America – to mention a continent, which is far away and currently has an entirely different climate. As has been evidenced by newer studies, during the Tahoe-, but also during the Tioga Stage (Clark et al., 2003), the Sierra Nevada, for instance, has shown a snow-line depression about 1050 m on its continental E-slope, whilst on the humid W-slope it was even more than 2000 m for the same Last Glacial maximum extensions of the glacier ice (James, 2003). To date the absolute datings on 14-C basis are only minimum values – if they are correct at all. With regard to the glacier stratigraphy, surface datings are very uncertain anyway (among others Putkonen and Swanson, 2003). This is the reason, why first it was arguably possible to shift the 2.4 million km^2-extended Ice Age glaciation of High Asia with the Tibetan inland ice (Kuhle, 1974–2004b) into an older Ice Age as probably belonging to it. However, according to the state of the glacier-historical synchronism research, for several years this can no longer be maintained. So, in Tibet (Zheng Benxing and Shi Yafeng, 1976; Zheng Benxing, 1988) and in the research area (Richards et al., 2001) several authors have dated end moraines, situated at an only small distance from the current glacier terminals and overthrust by the glacier at a snow-line depression of only 400 m and less compared with today, to 20,000–25,000 YBP (Isotope Stage 2). These absolute age data are necessarily not only wrong, because the snow-line depression is much too insignificant, but also, because here a large amount of the end moraine ramps from the late glacial, neoglacial and postglacial period, which occur worldwide, are completely absent between the supposed High Würmian end moraine and the current glacier margin. As has been described, between the lowest preserved glacier stages – which we have classified as belonging to the High Würmian (Stage 0) and which in our research area are situated decakilometres away and ca. 3000–4000 altitude-metres below the current glacier margins (Section 5.3), which points to orographic snow-line depressions of at least 1500 m – 13 Late Glacial to historical glacier stages could be verified (Kuhle, 1998a). According to the geomorphological extent of their reshaping, four of them have been placed into the Late Glacial (Stages I–IV), three into the Neoglacial (Holocene, Stages V–′VII) and six into the historical time up to 1980 (Stages VII–XII) (cf. Meiners, 1996, 1997). This approx. corresponds with the number of glacier stages e.g. in the Alps and Rocky Mountains since the Würmian- or the Wisconsin ice age, respectively (e.g. Porter, who has recently compared the glacier stages in the Cascade Range and the S-Alps; personal information kindly communicated on 3/8/2003).

On the occasion of the dating mistakes cited, the inadmissibility of surface datings on moraine boulders in the mountains of the investigation area will be explained by some examples. So e.g., augen-gneiss boulders, which due to frost weathering and hydration are extremely angular and superficially heavily roughened (see Photo 180 ○), give the impression of a considerable age, though the condition of their surface cannot be deduced from the period of time during which they have kept their positions, but to the hydrothermal decay already preparing the separation of crystals in the bedrock. The adjacent boulders, lying in the same position and completely exposed on the moraine surface, which are only slightly or not at all weathered (e.g. Photo 179 ○; 182) must be of the same age of

← *Photo 1.* At 5370 m a.s.l. from the orographic left Late Glacial lateral moraine terrace (Stage IV) of the Barun valley (27°49′45″ N/87°05′43″ E; SE of Pro. 4; Figures 3 and 4) facing WNW looking up the upper Barun glacier valley. No. 8 is Nuptse (7879 m), No. 2 Lhotse (8501 m), No. 10 Shar Tse or Peak 38 (7502 m) and No. 29 Cho Polu (6734 m). (□) is the tongue of the Barun glacier covered with surface moraine. Several hanging- and side valley glaciers join the glacier. (⌒) are glacially triangle-shaped slopes, polished back and rounded by the Ice Age glacier. (––– and 0 –––) mark the highest glaciogeomorphologically verifiable past glacier trim-line, which probably has been reached during the Last Glacial (Würmian) (Stage 0 = Last High Glacial maximum = LGM; cf. Table 1) (Figure 7); (⌒) is an ice transfluence of that time via which the Ice Age glacier trim-line of the Barun glacier has communicated with that of the neighbouring Imja glacier. (■) is the highest moraine occurrence at ca. 5980 m a.s.l.; V, VIII, X are ground- and lateral moraine remnants of the neoglacial to historical stages of the Barun glacier (cf. Table 1). ⇩ are rock crumblings in the tourmaline-granite bedrock of the Makalu superstructure caused by ice avalanches of the hanging glaciers and ice balconies above. (▽) is a lateral-, end- and ground moraine pedestal of a hanging glacier of the western Makalu-S-flank; it can also be described as a pedestal glacier, because its tongue lies on the moraine-pedestal. Analogue photo M. Kuhle, 3/12/1994.

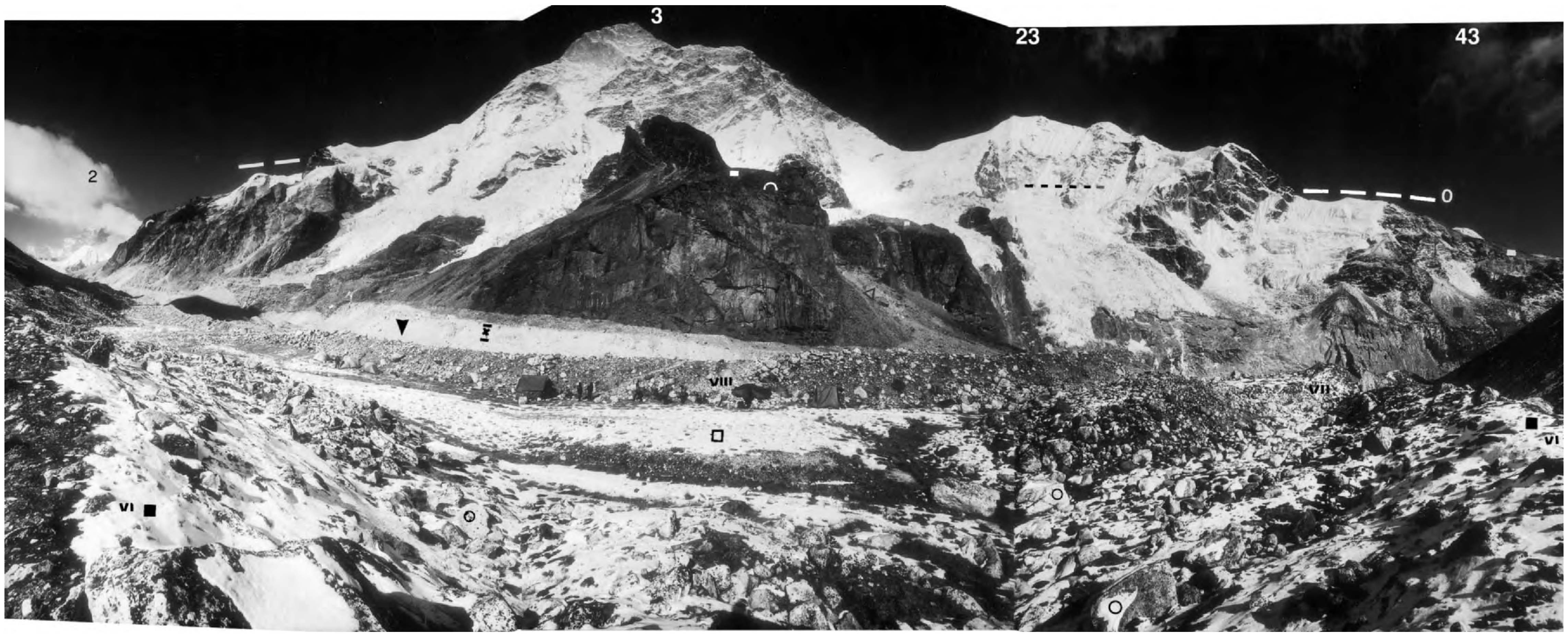


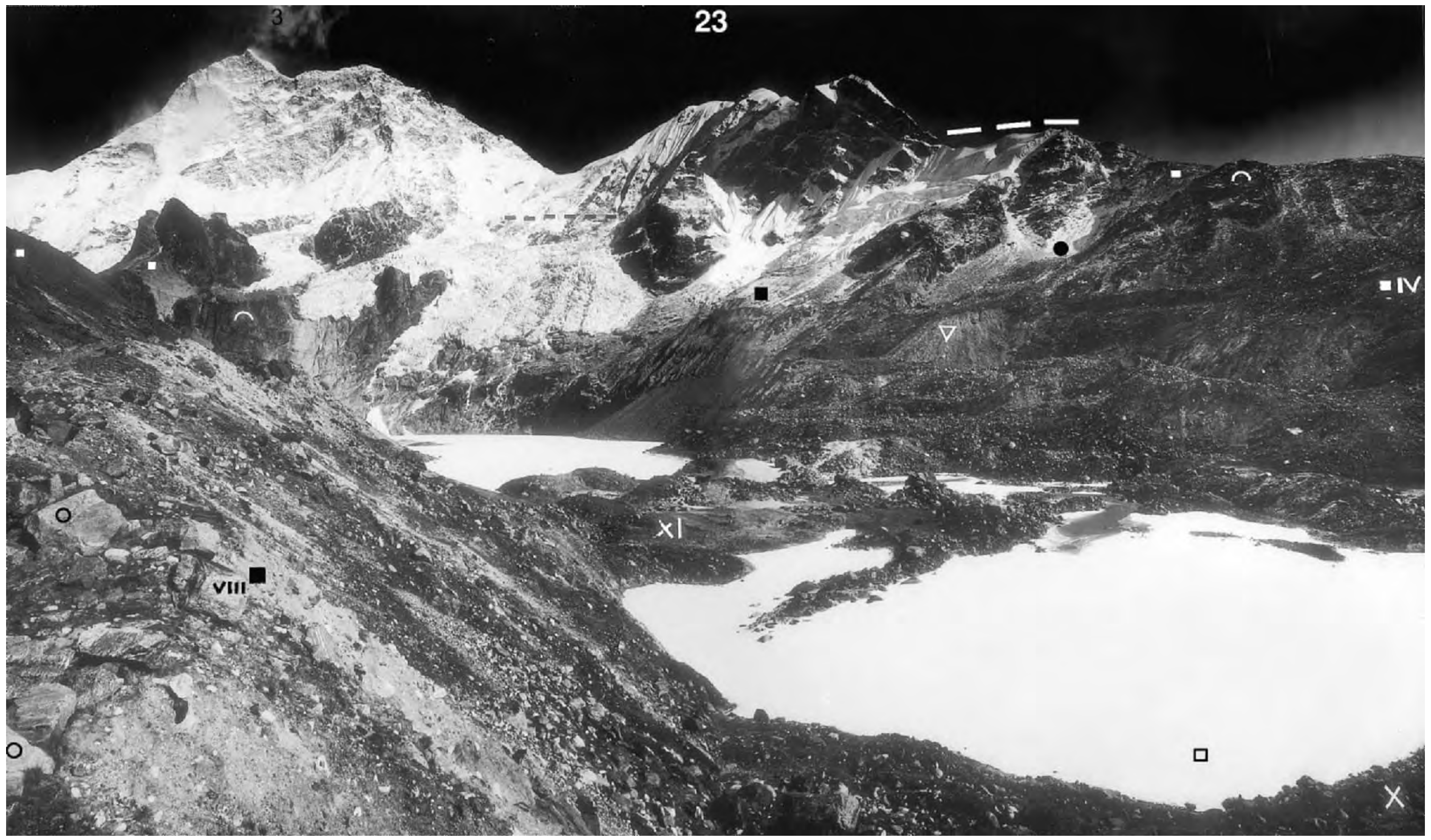
← *Photo 2.* View from 5220 m a.s.l. from the several decimetres-thick surface moraine (□) in the centre of the Barun glacier (27°51′55″ N/87°02′55″ E; NW of Pro. 2; Figure 3 and 4) facing WNW looking up the Barun glacier. In the background Mt. Everest (No. 1, 8872 m) with its Kangchung flank sloping down to the E is visible. No. 8 is Nuptse (7879 m), No. 2 Lhotse (8501 m) and No. 29 Cho Polu (6734 m). The glacier surface in the fore- and middle ground (□) shows differences in height up to 35 m; the surface moraine (□) is made up of polymictic, mostly angular, dark boulders of sedimentary rock and light tourmaline-granite (○) (as to the matrix of the surface moraine cf. Figures 6 and 9 in the table and columnar diagram). In places cliffs of sheer ice (above □) break through the surface moraine. (■) are ground- and lateral moraines of the Late Glacial on the valley flanks. (V, VIII, X) mark the neoglacial (Table 1) moraine deposits on the orographic left valley flank (ground- and lateral moraines). (⌒) is a rock bar (riegel) basally mantled with moraine, which has been polished round in the past. It is situated between two glacier branches which are currently separated. (***) indicates the highest reconstructed past (last glacial period = Stage 0) glacier trim-line about 6200 m. Analogue photo M. Kuhle, 6/12/1994.

↓ *Photo 4.* At 5050 m a.s.l. from the orographic right historical lateral moraine (Stage VIII or IX, Table 1) of the Barun glacier (27 °51′ 25″ N/87°03′57″ E; NW of Pro. 2; Figures 3 and 4) facing S looking up the orographic right Barun valley flank. (○) are large moraine boulders as well as boulders deriving from crumblings up-slope, which have fallen down from the rock walls. (■ black) are accumulations of the inner slopes of ground- and lateral moraines (Figure 8), reshaped by rock avalanches and solifluction since the deglaciation during the neoglacial period (Holocene). (■ white) are higher and older moraine sediments of the same genesis. The meltwater run-off has reshaped them in the way of alluvial- and talus cones. From the late Late Glacial (Stage IV) up to the neoglacial period (Holocene) a hanging glacier flowed down from this local, 5800 m-high, gully-like catchment area (▽), providing the meltwater. On both sides of the polished-out gully (▽), older (High- to Late Glacial) flank abrasions in the form of remnants of two glacigenically triangle-shaped slopes have been preserved (⌒). During earlier glacial times (pre-last glacial period, Riss) they have formed a connected triangle-shaped surface (cf. Figure 3 above arrow 4) towering above the glacier surface of the last glacial period (0 –––). Analogue photo M. Kuhle, 5/12/1994.

← *Photo 3.* At 5200 m a.s.l. from the several metres-thick surface moraine (□) NE of the centre of the Barun glacier (27°51′54″ N/87°03′ E; NW of Pro. 2; Figures 3 and 4) from facing WNW looking up the Barun glacier up to S into the orographic right Barun valley flank, which at the same time forms the N-flank of the 6550 m-peak (No. 39). N of the 6510 m-peak (No. 41) is the 6110 m-high Sherpani Col, above which the highest Ice Age glacier trim-line (––– and *** 0) has towered by ca. 100 m, so that a transfluence pass between the Barun- and the neighbouring Lower Barun valley has existed (⌒). This transfluence continued to the W via the West Col (6135 m) up to the Hunku Drangka (cf. Figure 3). No. 30 is the 6730 m-peak, the Baruntse-SE-satellite. (∩) are glacigenically triangle-shaped slopes and truncated spurs between the side valley junctions, polished back by the flank polishing of the Ice Age Barun parent glacier. (■) are accumulations of ground- and lateral moraines, classified by the Roman numerals V, VII, X as belonging to neoglacial (holocene) up to historical glacier positions (see Table 1). In the lateral moraines X dead ice is still contained. The surface moraine overlay (□) is interrupted by 30–45°-steep and up to 20 m-high ramps of sheer ice (below □ below). (○) are tourmaline-granite boulders which are edged (○ on the left) up to rounded at the edges and facetted (○ on the right). Analogue photo M. Kuhle, 6/12/1994.

↓ *Photo 6.* Panorama at 5050 m from the orographic right lateral moraine complex, taken from the lateral moraine rampart of the Barun glacier (27°50′50″ N/87°04′47″ E; between Pro. 2 and 4; Figures 3 and 4) classified as belonging to the neoglacial (Holocene) Stage VI (Table 1): Facing WNW looking up the Barun valley (No. 2 = Lhotse 8501 m) via N (No. 3 = Makalu 8475 m with S-face) and NE (No. 23 = 6825 m-peak) into the orographic left Barun valley flank up to ESE down-valley (No. 43 = ca. 6450 m-peak). (––– and –––0) is the highest glaciogeomorphologically reconstructable glacier trim-line, running down parallel to the valley ground from ca. 6300 m on the left to ca. 6000 m on the right (Figures 7–9). It is evidenced by the preservation of rock roundings caused by abrasion (∩) and by abrasion lines, which in an upward direction can be identified by a sharp increase of the rock roughnesses and high-lying deposits of moraines (■ white). (■ black, below No. 43) is a ground moraine remnant on a rock ledge, covered by a debris flow cone (Figure 3 above Photo 1); the rest (■ black) are neoglacial to historical glacier stages of the Stages VI, VII, VIII and X (Table 1) covered with boulders of tourmaline granite which are edged, rounded at the edges and facetted. The moraine of Stage VIII is already covered with fully-grown dwarf scrub (for scale: several tents and persons on the outer slope of moraine VIII). However, its mantle of vegetation has not yet reached the vegetation climax of the older moraine ramps of Stages VII and VI. The author considers it to be early-modern, i.e. 400–300 years old. Here, this world-wide early-modern glacier advance, which is to be observed in the entire Himalaya (Kuhle, 1982, 1983a), testifies to an orographic snow-line depression (ELA-depression) of ca. 50 m. (▼) is the steep inner slope of the Little Ice Age moraine X (Table 1), undercut by the current Barun glacier. This moraine is attached to the lateral moraine VIII on both sides of the glacier. Stage X is the second strong historical glacier advance: it took place between ca. 1820 and 1920. It exists all over the Himalaya and has been described world-wide. In the meantime, in the small lateral valley between the older and younger lateral moraines glaciofluvial gravels have been deposited as lateral sanders (□). (▽) is a debris flow cone made up of moraine material which has been re-deposited by the meltwater of the hanging glacier above (Figure 3 on the right above Photo 6). Analogue photo M. Kuhle, 5/12/1994.

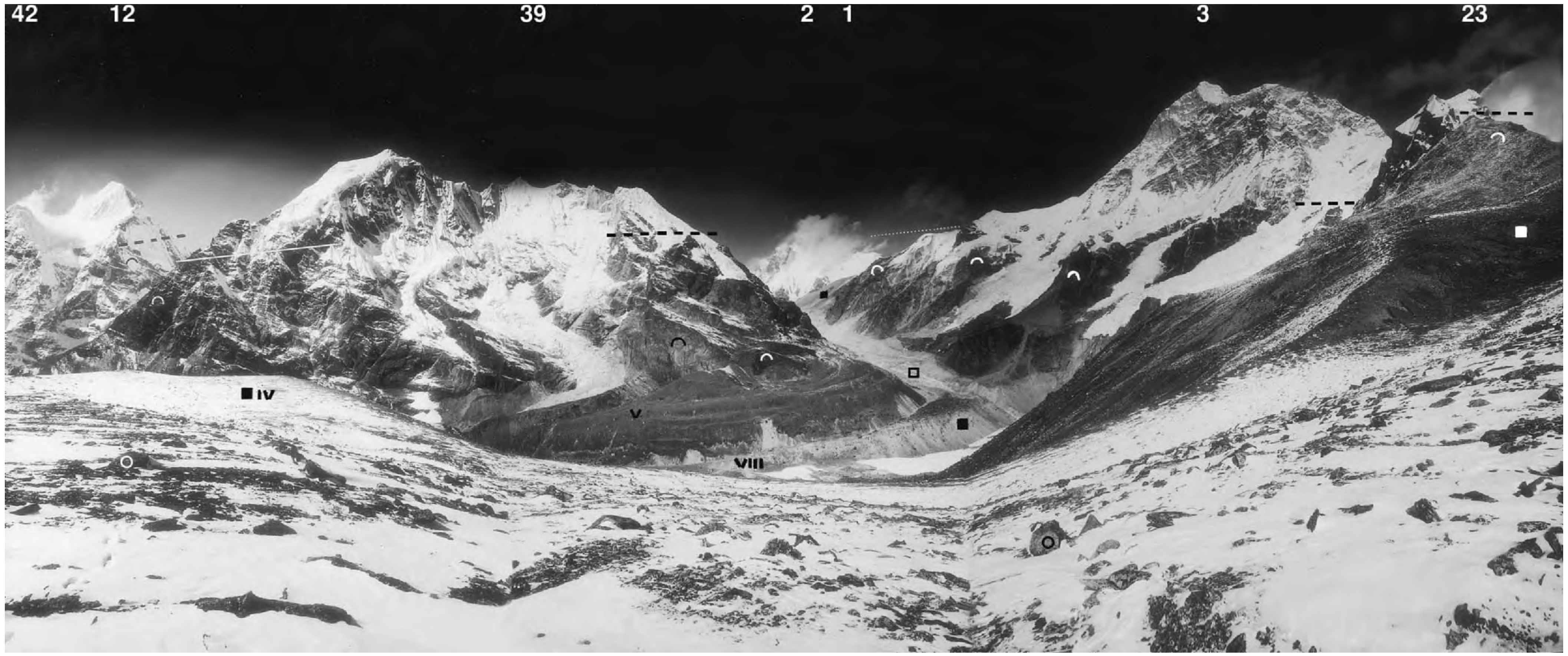




← *Photo 7.* Panorama taken at 4900 m a.s.l. from the orographic right historical lateral moraine complex and here from the lateral moraine of the Barun glacier Stage VIII (Table 1) (27°50′29″ N/87°04′17″ E; between Pro. 2 and 4; Figures 3 and 4; cf. Panorama 8 VIII): from facing N (No. 3 = Makalu) via NW (No. 23 = 6825 m-peak) up to WSW. The hanging glacier below the 3500 m- high Makalu S-flank has left the floor of the Barun valley since Stage XI (Table 1), i.e. since ca. 1920–1950. There are two moraine-dammed lakes, the Barun-Pokhari, wearing a snowy ice cover (□). The Little Ice Age moraine (Stage X), situated 1.5 km away from the foot of the Makalu flank, dams up the down-valley lake, the moraine of Stage XI the upper lake. The sediment analysis of the frontal moraine of Stage X (see Figure 6, No. 8 in Table 1 and columnar diagram) shows a very coarse matrix, the large grain sizes of which can be deduced from the significant proportion of tourmaline-granite, weathering into coarse crystals. The glacially crushed quartz grains have been partly reworked fluvially but also eolianly. The fluvial reworking is typical of frontal moraines situated near to the glacier mouth. (■) are High- to Late Glacial ground- (■ small) and Late Glacial to historical lateral moraines (Stages IV–VIII, Table 1). (○) are polymictic boulders consisting of darker metamorphic sedimentary rocks and light tourmaline-granite. The edges vary from angular to rounded. (∩) are rounded rock heads which have been glacially polished. They are partly mantled with moraine material (∩ on the right) or have been undercut and wasted away by the current flat glacier tongue through glacigenic lateral erosion (∩ on the left). Today the two rock heads are roughened by frost weathering. (– – –) marks the glacier trim-line of the maximum glacier cover during the last glacial period (Stage 0), evidenced by high-lying moraine material (■ small) and still higher glacigenic abrasions, which in an upward direction break off with a polish line against strong rock roughnesses (cf. Figure 10 left half of the profile). (▽) is a rock glacier still active today, i.e. a periglacial forming as a result of the permafrost content (see Figure 3 above arrow 1). Accordingly, the lower limit of permafrost runs here in a W-exposition about 4900 m a.s.l. (cf. Kuhle, 1978a; 1985c). The rock glacier emerges from a past cirque (●) filled with a glacier of sheer ice during the Late Glacial of Stage IV and the neoglacial Stages V–VI, perhaps even' VII. It proves an orographic snow-line in W-exposition about 5400 m a.s.l. at that time. In the meantime its end moraine has been modified into the rock glacier. Analogue photo M. Kuhle 4/12/1994.

← *Photo 5.* Panorama at 5200 m a.s.l. from the orographic right historical lateral moraine of Stage IX or X (Table 1) of the Barun glacier (27°51′48″ N/87°03′01″ E; NW of Pro. 2; Figures 3 and 4): Taken facing WNW up the Barun valley via N and NE into the orographic left Barun valley flank up to ESE looking up-valley. The 6730 m-peak, i.e. the Baruntse-SE-satellite (No. 30), is only just visible; beyond the upper valley head is Lhotse (No. 2, 8501 m), No. 3 is Makalu (8481, i.e. 8475 m) with its S-face; No. 23 is the 6825 m-peak, No. 43 a ca. 6450 m-high summit. Since the last strong advance during the Little Ice Age (Stage X, cf. Table 1) the debris-covered Barun glacier (□) has subsided by 60–120 m. This is shown by the height of the orographic left lateral moraine (X). The corresponding orographic right lateral moraine (viewpoint of the photo, foreground) is mostly made up of angular, coarse boulders (○) and – according to the laboratory analysis (Figure 6, No. 10, Table 1 and columnar diagram) – a typically triturated matrix of glacially crushed quartz grains. Due to the meandriform course of the intraglacial and supraglacial meltwater stream close to and on its surface, the current glacier has been locally increasingly laid deeper by thermo-erosion. Accordingly, steep ramps of sheer ice (▲) have been developed along the meltwater stream and down to it. The surface moraine slides down on these ramps (□) and – as a result – is continuously re-deposited. (■) are older ground- and lateral moraines. The latter can be classified as belonging to the historical Stage VII (cf. Table 1). (∩) are rocks, abraded during the late to high glacial period. They reach much higher up than the moraine remnants and prove the highest past glacier level (––– and ––– 0) about 6000–6400 m a.s.l. (Figures 7 and 8). Analogue photo M. Kuhle, 6/12/1994.

↓ *Photo 8.* This panorama was taken at 5360 m a.s.l. from the orographic left Late Glacial lateral moraine terrace (Stage IV) of the Barun valley (27° 49′ 45″ N/87° 05′ 43″ E; SE of Pro. 4; Figure 3 and 4) from facing SW with the 6480 m-peak (No. 42, see also Figure 10) and the 7290 m-high Chamlang (No. 12) via W with the 6720 m-peak (No. 31) and the 6550 m-peak (No. 39), via NW with the 8501 m-high Lhotse (No. 2) and the 8872 m-high Mt. Everest (No. 1) looking up the upper Barun glacier valley, via N with the 8481 m-high Makalu (No. 3) up to NE to the 6825 m-peak (No. 23). Below No. 2 and 1 the cross-profiles 1 and 2 across the upper Barun valley (Figure 7 and 8) are to be imagined. (□) is the current Barun glacier covered with surface moraine debris. (■) marks the inner slopes of ground-, i.e. lateral moraines. (IV, V and VIII) are moraine generations from the late Late Glacial up to the historical 'younger Dhaulagiri Stadium' (Table 1), the differentiation of which is especially clear in this valley chamber. The lateral moraine (VIII) is undercut by the two Barun-Pokhari (lakes) (below VIII). The moraine surface of Stage IV (■ IV) is ca. 200 m above that of Stage V. (○) are large polymictic moraine boulders of granite and metamorphic sedimentary rocks, embedded into a clay- containing matrix. (∩) are glacigenic rock abrasions. Despite its reworking since the deglaciation after the last glacial period, these abrasion forms have been preserved up to an approximately continuously observable diagonal level. It runs (––– white) down from 6200 m a.s.l. on the right below No. 1 up to ca. 5850 m (––– white) below No. 31 and marks the glacier trim-line of the Last Maximum Glaciation (Stage 0) ca. 1000 m above the current glacier surface (Figures 7 and 8), i.e. ca. 1100 m above the valley floor near Sherson (cf. Figures 3 and 10). The ice level lay below No. 12 at ca. 6300 m a.s.l. (–––) in the lower Barun glacier valley in the Chamlang flank (Figure 9). Below No. 23 the glacier abrasion, i.e. the Ice Age glacier trim-line reached a height of ca. 6000 m (Figure 10 left margin of the profile). Analogue photo M. Kuhle, 3/12/1994.

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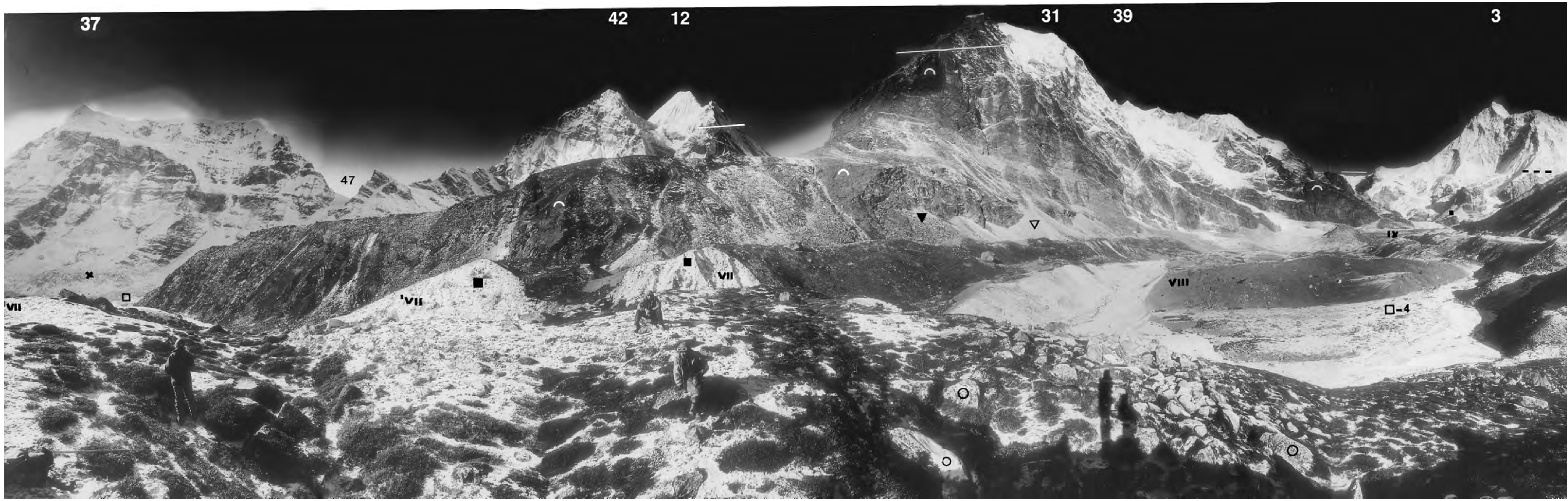
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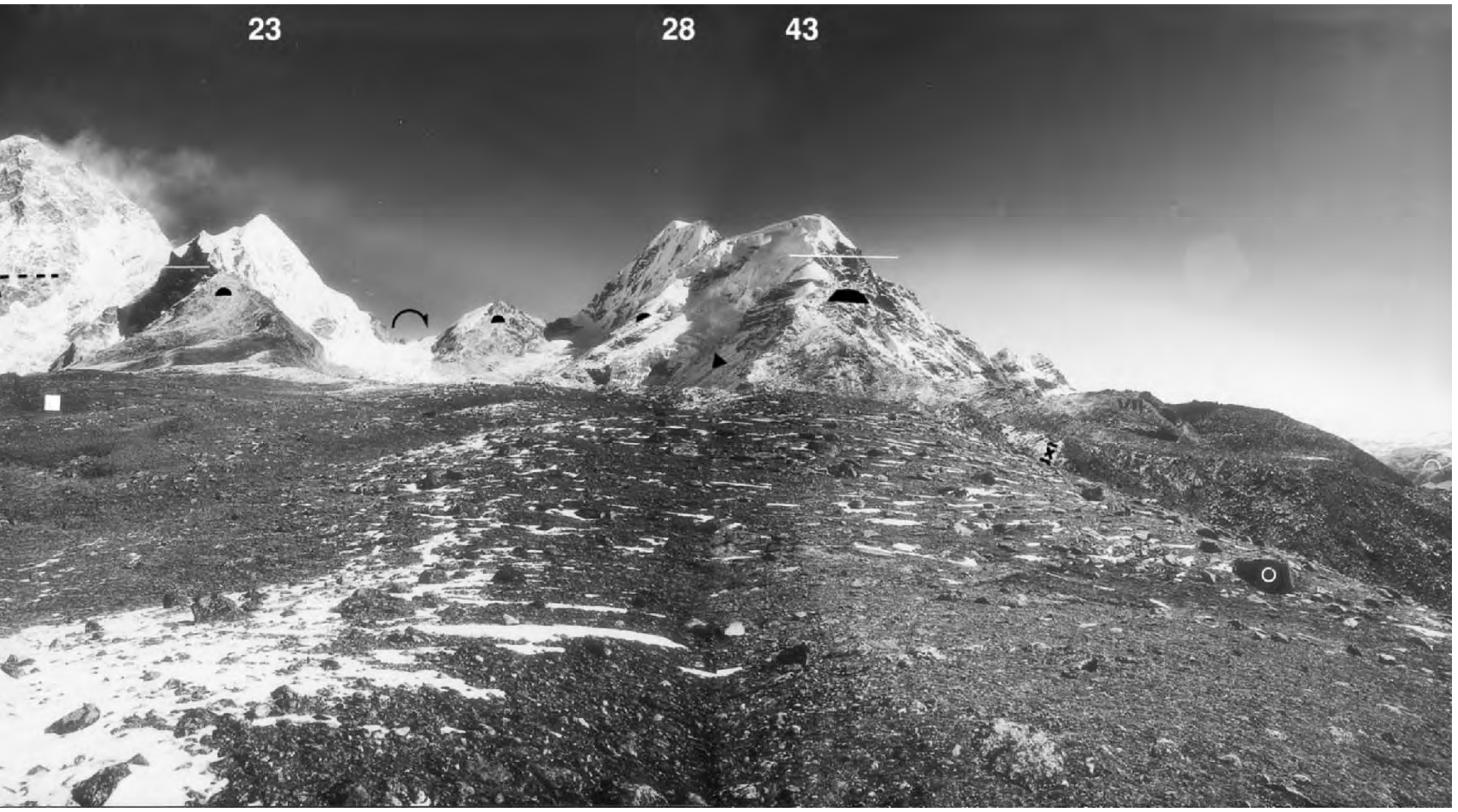
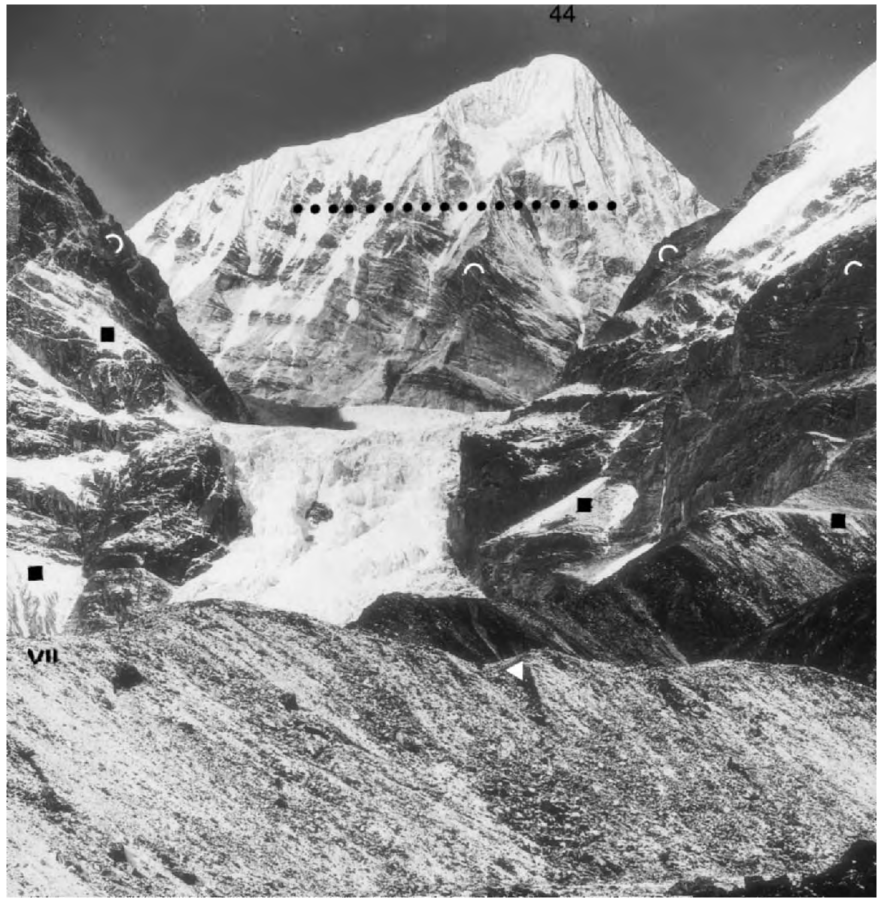


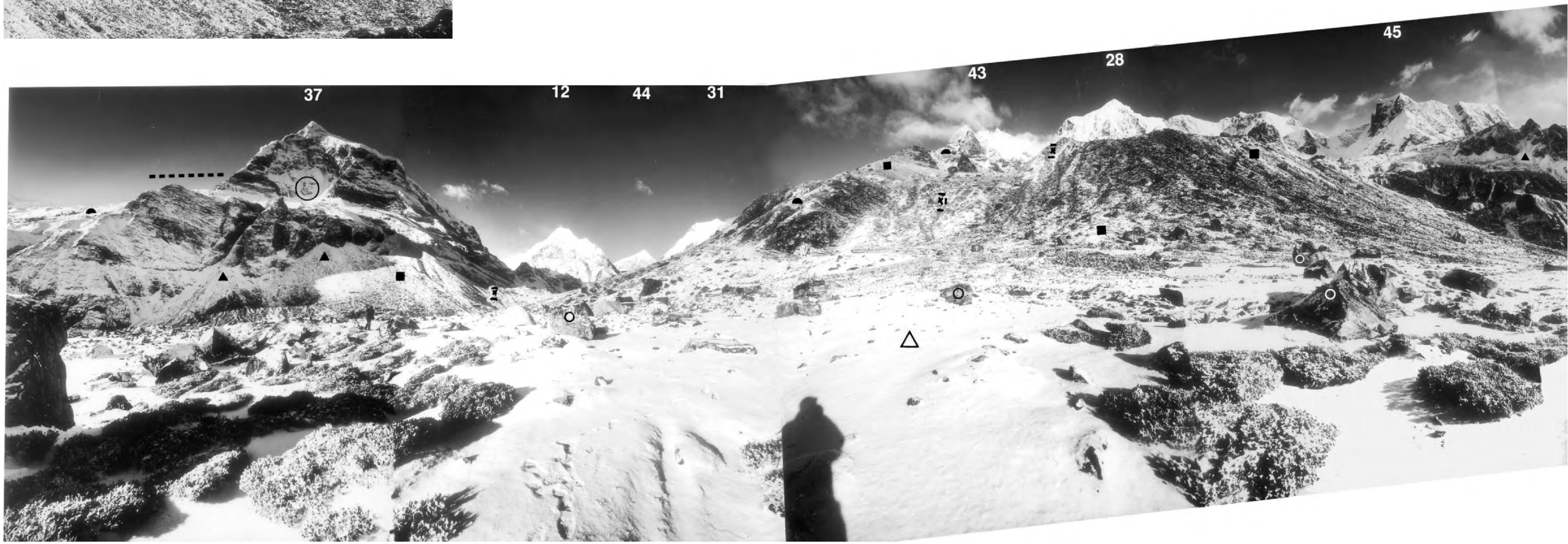
← *Photo 9.* 360°-panorama at 5290 m a.s.l. taken from the orographic left Late Glacial lateral moraine terrace (Stage IV) of the Barun valley (27°49′30″ N/87°05′19″ E; SE of Pro. 4; Figures 3 and 4) from facing SE down the Barun valley (left margin) via the ca. 6600 m-high Iswa Peak (or Peak 6, 6739 m = No. 37) in the S, via the Iswa La (No. 47 = 5340 m) to the adjacent Irkhuwa Khola, the Chamlang (No. 12 = 7290 m) in the SW, up the Lower Barun valley, with the 6720 m-peak (No. 31) and the 6550 m-peak (No. 39) in the W up to WNW, looking up the upper Barun glacier valley with the 8481 m-high Makalu (No. 3) facing N, via NE to the 6825 m-peak (No. 23) up to E to the ca. 6450 m-high summit (No. 43). (□) is the tongue of the Lower Barun glacier (Figure 10) covered by surface moraine debris and fresh snow. X (on the left below No. 42; Figure 3 half-right above No. 42) is its orographic right lateral moraine, which has been overthrust during the 'Little Ice Age' (ca. 1820–1920). (X below No. 37) is the corresponding orographic left lateral moraine with basal ice contact. Here, samples 29.11.94/1 and /2 (see Figure 3) have been taken from the moraine ridge, 0.2 m below the surface (Figure 6, Nos. 3 and 4). (■ on the very left, i.e. VII, IX and X on the very right (Figure 3: on the right below 3.12.94/1)) are historical moraines of the S-glacier, flowing down from the 6825-peak (No. 23), from the ca. 6750 m-peak and from the ca. 6450 m-peak (see also Figure 10 on the right below the 6260 m-peak). They belong to the corresponding historical glacier stages (see Table 1). In the moraines X and IX (on the very right) dead ice is still contained. The hollow form on the right of VII (on the very right) is a thawing-out funnel of a dead ice body. VII (below No. 42) is the terminal moraine of the early-historical Barun glacier undercut by the Barun river (see Table 1). Here, the glacier reached down as far as the Sherson alpine pasture (Figure 3, VII on the left above Sherson). (IV ■ below No. 3 but also ○ from left to right in the fore- to middleground) is the over 2 km-long and over 1 km-wide late Late Glacial middle moraine terrace between the then 6825 m-peak-S-glacier (see above) and the simultaneous Barun glacier or a ground moraine pedestal (as to the sediment analysis of the moraine see Figure 5; 6 No. 7) of the then 6825 m-peak-S-glacier (Figure 10 centre to left half; Figure 3 viewpoint 9). At least part of the large round-edged moraine boulders are erratic, because tourmaline-granite boulders (○) are concerned, which the Barun glacier must have transported here from the Makalu-massif (No. 3) over a minimum distance of 5.5 km. (∩) are glacigenic flank polishings which – despite the roughening by subaerial frost weathering since the deglaciation – have been preserved as abrasion-smoothings on the rocks (Figure 3). In places these abrasions can be observed on glacigenically triangle-shaped faces (☗) (Figure 3). (– – – and ____) is the highest glacier trim-line of the last glacial period verifiable according to these abrasions. It ran between heights of 6300–6200 m (– – – or ___ below No. 12, 3, 23 and 43) and 5850–5800 m (___ below Nos. 37 and 31). (▼) are debris cones and slopes deriving from postglacially weathered debris from steep walls. At some places they cover the ground moraines (■ below No. 31). (⌒) is a ca. 5770 m-high, High Glacial transfluence pass across which the ice flowed steeply down to the Arun main-valley. Due to this discharge across the pass the level of the upper Barun glacier was limited to the reconstructed level (see above) about 6000 m. Analogue photo M. Kuhle, 3/12/1994.

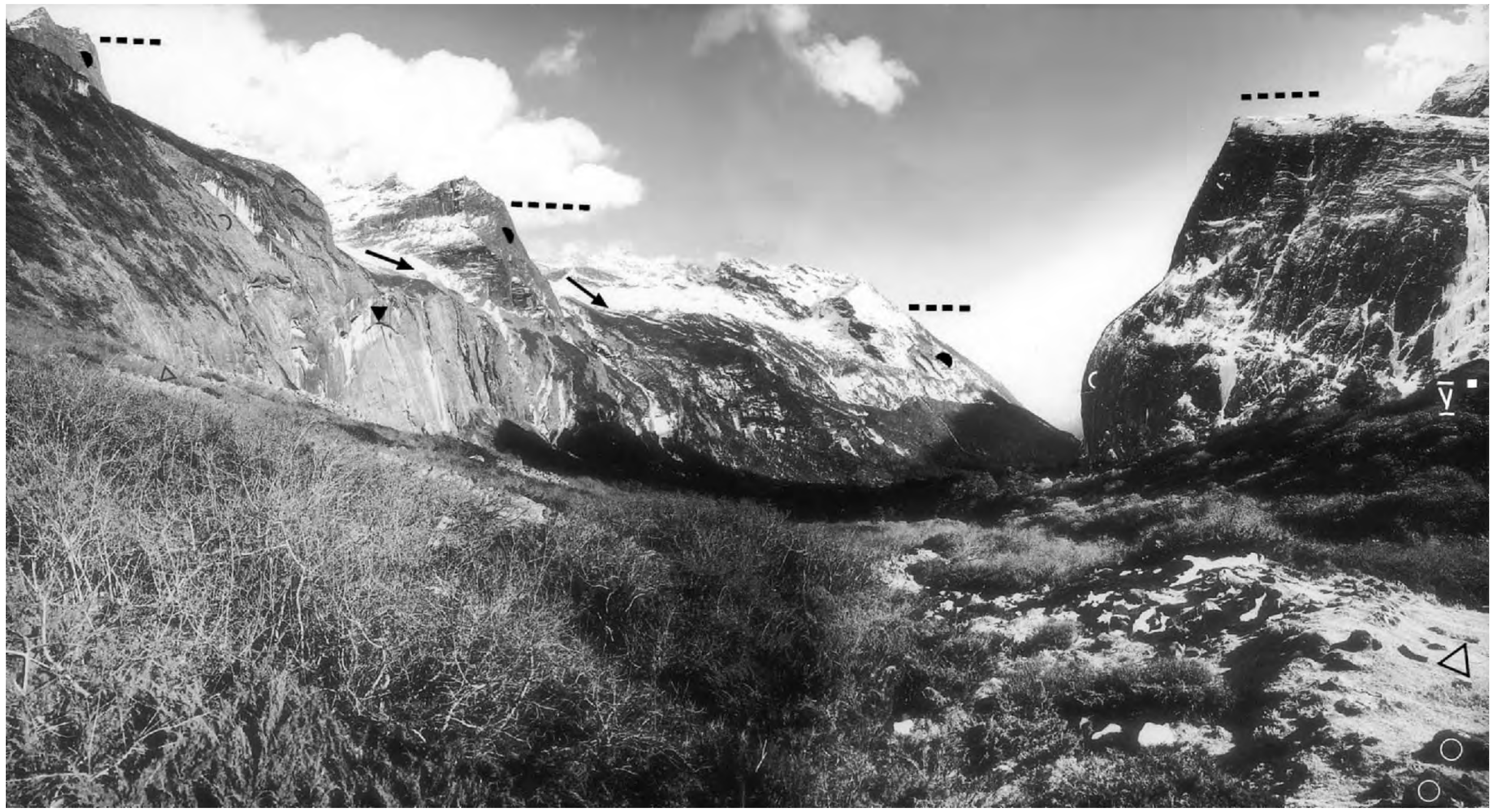
← *Photo 10.* 270°-panorama at 4800 m a.s.l. in the Barun valley NW of the Sherson alpine pasture, taken from the orographic left historical terminal moraine terrace of the 'Younger Dhaulagiri- Stage' (Stage VII) of the Barun glacier (27°48′57″ N/87°04′39″ E; SE of Pro. 4; Figures 3 and 4) from facing SSE to the ca. 6600 m-high Iswa Peak (or Peak 6, 6739 m = No. 37) (left margin) and Lower Barun glacier (□) down the Barun valley, via the Iswa La (No. 47 = 5340 m) to the neighbouring Irkhuwa Khola, via SW to the 6480 m-peak (No. 42) and Chamlang (No. 12 = 7290 m) via NW into the orographic right Barun valley flank with the 6720 m-peak (No. 31) and the 6550 m-peak (No. 39), via N, looking up the upper Barun valley with the 8481 m-high Makalu (No. 3), via NE with the 6825 m-peak (No. 23) and the ca. 6750 m-high summit (No. 28) up to E (right margin). (□) is the tongue of the Lower Barun glacier covered by surface moraine debris and some freshly fallen snow. X (below No. 37; Figure 3 on the right of No. 42) is the orographic right lateral moraine, overthrust during the 'Little Ice Age' (ca. 1820–1920) (Table 1). (IV, ′VII, VII, VIII, IX, X) mark the late Late Glacial, neoglacial (Holocene) to historical moraine sequences (see Table 1) in the Barun valley as they are mapped in Figure 3 and which provide evidence of the step-by-step deglaciation. (■) are ground- (■ below No. 3; on the right below No. 23) and end moraines (■ ′VII, VII, X). (□ –4) is the glacier-mouth gravel-floor of Stage VIII (Table 1). (○) are facetted and round-edged boulders of tourmaline-granite, shaped by the glacier-transport over a distance of at least 5 km. From moraine VII (in the foreground) matrix of fine material (sample 1.12.94/1 see Figure 3) has been taken from a depth of 0.3 m (Figure 6, No. 5) and also (sample 2.12.94/2, see Figure 3) from the moraine of Stage VII (below No. 3 on the right of IX; Figure 6, No. 6). (∩) are rock faces on the valley flanks smoothed by the past glacier abrasion (∩ on the left below Nos. 31 and 3) and roche-moutonnée-like rock knolls in the area of the past glacier ground scouring (∩ on the left and right below No. 12). (– – – and ___) are the Ice Age glacier trim-lines between 6300 m (___ on the left below No. 3) and 5850 m (___ on the left of No. 31) and about 6200 m (___ below No. 12) proved by polish lines. (▼) is a coarse-blocky debris cone derived from postglacial rock crumblings. (▽) shows a debris- and mudflow cone made up of fine-grained debris of crumblings (Figure 3 on the left of Photo 10), which has also been developed since the deglaciation. The last one is still active. Analogue photo M. Kuhle, 2/12/1994.



← *Photo 11.* At 4560 m a.s.l. from the orographic left lateral valley of the Lower Barun glacier (27°52′55″ N/87°06′05″ E; SE of Pro. 4, Figure 4) in the area of the Mera alpine pasture, facing NW looking up the Lower Barun glacier valley in the direction of the 6830 m-high Chonku Chuli (No. 44). (VII) is the orographic left lateral moraine (with some freshly fallen snow) of the Lower Barun glacier, overthrust during the first historical advance of the 'Younger Dhaulagiri Stage' (Table 1, VII). The meltwater spillways (▼), which have been preserved in a geomorphologically non-reworked condition, are evidence of rather fresh, i.e. young lateral moraines. (■) are remains of lodgement till on rock ledges. Now and then they (the three ■ on the left) have been – and still are – furrowed by debris-containing snow- and ice avalanches (■ on the very left), but also covered by debris falling from the walls (the two ■ in the centre). (∩) are abrasion faces on stratified rocks of gneiss- and metamorphites which can still unambiguously be classified as being of glacigenic origin. They are interrupted by rock faces roughened by holocene crumblings. (...) is the upper limit of the smoothings by abrasion. Above, the wall ravines and avalanche gorges merge without a smooth space in between. (...) marks the minimum height of the glacier trim-line during the maximum glacier filling of the relief during the last glacial period (Stage 0 = Würm), ca. 630 m below the summit at ca. 6200 m a.s.l. Analogue photo M. Kuhle, 1/12/1994.

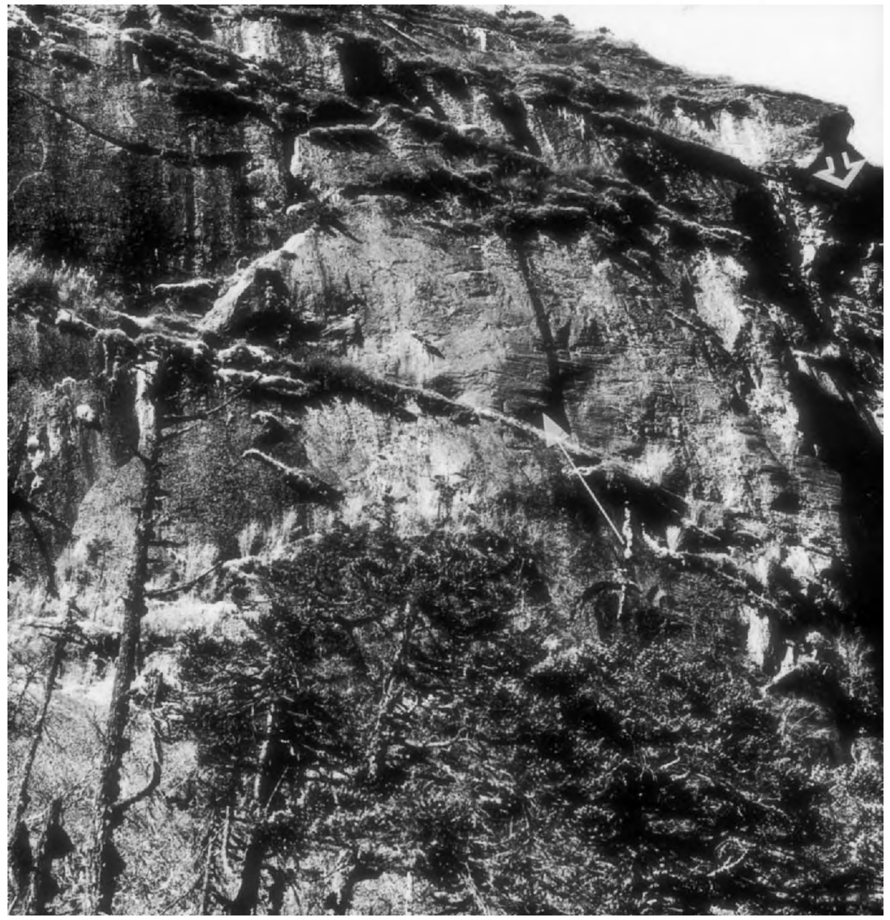
↓ *Photo 12.* Panorama from the Barun valley bottom at 4300 m a.s.l. down-valley of the tongue end of the Lower Barun glacier on the orographic left (27°52′55″ N/87°08′55″ E; SE of Pro. 4, Figure 4) in the area of the Ramara alpine pasture from facing WSW (left margin) via W to the Iswa Peak (No. 37 or Peak 6 ca. 6600–6739 m) via WNW to the 7290 m-high Chamlang (No. 12) and NW to the 6830 or 6809 m-high Chonku Chuli (No. 44) and the 6720-peak (No. 31, also Peak 4) looking up the Lower Barun valley as far as the orographic left valley flank, via NE with the ca. 6450 m-peak (No. 43) and the 6750 m-peak (No. 28), via facing E to Peak 3 (6477 m-peak: No. 45) up to ESE into the orographic left Barun valley flank looking down-valley (right margin). (X and XI below Nos. 43 and 28) are younger historical end moraines of the (unnamed) 6450 m-peak and 6750 m-peak WSW-glacier (see Table 1). This glacier has thrust a moraine pedestal (■ below and on the right below No. 28) into the main valley (Figure 11 on the left below No. 43). Its steep outer slope is an outwash apron, glaciofluvially developed by meltwater which has flowed over and seeped through the moraine, but also by debris flows (■ below No. 28). In the foreground (△) a large, over 1 km-wide alluvial debris- and debris-flow fan is situated, which the summer-meltwater stream emerging from the glacier mouth has accumulated to cone-shaped outwash. (○ small) are moraine blocks, shifted and transported by episodical debris flows. (X below No. 12) is the perfect orographic right Little Ice Age lateral moraine of the current Lower Barun glacier (Figure 3 in the right lower corner; Figure 11 on the right of No. 37). (■ below No. 37) indicates older neoglacial to Late Glacial ground moraine, overlain by debris material in the form of a cone (▲ below No. 37), which has been sedimentated since deglaciation (Figure 3 right lower corner). (▲ on the right below No. 45) is a corresponding form. (○ large) is a cirque, situated above the modern snow-line. It contains a cirque glacier. Its bottom represents an old surface level about 5700 m a.s.l. (■ on the left below No. 43; Figure 11 on the left of No. 43) is Late Glacial ground moraine with boulders up to metres high which are partly round at the edges. (◓) are glacigenically abraded rock spurs and triangle-shaped slopes. In places the High- to Late Glacial flank polishings can still be recognized by rock lineations; in parts they have a thin ground moraine cover (◓ on the left below Nos. 37 and 43). The upper limit of these indicators of flank polishing proves a highest Ice Age glacier trim-line at 5800 (––– on the left) and 5900 m (––– on the right) (Figure 11 on the right below No. 37 and on the left below No. 45). Analogue photo M. Kuhle, 29/11/1994.





← *Photo 13*. Panorama from the bottom of the Barun Khola at 4120 m a.s.l., ca. 4.75 km down-valley of the tongue end of the Lower Barun glacier on the orographic left (27°47′35″ N/87°08′40″ E; SE of Pro. 4, Figure 4), halfway between the Ramara and Jark Kharka alpine pastures, from facing E into the orographic left valley flank (left margin) via SE down-valley (centre) up to SW looking into the round-polished bulging (∩ white) right valley flank (right margin). The box-shaped valley cross-profile is that of a glacigenic trough valley, filled with lodgement till, upon which glaciofluvial gravels and debris flow fans have been accumulated (△ large and small) (Figure 11 on the left below No. 45). The lower sections of the valley flanks have been abraded by the High- to Late Glacial Barun glacier into continuously united rock fronts (∩); the upper ones are interrupted by hanging valleys, which at that time were also filled with glacier ice (→). They are connected to the main valley via confluence steps. The main glacier has polished back the separating crests, i.e. mountain spurs, which rise between these side valleys, to triangle-shaped faces (☗). They verify a polish line about 5700 m a.s.l. and, accordingly, the High Glacial minimum height of the then glacier trim-line (– – –). (○) are large moraine blocks, secondarily dislocated by the dynamic forces of debris flow. The debris flow fans (△) discharged from the orographic left valley flank, which are recognizable here, have been accumulated against the outer slope of the left, oldest neoglacial lateral moraine (V ■) of the Barun glacier (cf. Photo 14). (▼) are huge, shell-shaped crumblings in the massive-crystalline gneiss, weighing many tons. They are the result of separate rock falls which have come down since the deglaciation. (⇩) is the largest of several strata springs of the thick horizontal layers of the gneiss, frozen in the winter. They force the postglacial roughening of the glacigenic polishing of the outcropping edges of the strata by frost weathering. Cf. Figure 11 on the left below No. 45. Analogue photo M. Kuhle, 7/12/1994.

← *Photo 14*. Panorama from the bottom of the Barun Khola at 4040 m a.s.l., ca. 5.57 km down-valley from the tongue end of the Lower Barun glacier on the orographic left (27°47′32″ N/87°09′20″ E; SE of Pro. 4, Figure 4) of the Jark Kharka alpine pasture (▽ large, wall of yak pasture) from facing SE down-valley into the orographic right flank of the Barun Khola (left margin) via SSW on to the glacial horn (⇩ on the left), facing WNW looking up the Barun trough valley (∪) as far as NW into the orographic left flank of the Barun Khola (right margin). The glacial horn (⇩), completely overflowed by the Barun glacier during the high glacial period (– – – on the left), is ca. 1000 m-high from the current valley bottom (4808 m) and polished up to the summit (∩ below – – – on the left). The sharpening of the horn is due to the continuous flank polishing in the lower flank regions which took place at a decreasing glacier level during the Late Glacial, when the horn has increasingly pierced through the glacier surface. (■ above) is a ground moraine overlay only a few metres-thick on the convex-polished gneiss rocks (∩ beside ■). It is covered with alpine meadow. However, this overlay of loose rock cannot originate from a crest which is sharpened in the upward direction, because this cannot develop a catchment area for the slope. Additionally, it cannot be weathered *in situ* on the rock surface planed down as far as the fresh gneiss bedrock since the post-Late Glacial (post Stage IV; Table 1) deglaciation ca. 13 Ka ago. (△ small) are debris cones which largely consist of corresponding but dislocated ground moraine from the flank of the horn and the debris of crumblings. (⇩ on the left) marks a ca. 400 m-high subsequent breaking away. As a younger form which destroys the older rounding, it is an indirect proof of the former glacigenic abrasion. It should have taken place during the late Late Glacial deglaciation, because its definitely very coarse-blocky material situated at the slope foot of the crumbling, has been transported away. (⇩ on the right) is a corresponding, also overhanging breaking-away. This can be recognized by its light rock face that has not been darkened by the discharging water. (■ on the left) are moraines primarily deposited in the break of slope at the foot of the valley wall during the High- to Late Glacial. Currently they are cut up by temporary streams flowing down from the wall. (■ V) is the outer slope of the orographic left lateral moraine of the neoglacial (Stage V; Table 1) Barun glacier (cf. Photo 13). (■ black) is ground moraine, the surface of which has been dislocated (▽ large) and reshaped by activities of debris flow. (∩) are areas of flank abrasion verifying an Ice Age trim-line at least 5400 m in this valley chamber. Cf. Figure 11 on the left below No. 45. Analogue photo M. Kuhle, 28/11/1994.



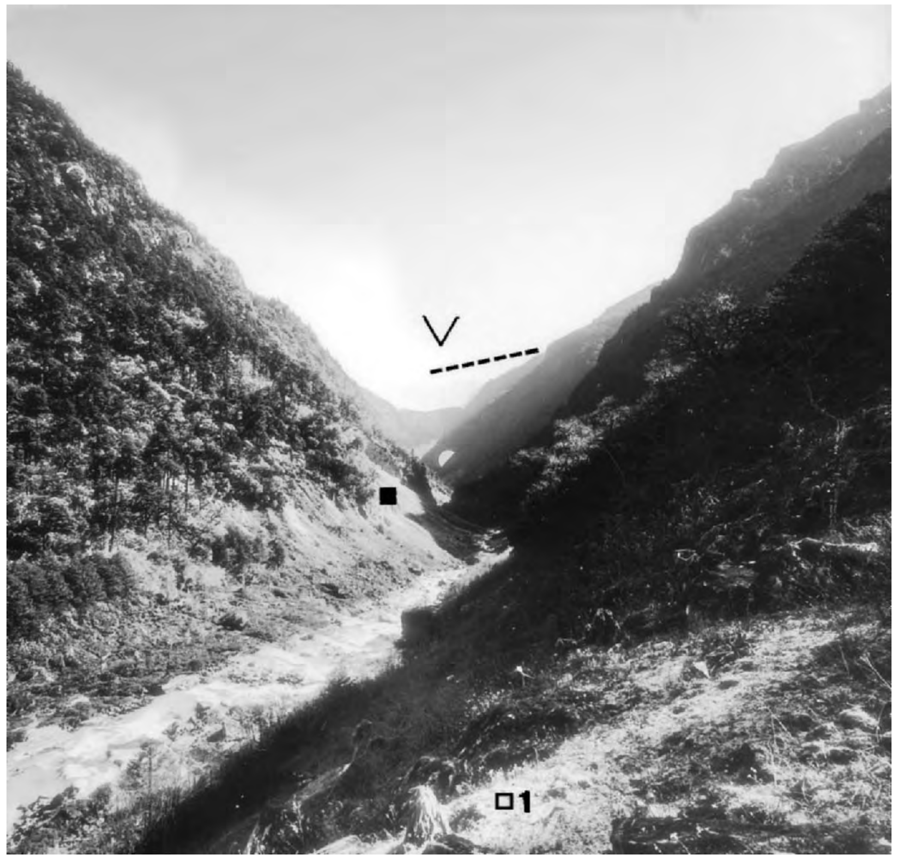
↑ *Photo 15.* 340°-panorama taken from the valley bottom of an orographic left side valley of the Barun Khola in the area of the valley chamber of the Yangri Kharka alpine pasture (right margin) at ca. 3970 m a.s.l. (27°45′ 52″ N/87°09′05″ E; NW of Pro. 5; Figure 4, Panorama 15) from facing SE (left margin) into a trough-shaped hanging side valley (▽) via facing SSW into a further hanging side valley connected over a confluence step (below – – – on the left), via NNW into the trough-shaped Barun Khola (◡) with the 6720-peak (No. 31), the ca. 6750 m-peak (No. 28) and Peak 3 (No. 45, 6477 m), via NE into the orographic left flank of the Barun Khola up to ESE looking down the Barun Khola (left margin). The upper regions of the valley flanks are marked by glacier abrasions in the form of roundings and polishings (⌒), remoulded by roughenings dependent on the rock structure, which are due to weathering since deglaciation. The cleft-controlled crumblings (◇) are part of these. These dynamics of removal identify postglacial accumulations as e.g. debris flow fans (△) containing dislocated and buried moraine (■ on the very left) with large, rounded boulders (○ white) as well as young, edged boulders of crumblings (□, see person for scale on the right). In the area of the convex-rounded confluence steps of the exits of the hanging valleys, roche-moutonnée-like polish forms have been developed with a flat scour- and a steeper lee side (⌒ below – – – – – – on the left and above IV). At the time when the picture was taken, frozen meltwater streams were running down the confluence steps, increasingly dissecting these rock steps (above △; below – – – on the very left). (▽) are remains of debris bodies with steep slopes, worked out of the High- to Late Glacial ground moraine (■ black) by fluvial dynamics since the deglaciation. (■ IV) is a ground moraine pedestal of the Late Glacial Stage IV (Table 1) fluvially cut by the Barun glacier stream since deglaciation. The ground moraine covers and glacigenic abrasion lines above (■ and ⌒ below – – –0 and – – – on the right) verify a maximum glacier trim-line at 5300 (– – –0) to 5100 m a.s.l. down-valley (right margin) during the last glacial period. (– – – on the very right) marks the somewhat higher ice level at the exit of a cirque (○ black). (■ on the very right) are ground moraine covers preserved between inflowing side valleys and ravines cut into the slopes since the deglaciation. (→) shows the locality with glacial striations (Photos 16 and 17). Cf. Figure 11 in the middle between Nos. 37 and 46. Analogue photo M. Kuhle, 27/11/1994.

→ *Photo 16.* From the orographic right margin of the valley bottom of the Barun Khola in the area of the valley chamber of the Yangri Kharka alpine pasture S of the bridge at 3700 m a.s.l. (27°45′50″ N/87°09′40″ E, NW of Pro. 5, Figure 4, Photo 16), ca. 150 m above the current talweg facing SW looking into the orographic right Barun Khola flank (Photo 15 →). The steep wall in the gneiss bedrock has already been heavily damaged and dispersed by postglacial crumblings (⇓). This must have taken place after the deglaciation, because the older preserved rock surfaces show glacial striations (↑). For their development a thickness of the valley glacier of at least 200–250 m was required. Accordingly, in the end the late Late Glacial Barun glacier of Stage IV (with regard to age and ELA-depression see Table 1) might have caused these striations. For a young age pleads the observation, that – due to the coarse crystal structure – glacial striations in a coarse-crystalline rock such as gneiss very fast become dull, splinter away and are finely destroyed by weathering. The alternative preservation by a former overlay of ground moraine has to be ruled out because of the here 70°-steep rock face. Cf. Figure 11 in the middle between Nos. 37 and 46. Analogue photo M. Kuhle, 27/11/1994.

↑ *Photo 18.* At 3490 m a.s.l., taken from the orographic right valley side of the Barun Khola, ca. 4.1 km down from the valley chamber of the Yangri Kharka alpine pasture (27°44′11″ N/87°11′23″ E, WNW of Pro. 5, Figure 4, Photo 18), ca. 50 m above the current valley floor facing NW looking up-valley. The two valley slopes in the middleground are mantled by moraine material. On the orographic left the primarily deposited ground moraine can be observed in a ca. 10 m-high exposure band (above ■ and on the left of it). Below, a debris slope sets in, which is displaced and extended up-slope. It consists of ground moraine material which slides down and is transported by debris flows. The primary ground moraine slope has been – and still is – undercut by the Barun river. The same applies to the orographic right slope (△). Here, the largest boulders of the moraine are accumulated at the slope foot. The largest granite boulders up to the size of a hut (○) lie in the talweg, i.e. in the bed of the Barun river, which at the time when the picture was taken carried only relatively little glacier- and snow-meltwater. The fine material transported down the slopes by debris flows has immediately been removed by the Barun river, so that the largest fractions of the moraine concentrate in the talweg. The sub- and postglacially fluvially incised High- and Late Glacial ground moraine which covers the bottom of the Barun trough valley and obviously was decametres-thick, creates the impression of a fluvially V-shaped profile in this lowest section of the cross-profile. However, this V-shaped form only occurs in the loose material. The rock bottom has got a classic trough form with steep flanks or a glacigenically U-shaped valley form. This can be verified by the rock valley flank (below ▲) which plunges steeply down below the moraine overlay and postglacial debris cone forms. The Iswa Peak (No. 37, ca. 6600 m) stands ca. 17.5 km away. There, the level of the glacier surface ran about 5800 m (– – – below No. 37) during the last glacial period and – verifiable by the back-polishing of the crests and mountain spurs of the glacigenically triangle-shaped slopes (▲) – at 5100 m (– – – on the left) in the middleground. Cf. Figure 11 between Nos. 37 and 46, nearer to 46. Analogue photo M. Kuhle, 26/11/1994.

↑ *Photo 19.* At 3450 m a.s.l. ca. 5.3 km down from the valley chamber of the Yangri Kharka alpine pasture (27°43′47″ N/87°11′55″ E, WNW of Pro. 5, Figure 4, Photo 19) ca. 20 km above the current talweg looking down the Barun Khola facing SE. The rock forms of the valley, which are glacigenically abraded (∩) up to 4300 m (– – – on the right) and further down-valley up to ca. 3400 m (– – – on the left), show the classic character of a trough valley (⋃). (□1) are glaciofluvial gravels of Stage IV, accumulated over the ground moraine (■ III) in the trough ground during the late Late Glacial Stage IV (Table 1). Accordingly, this ground moraine near to the surface (also ■ white) (see also Figure 6, No. 11) belongs to Stage III, which 14,250–13,500 YBP (Table 1) ago was the last one whose glacier has reached this valley area. (○) are large moraine blocks rounded at the edges and facetted which the Barun river has flushed free when the ground moraine (i.e. the pedestal) was cut. Fresh faces and edges of fractures (○ above) show that they can also have been broken later. Cf. Figure 11 between Nos. 37 and 46. Analogue photo M. Kuhle, 26/11/1994.

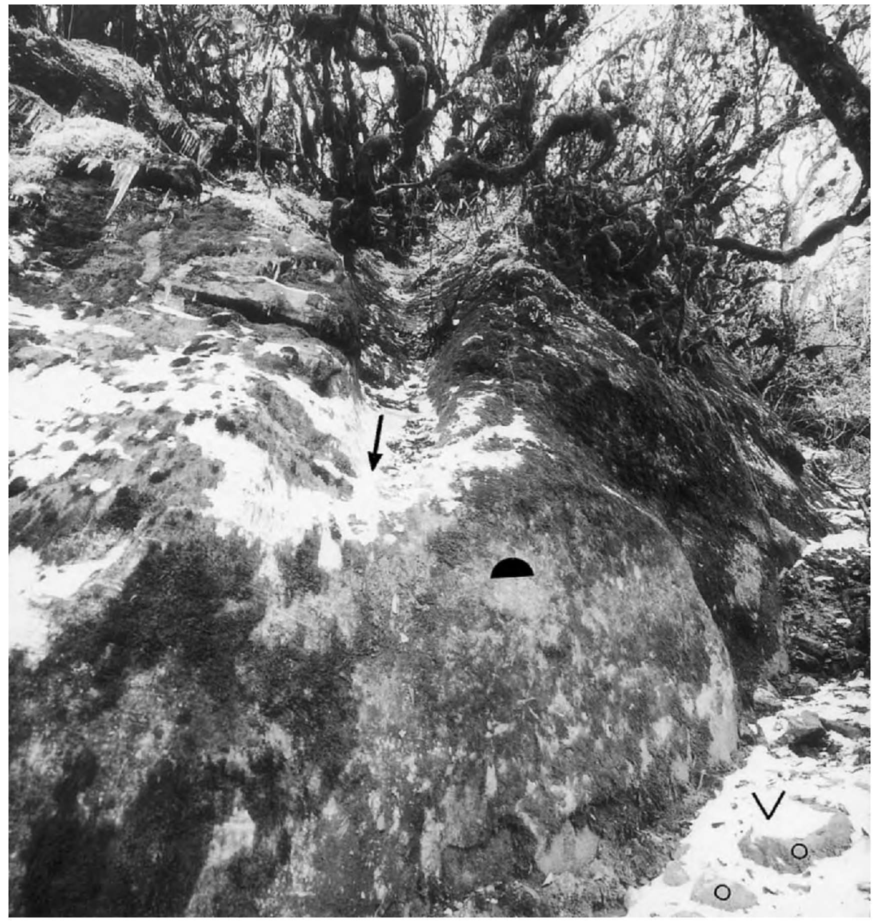
← *Photo 17.* From the orographic right margin of the valley bottom filling of the Barun Khola in the area of the valley chamber of the Yangri Kharka alpine pasture S of the bridge at 3700 m a.s.l. (27°45′50″ N/87°09′40″ E, NW of Pro. 5, Figure 4, Photo 17), ca. 150 m above the current talweg facing SW looking into the orographic right Barun Khola flank (Photo 15 →). 150 m down-valley of Photo 16 further glacial striations (↓) are preserved. Here, too, the striations are horizontally arranged, so that vertical damage to the rock caused by boulders or avalanches as convergence phenomena are to be ruled out. The striations are decimetres- to metres-long. After deglaciation they were first covered by moraine material. Afterwards they have been flushed free. The longish, vertical white spot (on the right below ↓) is frozen water seepage. (⇩) is a rock overhang originating from a boulder of many cubic-metres which has weathered and fallen out of the wall. Cf. Figure 11 in the middle between Nos. 37 and 46. Analogue photo M. Kuhle, 27/11/1994.



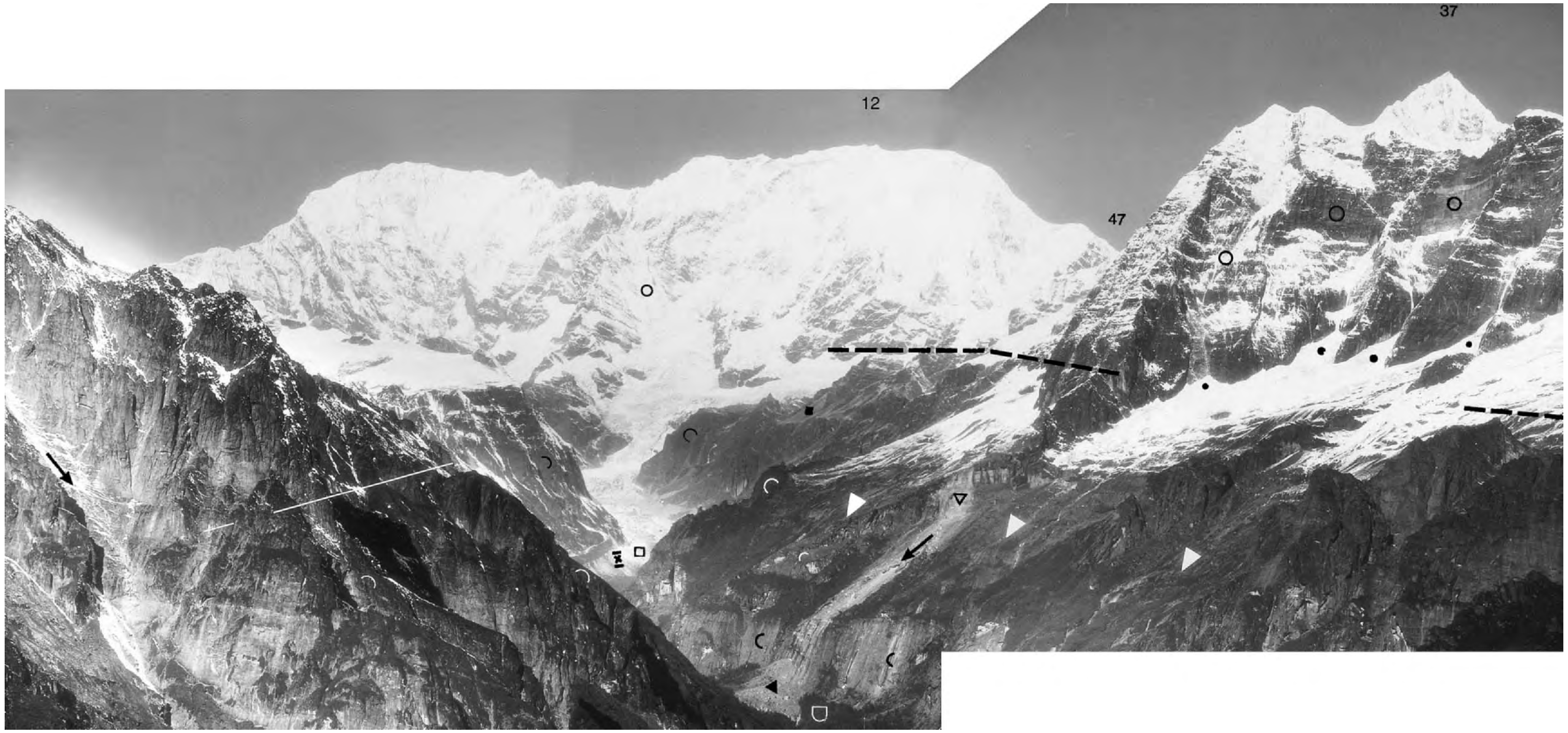
↑ *Photo 20.* At 3350 m a.s.l., ca. 6.2 km down from the valley chamber of the Yangri Kharka alpine pasture (27 °43′37″ N/87°12′25″ E, ESE of Pro. 5, Figure 4, Photo 20) ca. 40 m above the current talweg, looking down the Barun Khola facing SE. The rock forms of the valley, glacigenically abraded (∩) up to 2800 m (–––), already show the character of a V-shaped valley (∨). The reason for this is the regressive linear erosion forced by the steepening of the slope from the 2000 m lower relative erosion base on the valley bottom of the Arun main valley (cf. Figure 15, Pro. 8), because the inflow of the Barun into the Arun river is only 17 km away from here. Since the Late Glacial Stage II (cf. Table 1), i.e. since the ELA was lifted above the glacier surface in this cross-profile of the Barun Khola, so that subglacial meltwater erosion occurred, this glacigenically V-shaped valley form (∨) has already been developed subglacially and syngenetically with the glacier polishing of the flanks (∩) from here on down the valley (cf. Figure 13, Pro. 6). But also today linear erosion occurs, which from here on is intensified down-valley. Accordingly, the past ground moraine (■) has been cut up to a depth of decametres and removed. (☗) is an abraded and rounded mountain spur between the junctions of two side valleys. (□1) is the glaciofluvial gravel cover of Stage IV (Table 1), also preserved on the orographic right valley side on the ground moraine of Stage III (cf. Photo 19) – here as a terrace. Also the orographic right valley slope further upward is cloaked with High- to Late Glacial ground moraine. Especially in the basal parts of the slope a minor, probably subglacial, glaciofluvial washing-out can be observed due to the forming of the quartz grains in the moraine matrix (cf. Figure 6, No. 11). Cf. Figure 11 half-left above No. 46. Analogue photo M. Kuhle, 26/11/1994.

→ *Photo 22.* At 4060 m a.s.l. somewhat below the 4075 m-high Tutu La (pass) (27°41′51″ N/87°12′34″ E, Figure 4, Photo 22) facing NNE across the Barun Khola (☗) looking up its orographic left, trough-shaped side valley (▽). The orographic right flank has been abraded (∩ black) up to an Ice Age transfluence pass leading into the adjacent valley (⌒). (○ on the left) is a cirque at the valley head, which still today is filled by a glacier. Recent glaciers at the valley head (on the right of ▲) and in an orographic right cirque (on the left above ▲) also belong to the catchment area of the trough valley (▽). The meltwater discharge of the last one takes place in two steep gullies (▲) cutting the orographic right trough flank since the Late Glacial deglaciation. (○ on the right) is a flatly inset rock bottom, abraded by a former hanging glacier. Below, the highest verifiable and, correspondingly, Ice Age glacier level is marked (–––) at 3800 m a.s.l. It crosses a round-polished truncated spur (☗). (□) is ground moraine immediately N of the Tutu La (transfluence pass) (Photo 23). It is covered with rhododendron bushes. (△) is an also covered debris cone from the orographic left side valley flank which further up is rocky. Preserved glacigenic polishings (∩ white) on the orographic left rock flank alternate with younger roughenings by crumblings (⇩). (↓) shows a currently very active debris flow which has built up a ca. 200 m-wide debris cone, partly from displaced moraine. Cf. Figure 11 above No. 46. Analogue photo M. Kuhle, 9/12/1994.

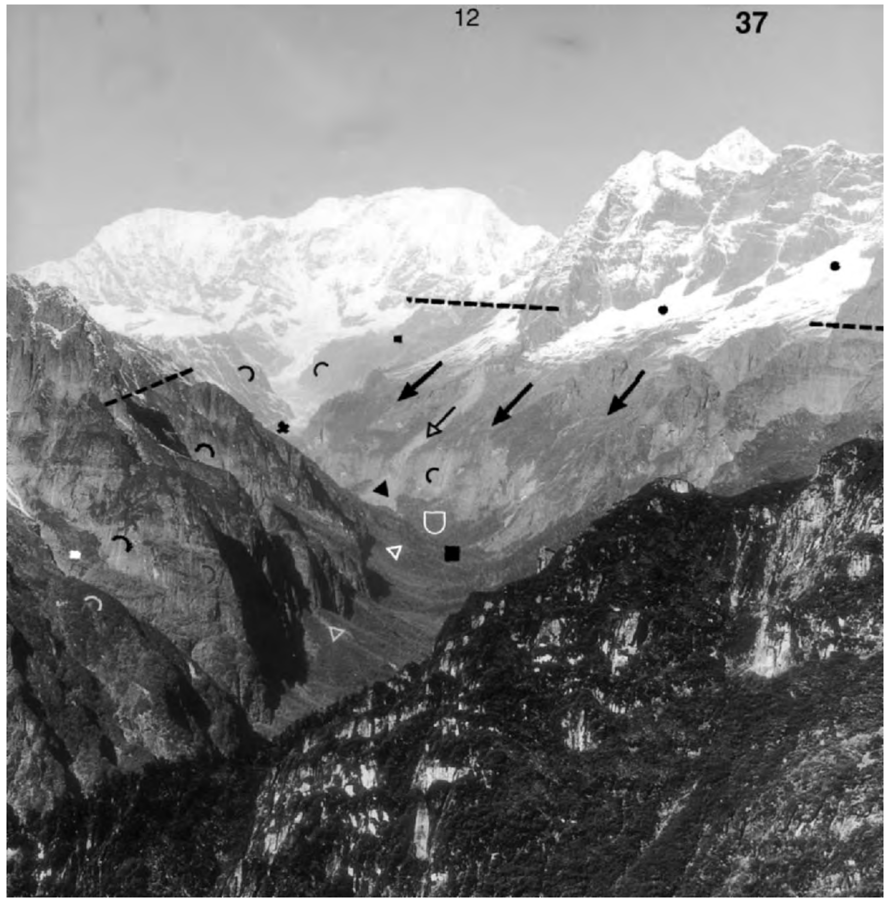
→ *Photo 21.* At 3440 m a.s.l. on the orographic right, ca. 230 m above the talweg of the Barun Khola (27 °43′28″ N/87° 12′55″ E, between Pro. 5 and 6, Figure 4, Photo 21) a pothole-like groove (↓) appears in the valley flank. It has been formed on round-polished gneiss rocks (☗). In the upper reaches (above ↓) it is covered by a centuries-old woodland of rhododendron and in the lower ones by moss and lichens. This is an older form of past ages, because gullies and small valleys arranged in parallel (∨) discharge the temporary water. Additionally, the conditions for water discharged under pressure and, accordingly, at high speed, are not given today. For the development of this flushing rill a tube-like closure through an attached glacier is needed. A closure such as this has been provided by the ice clinging to the rock wall. Independently of the surrounding relief of the talweg (∨), it has canalized the meltwater between the glacier and the rock wall. Owing to this, the course of the flushing rill on the convex rock surface (☗) was possible. The debris-filling of the adjacent gully (∨) contains ground moraine with polymict, edged, round-edged and facetted boulders (○). Cf. Figure 11 above No. 46. Analogue photo M. Kuhle, 8/12/1994.



→ *Photo 23.* 180°-panorama taken from the 4127 (4135) m-high Keke La or Shipton La (pass) (No. 46) (27°41′01″ N/87°12′35″ E, Figure 4, Panorama 23) from facing NW with the Chamlang (No. 12, 7290 m) and Iswa Peak (No. 37, ca. 6600 m) via N to the Tutu La (∩ black on the right below – – –) up to E (right margin with tschorten of the Keke La). Beyond the Tutu La (∩ black on the right below – – –) one looks straight across the Barun Khola into its orographic left, trough-shaped side valley (∪) (Photo 22). (○ below No. 37) is a still currently glaciated cirque terrace with a steep back wall and ice avalanche cones (Photo 24). (○ on the right) is a cirque-like, 2 km-long, formerly glaciated high valley (last glacial period, LGM, Stage 0, Last High Glacial Maximum, Würm (see Table 1) the bottom of which is covered with moraine debris. The summit at the valley head is 4830 m-high. Since deglaciation debris- and debris flow cones have been developed in this cirque, which contain permafrost and are in the process of rock-glacier-like flow movements (△ on the left). Further down the cirque ends (○ on the right) in a rock-threshold (∩ white on the left). (△ in the middle and on the right) are further accumulations of debris- and debris flow cones. (∩ white on the right) is glacigenic flank polishing reaching up to 4270 m a.s.l. It enables the glacier trimline of the maximum Ice Age glacier filling between Tutu and Keke La (– – –) to be recognized. Correspondingly, the polish threshold with its three forms of roches moutonnées (∩ black large on the left), the Keke La (∩ above No. 46) and the Tutu La (∩ black small in the middle) have been overflowed and polished by an at least 130–200 m-thick ice. Cf. Figure 11, No. 46. Analogue photo M. Kuhle, 25/11/1994.



→ *Photo 24.* From the mountain ridge between Irkhuwa Khola and Kasuwa Khola N of the Kauma alpine pasture at 3873 m (27°39′43″ N/87°12′26″ E, Figure 4, Photo 24) facing NW up the Irkhuwa Khola looking on to the Iswa glacier (II), a good 3 km-long. The semi-circle of the Chamlang massif, which over a distance of ca. 3 km is more than 6000 m-high, culminates at 7290 m (No. 12). Its longitudinal extension is SW/NE. The height of the ESE-wall is 2200 m (on the left below No. 12). Between the Chamlang and the ca. 6600 m-high Iswa Peak (or Peak 6, 6739 m, No. 37) the 5340 m-high saddle of the Iswa La (No. 47) is situated, beyond which the Lower Barun Khola flows into the Barun Khola (see Figures 4 and 11; Photo 9 and 10, No. 47). (○) are wall valleys with semi-circular cross-profiles, which canalize the avalanches and have been polished out and abraded by them. At their lower exits the avalanches accumulate as avalanche cones (●), which close over to form glacier ice. The tongue of the Iswa glacier reaches down to 3900 m a.s.l. (II) and is in the process of retreat. It is attached to the 'Little Ice Age' moraine (Stage X) (see Table 1). The highest former moraine deposits lie on the orographic left at 4900 m a.s.l. (■), 700 m above the current glacier surface (□). The glacigenic flank abrasions (∩) reach up to this altitude; in places even higher. They show separate roches moutonnées (the right white ∩). During the last glacial period the box-profile of the valley (Figure 14) determined by a tectonic graben, has been filled with the Irkhuwa glacier up to altitudes of 5300 m at the valley head (– – – below No. 12) and 4000 m (right margin), i.e. 3800 m a.s.l. (____ white) and reworked to a trough-like form (▢). At the valley head the glacier was ca. 1300 m-thick (below – – – below No. 12), i.e. ca. 800 m somewhat down-valley seen from half the valley length (___ white) (cf. Figure 14). After the depression of the level of the valley glaciers the Late Glacial tongues of the hanging glaciers of the orographic left valley flank flowed down to 4000 m and even lower (▼ white). At the same time they have reworked the earlier flank polishing of the valley glacier at right angles and partly destroyed it. The recent rock avalanche (←) is due to this secondary reworking and glacigenic undercutting. (▽) is the breakout scar, (←) the slide track and (▲ black) the accumulation cone of the rock avalanche. The latter has destroyed the woodland during the last years. Cf. Figure 11 signatures from below No. 47 up to 46. Analogue photo M. Kuhle, 25/11/1994.

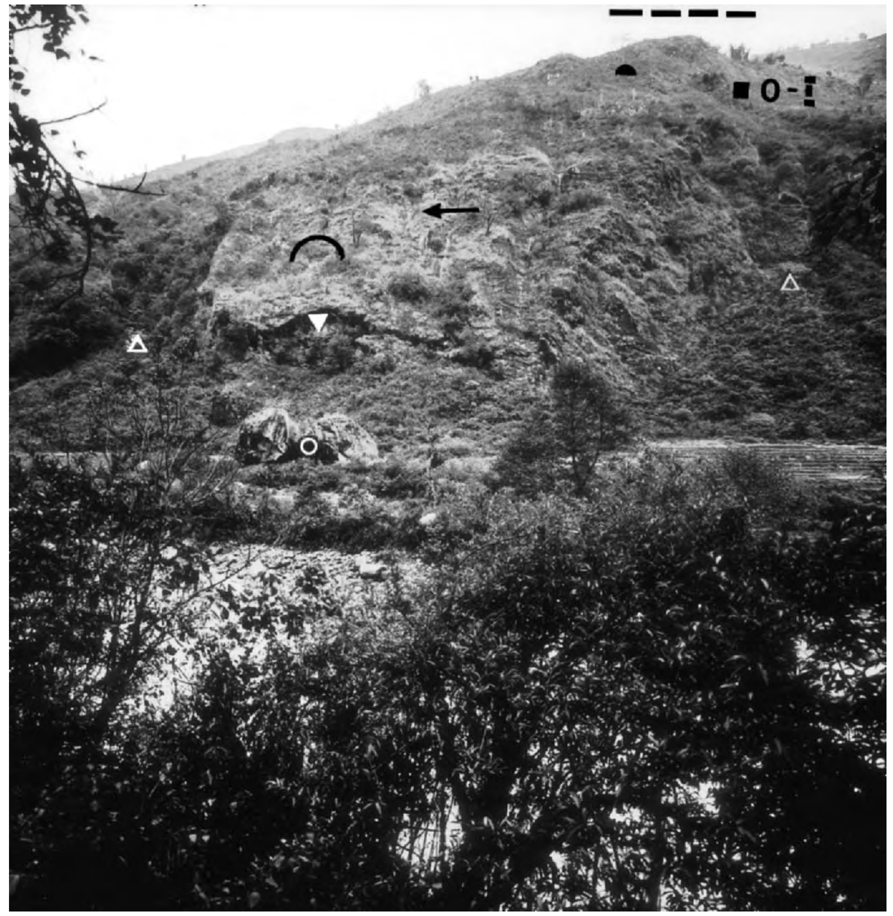


← *Photo 25*. From the mountain ridge between the Irkhuwa- and Kasuwa Khola N of the Kauma alpine pasture at 3873 m (27°39′43″ N/87°12′26″ E, Figure 4, Photo 25) facing NW looking up the Irkhuwa Khola (▢) into the ESE-wall of the Chamlang-massif (No. 12, 7290 m) and to the ca. 6600 m-high Iswa Peak (or Peak 6, 6739 m, No. 37). In the SW-flank of the Iswa-Peak-massif the current hanging glaciers (●) have made up a kind of cirque- terrace with a steep back wall (●). (X) is the orographic right lateral moraine of the Little Ice Age (Stage X, Table 1) the base of which is still attached to the current Iswa glacier. By analogy with the Lauterbrunner trough in the Bernese Alps, the Irkhuwa Khola is a tectonic graben forming a box-shaped valley, which the valley glacier has polished out to a trough. During the Ice Age the glacier was 800–1300 m-thick (glacier trim-line: −−− and ___) (cf. Figure 14). The former glacier trim-line (−−− and ___) can be evidenced by deposits of ground moraine preserved high above the valley bottom (■ small) and still higher glacigenic flank abrasions (∩). Between the mountain spurs polished back at the valley flanks (e.g. ∩ white), steep, postglacially regenerated side valleys and ravines (e.g. in the foreground) are situated. (← full) are steeply sloping rock tongue basins of the Late Glacial hanging glaciers in the orographic left valley flank. They have been polished out after the lowering of the level of the valley glacier from ca. 18 Ka on. The rock in the valley bottom is covered by ground moraine (■ large); debris flow cones (▽) have been accumulated on it. Recently, a rock avalanche (← hollow) has come down on the moraine on the valley bottom (▲). From the position of the valley cross-profile in the foreground on the left, the Irkhuwa glacier has even flowed down for another 15 km during the Late Glacial Stage I (cf. Table 1). It extended to ca. 1000 m a.s.l., i.e. up to the valley exit. Cf. Figure 11 signatures from below Nos. 47 to 46. Analogue photo M. Kuhle, 25/11/1994.

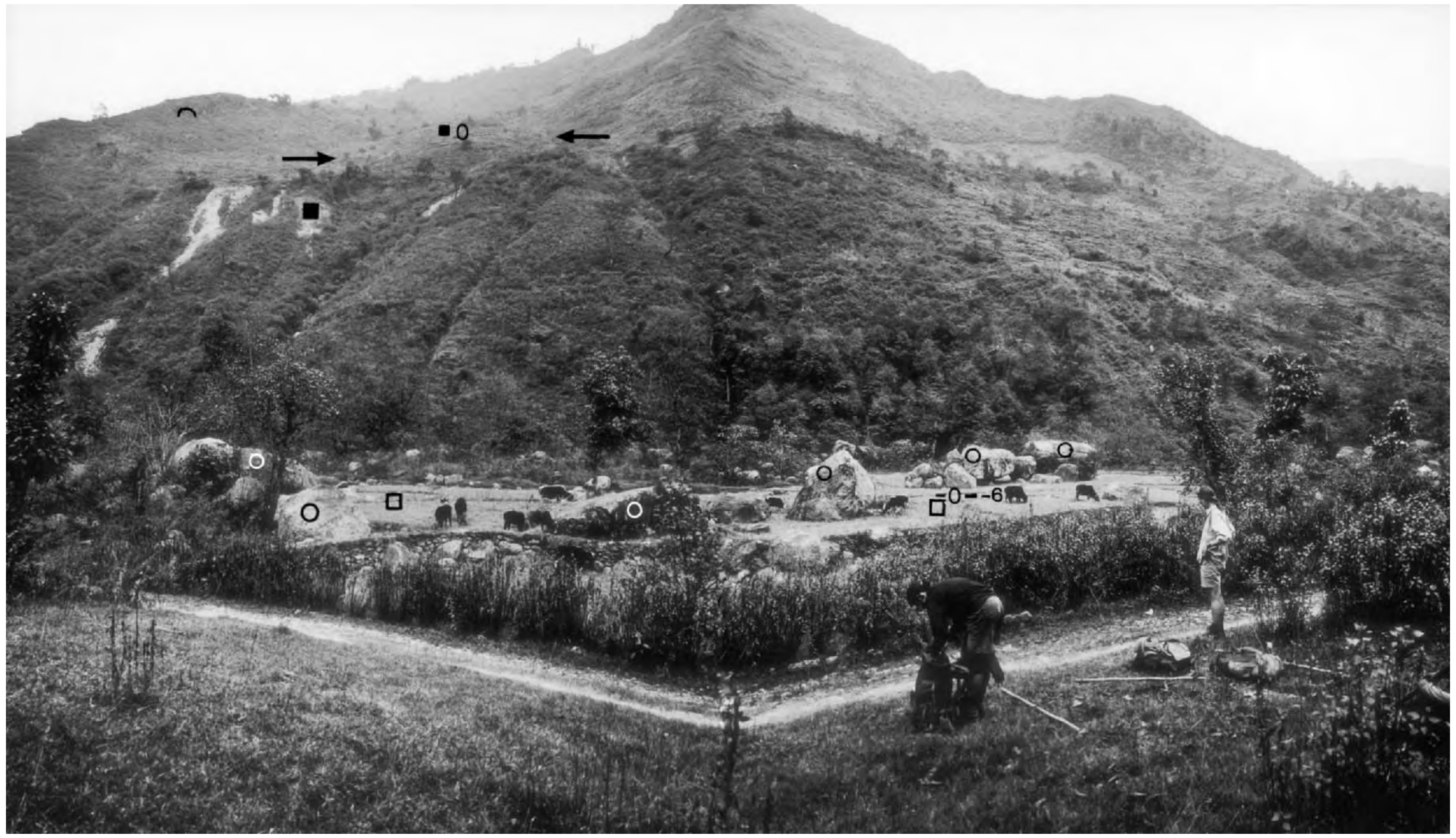
↓ *Photo 26*. From the orographic right flank of the Kasuwa Khola above the Tashigaon settlement and the Dharikharka alpine pasture, below the Unshisa alpine pasture, at 2700 m (27°37′31″ N/87°13′13″ E, Figure 4, Panorama 26) 40°-panorama from facing NNW (350°, left margin) via NNE (10°, centre) up to ENE (30°, right margin) via the 3490 m-high (altitude of the summit above ○ on the very right) up to 4447 m-high (summit above ○ on the very left) mountains and ridges in the catchment area of the Kasuwa Khola. (○) are cirques and cirque floors in a S- to SW-exposition which for the last time have been filled with glaciers and polished out by them during the last glacial period (= Würm, Stage 0, Last High Glacial Maximum; see Table 1). The corresponding snow-lines (ELA) marked by (○) ran about 3600–3300 m a.s.l. in this glaciologically unfavourable position. Cf. Figure 11 signatures on the right and half-right above No. 46. Analogue photo M. Kuhle, 24/11/1994.

← *Photo 27.* From the exit of the Barun Khola at 1100 m a.s.l. looking into the orographic left flank of the Arun main valley (27°41′34″ N/87°21′56″ E, Figure 4, Photo 27) facing E. (○) are moraine blocks in the bed of the Barun stream condensed by the washing-out of matrix. They consist of very solid crystalline substrate as e.g. gneiss and granite. During the winter the Barun- and Arun stream carry only small amounts of glacier meltwater, so that they take up only ca. 1/8 of the current gravel bed. During the monsoonal high water the glacigenically abraded main valley flank (∩) has been undercut and, accordingly, has crumbled away (▼). Here gneiss bedrock crops out. (■) is an up to decametres-thick ground moraine cover, which close to the surface, has been reworked by flushing and transport down-slope since the deglaciation. Rill-rinsing has also taken place (→); it is of High- to early-Late Glacial age (Stages 0–I; cf. Table 1). The cross-profile of the main valley is identified by a denudation terrace (above ■ on the right), i.e. a division of the cross-profile. This can be explained by the subglacial meltwater erosion underneath the large Arun outlet-glacier from S-Tibet. (⏶) is a fluvially reworked and thus marginally edged mountain spur and triangle-shaped slope polished-back glacigenically. Cf. Figure 11 signatures half-left below No. 48. Analogue photo M. Kuhle, 13/12/1994.

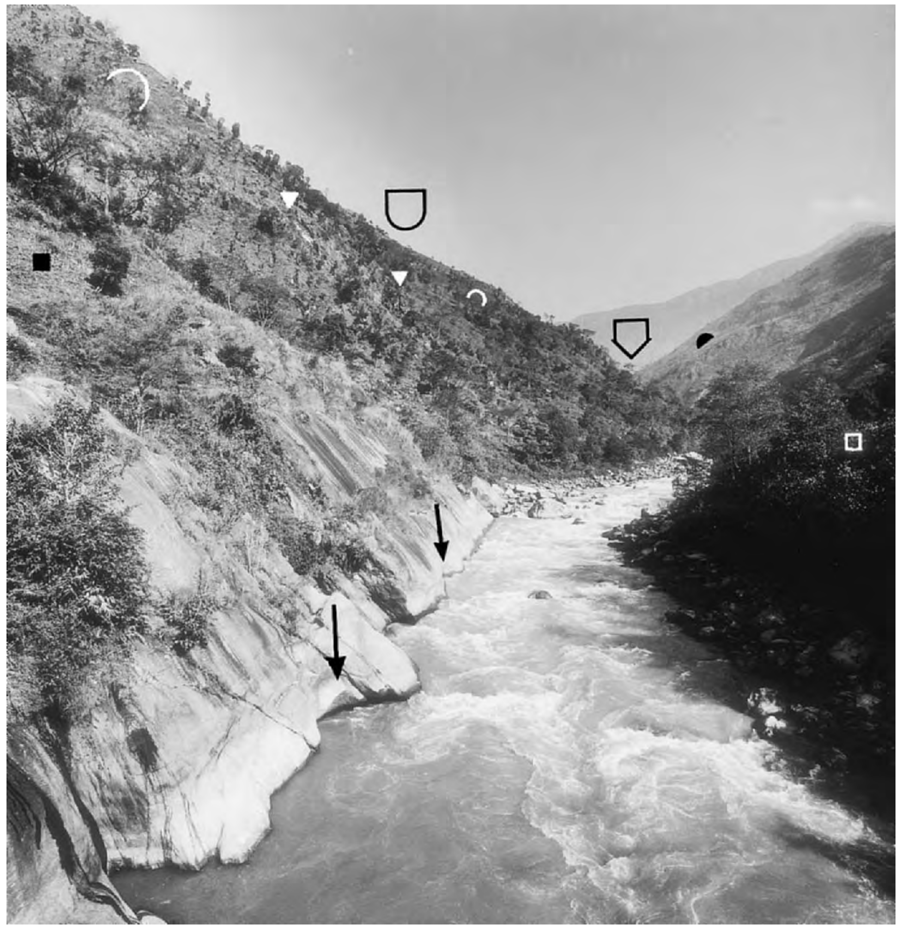
→ *Photo 28.* At 1120 m a.s.l. down-valley of the Barun Khola- (Barun Nadi-) influx and up-valley of the Leksuwa Khola (27°40′50″ N/87°21′59″ E, Figure 4, Photo 28) across the Arun river (behind the bushes in the foreground) looking into the orographic left Arun main valley flank facing E. (∩) is a glacigenically polished rock face between two steep, small hanging valleys (△). Through these small hanging valleys the moraine material, deposited on the highest slope sections during the High- to early Late Glacial (Table 1) (■ 0–I marks ground moraine material which still exists in a primary position), has partly been dislocated down to the slope foot and re-sedimentated cone-like (below △) since the deglaciation. (⏶) is the triangle-shaped face which the Arun glacier of the last glacial period (Stage 0; see Table 1) has polished up to its culmination. (– – –) establishes the corresponding minimum trim-line of the Arun glacier at ca. 2100 m a.s.l. derived from the glacigenic forms. (▼) is an area of crumbling in the outcropping gneiss initiated by fluvial lateral erosion and undercutting of the Arun river. It causes the glacigenic flank polishing (∩) to waste away from below. (←) are flushing channels segmenting this abrasion face (∩). Possibly they have already been laid out as subglacial meltwater channels. (○) are two rounded gneiss boulders the size of a hut lying very close to each other. They have been transported both by the High- to Late Glacial (see above) Arun glacier and mudflows in the talweg of the Arun Khola. Finally they have been flushed free. Cf. Figure 11 signatures on the left below No. 48. Analogue photo M. Kuhle, 13/12/1994.



→ *Photo 29.* Panorama from 1080 m a.s.l. over the junction area of the Leksua Khola, an orographic left side valley, looking into the Arun main valley from its orographic right side (27°40′11″ N/87°21′44″ E, Figure 4, Panorama 29) facing NE (left margin) up the Leksua Khola, via E (centre) on to the mountain spur between the two valleys, up to S down the Arun Khola and facing SSW into its right flank (right margin). (■) are High- to early Late Glacial (Stage 0–I, see Table 1) remnants of ground moraine in the Arun main valley. (▼) are edges of the break-off of moraine material caused by a holocene fluvial undercutting by lateral erosion and the development of an outer slope. (□) are three fluvial terrace-levels: (□ −6 and white above) are the two lowest holocene to historical terraces (Figure 11 Nos. −0 to −6; see also Table 1 gravel field, sander) which have also been accumulated in the Arun main valley. They consist of re-arranged moraine material (compare Figure 6, No. 12 (moraine) with No. 13 (glaciofluvially reshaped moraine in adjacent locality)) and in part have also been developed by mudflows. (□ 4–3) is a glaciofluvial terrace which in the Arun Nadi (Khola) is lacking and in the Leksuwa Khola has been heaped up against the Arun glacier, i.e. in the Late Glacial has been dammed up by it. Cf. Figure 11 signatures on the left below No. 48. Analogue photo M. Kuhle 13/12/1994.



← *Photo 30*. Panorama at 1080 m a.s.l. between the influx of the orographic left Leksuwa Khola side valley and the Lamobagar Gola settlement taken from the orographic right side (27°40′05″ N/87°21′35″ E, Figure 4, Panorama 30) across the orographic left side of the Arun main valley from facing NE (left margin) diagonally up-valley via E (centre) up to SE (right margin) looking diagonally down-valley. The left valley flank visibly increases here up to ca. 2200 m a.s.l. At ca. 1700 m is an abraded rock head (∩) in the glacier flow shadow of which High Glacial ground moraine can be observed (■ 0). Due to marginal channels (→ ←) caused by the discharge of considerable monsoonal rainfalls it has developed a slightly bulging form. (■) marks moraine exposures. (□ −0 to −6) is an orographic right river terrace heaped up in the holocene to historical time (see Table 1: No. −0 to −6). (○) are partly rounded gneiss blocks up to the size of a hut or a house in and on the terrace body. They have been washed out of the Ice Age moraine material in the Arun-Nadi (Khola) and displaced by mudflows. The ground moraine (□) lies on a ca. 150 m-high rock terrace (denudation terrace), the surface of which has been polished by the valley glacier. In the area of the talweg it has been dissected by subglacial meltwater. Cf. Figure 11 signatures on the left below No. 48. Analogue photo M. Kuhle, 13/12/1994.



← *Photo 31*. At 1040 m a.s.l. from the N-margin of the Lamobagar Gola settlement (27°39′54″ N/87°21′32″ E, Figure 4, Photo 31) looking up the Arun-Nadi (Khola). (↓ are two half-potholes at the level of the current Arun river on the outer slope in the coarse- bedded outcropping gneiss. On the opposite river side on the slip-off slope a holocene to historic (see Table 1, No. −0 to −6) gravel terrace (□) of washed and displaced moraine debris is situated. (■) is ground moraine on abraded gneiss rock (∩); (▼) are small-scale crumblings in the glacigenically polished bedrock. The flank polishing has planed down the rock slope in a slightly concave fashion (▽), so that a glacigenically V-shaped valley has been formed with tendencies towards the development of a trough. Below of (∩ small) a second lower cross-profile (⇩) is set into the upper valley cross-profile. It is V-shaped. (▲) is a truncated spur near the influx of the Leksuwa Khola. Cf. Figure 11 above No. 49. Analogue photo M. Kuhle, 14/12/1994.

→ *Photo 32*. At 1040 m a.s.l. from the N-margin of the Lamobagar Gola settlement (27°39′54″ N/87°21′32″ E, Figure 4, Photo 32) looking across the Arun river into the orographic right flank of the Arun Khola. (▼) is a half-opened former pothole, 1.6 m in diameter and vertically worked into the gneiss up to a depth of 8 m, which probably has been established subglacially. (←) marks glacier striae on the gneiss rock, 6–10 m above the current Arun river. (□) are granite boulders several metres in size, rounded up to rounded-edged and facetted, originating from ground moraine covers (■) in this valley section. They have been accumulated in the talweg of the Arun Nadi (Khola) by plunging into the Arun river because of fluvial undercutting or by rinsing of the moraine matrix *in situ*. From the matrix of the second-lowest, i.e. second-youngest terrace accumulation a sample has been taken (in the foreground near to the bridge: Figure 4; 14.12.94/2) and morphoscopically compared with that of a moraine sample (14.12.94/1: below ■ I) (cf. Figure 6, No. 12 (moraine) with No. 13 (fluvially remoulded moraine in an adjacent locality)): the quartz grain forms and the proportions of the matrix are largely corresponding. (△) is a current fluvial rill on the ground moraine slope. It proves that today the moraine material is removed and secondarily transported in the direction of the talweg, so that this debris material is no current accumulation. (○) shows a rounded, i.e. round-edged moraine block in size of a house which has been rinsed free. (■ I) is a moraine ledge which, due to the height of its edge, is classified as being from the early Late Glacial (Stage I; Table 1). Up to now it is not clear whether it represents a trim-line ca. 120 m above the talweg or whether it is only a youngest ground moraine packing of the valley glacier body which during the Late Glacial became narrower. The ground moraine is decametres-thick here and contains boulders in size of up to 20 vol.%. Several of them are rounded at the edges and facetted. The flank of the Arun valley has been glacigenically abraded, i.e. rounded (∩ white) up to the intermediate valley ridge toward the side valley joining from the S, the Wan Khola. Thus, (– – –) verifies a High Glacial (Stage 0; Table 1) minimum height of the ice level. The young and youngest crumblings controlled by the clefts have already damaged the abrasion faces. On the valley floor, too, forms of ground polishing such as small round knobs (∩ black, small) are preserved. Cf. Figure 11 above No. 49. Analogue photo M. Kuhle, 14/12/1994.

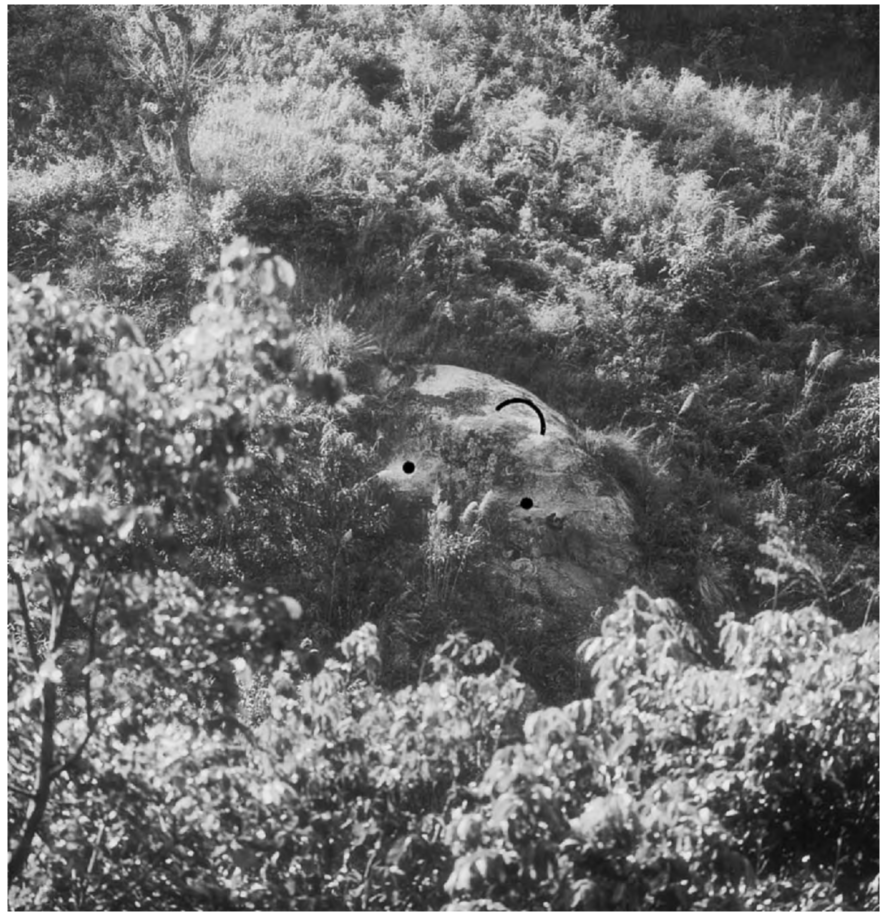
← *Photo 33.* At 1100 m a.s.l. from the orographic right flank of the Arun Nadi (Khola) on the S margin of the Lamobagar Gola settlement (27°39′42″ N/87°21′30″ E, Figure 4, Photo 33) looking diagonally down across the Arun Khola into its orographic left flank (■). (∩) is a 'whale back'-roche moutonnée in the outcropping gneiss, the culmination of which (⇓) towers ca. 70 m above the current Arun river. The talweg with the Arun river is behind the roche moutonnée. Ground moraine covered by glaciofluvial gravel (□) lies this side of the roche moutonnée. It is used as terraced farmland. (○) are edged, round-edged and facetted moraine boulders in size from metres up to that of a hut, glaciofluvially rinsed out of the fine matrix. (■) is ground moraine on the orographic left valley slope, preserved ca. 350 m above the talweg in the position of a spur. One can see the leeward half of the roche moutonnée (∩), which falls away remarkably flat in the down-valley direction. This is a typological characteristic of 'whale back'-roche moutonnées indicating nearly perfect streamlined contours. (⇓) marks the locality of large far-travelled boulders and of potholes on its culmination (Photos 34–36). Cf. Figure 11, No. 49. Analogue photo M. Kuhle, 13/12/1994.

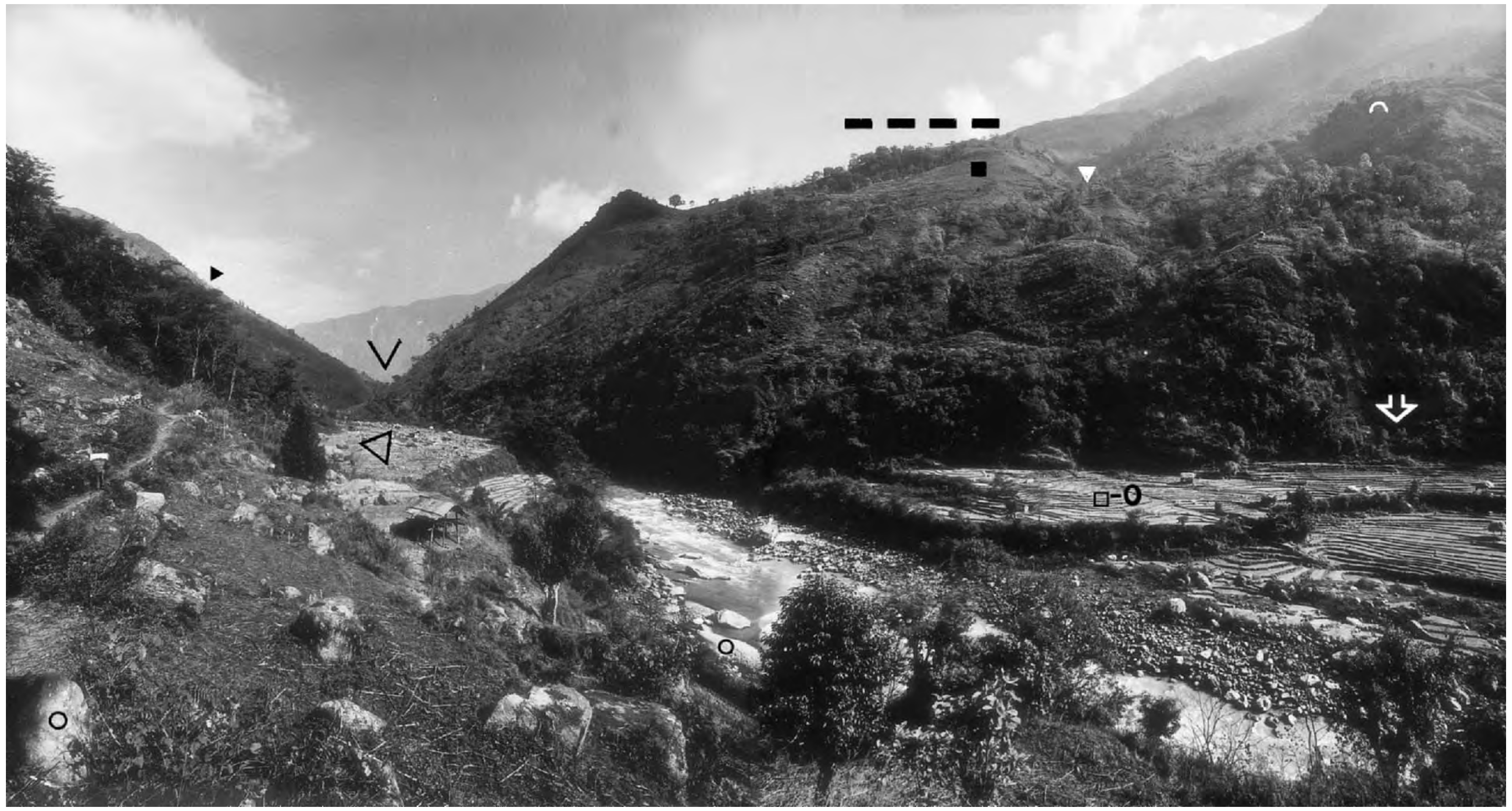
→ *Photo 35.* At 1100 m a.s.l., E of the culmination of the roche moutonnée (Photo 34) in the middle of the Arun Nadi (Khola) (27° 39′ 40″ N/87° 21′ 37″ E, Figure 4, Photo 35) on the S margin of the Lamobagar Gola settlement facing SSW looking down the Arun Nadi. The highest point of the roche moutonnée (∩) lies 70 m above the Arun river. (⇑) marks glacier striae which are still visible in a slightly weathered, i.e. crumbly state of preservation. The person stands in a bowl-form which has been flushed out very fast, i.e. probably by water flowing down under hydrostatic pressure. The subglacial meltwater has a formative effect through cavitation corrasion such as this. Cf. Figure 11, No. 49. Analogue photo M. Kuhle, 13/12/1994.

← *Photo 34.* At 1100 m a.s.l. from the culmination of a roche moutonnée (∩) in the middle of the Arun Nadi (Khola) (27° 39′ 40″ N/87° 21′37″ E, Figure 4, Photo 34) on the S margin of the Lamobagar Gola settlement looking down-valley facing SSW. The viewpoint is 70 m above the Arun river. (○) are rounded to round-edged, i.e. facetted and angular boulders (○ on the right) extended up to 2.8 m (○ on the left; see person for scale on the right). These boulders lie hollow on the convex surface of the roche moutonnée, i.e. they only come into contact with the surface at a few small-scale points in 'wobbly', unstable positions. In dependence on the structure of the gneiss banks outcropping to the left upward, the surface of the roche moutonnée (∩) has been broken in an irregular-convex way and ground down by the glacier. (■ black) is ground moraine on the orographic left slope with boulders in size up to that of a hut ca. 300 m above the talweg. Coarse-blocky ground moraine (■ white) also occurs on the orographic right side, ca. 1 km further down-valley, 400 m above the talweg. The cross-profile of the Arun Nadi (Khola) is V-shaped. Cf. Figure 11, No. 49. Analogue photo M. Kuhle, 13/12/1994.

← *Photo 36*. At 1100 m a.s.l. W of the culmination of the roche moutonnée (Photo 34) in the middle of the Arun Nadi (27° 39′ 40″ N/87° 21′ 37″ E, Figure 4, Photo 36) on the S-margin of the Lamobagar Gola settlement facing SW looking diagonally across a section of the highest profile line of the roche moutonnée (∩ small). Its highest point lies 70 m above the Arun river. (∩) are polished and thus rounded and smoothed faces of gneiss rock reworked by a glacier from right to left. (○) is a pothole (person for scale) vertically set into the 'whale back' a good 5 m-deep. It is 1.5–1.7 m in diameter. (■) is ground moraine which together with coarse boulders fills part of the potholes. Cf. Figure 11, No. 49. Analogue photo M. Kuhle, 13/12/1994.

→ *Photo 38*. At 1100 m a.s.l. looking onto a roche moutonnée in the orographic right flank of the Arun Nadi (27° 39′ 23″ N/87° 21′ 38″ E, Figure 4, Photo 38), down-valley of the Wan Khola junction, facing E. The down-valley lee slope of the roche moutonnée is visible (∩), which especially on its windward side is for a large part mantled by ground moraine and slope debris. It has been developed in the gneiss bedrock. Its primarily glacigenic-convex smoothings (∩) have been fluvially polished by subglacial meltwater. This can be evidenced by small concave flushing bowls (●) secondarily set into the glacigenic abrasion roundings. Cf. Figure 11 below No. 49. Analogue photo M. Kuhle, 14/12/1994.





← *Photo 37*. At 1080 m a.s.l. immediately above the Wan Khola-junction (27° 39′ 38″ N/87° 21′ 29″ E, Figure 4, Panorama 37) from facing N (left margin) up the Arun Nadi up to E (right margin) looking into the orographic left flank of the main valley. As with most of the Himalaya cross-valleys the Arun Nadi is V-shaped (∨), but due to flank abrasion of the Ice Age Arun glacier it has been slightly concavely widened (▼ black). This also applies to the numerous other Himalaya cross-valleys which were glaciated during the Ice Age (Kuhle, 1982: 59; 1983a: 155). (∩) are forms of glacigenc flank abrasion reworked by crumblings and rill-rinsing since deglaciation. (■) are ground moraines verifiable here up to at least 1600 m a.s.l., i.e. 550 m above the talweg. They contain round-edged boulders in size of several metres. The moraine overlay indicates (−−−) a past minimum glacier trim-line. The discharge of the monsoonal rainfalls down from the here 2800 m-high catchment area of the slope (upper right corner) has led to a decametres-deep cutting of rills (▼ white), which have sunk through the ground moraine up to the glacigenically abraded bedrock and in between have left characteristic morainic iron-forms (■). At the same time moraine has been dislocated. (△) is an orographic right fossilized debris flow fan of dislocated material from the right Arun Nadi flank. Its margin has been undercut by the Arun river, so that it falls away decametres-deep as a steep wall. (○) are facetted and round-edged ground moraine boulders of granite and gneiss preserved *in situ*. (□) are neoglacial (Glacier Stage V corresponds to gravel field −0, see Table 1) gravel fields still accumulated during the Little Ice Age (Glacier Stage X corresponds to gravel field −6, see Table 1). The highest one is gravel field −0 (□ −0). In the river bed moraine blocks in size up to that of a house have been concentrated by washing-out of the matrix. (⇓) is a lower slope in the gneiss bedrock, steepened by fluvial undercutting. It might have already been developed by subglacial meltwater. Cf. Figure 11, No. 49. Analogue photo M. Kuhle, 13/12/1994.

← *Photo 39*. At 1050 m a.s.l., ca. 1.3 km down-valley from the Wan Khola junction (27° 38′ 54″ N/87° 21′ 28″ E, Figure 4, Photo 39) looking down the Arun Nadi facing SSW. (⌒) is a well preserved glacigenic flank polishing on outcropping gneiss banks between 100 and 400 m above the talweg (□). The weathered-out clefts show the banking structure which falls away to the WNW (23°/300°), so that a band polishing of the outcropping edges of the banks has been developed. The stretched orographic right slope of this typical V-shaped profile of a Himalaya cross-valley is clearly visible. (□) is the monsoonal gravel floor of the Arun river. Cf. Figure 11 below No. 49. Analogue photo M. Kuhle, 14/12/1994.

↓ *Photo 40*. Panorama at 1220 m a.s.l. ca. 0.7 km down-valley from the inflow of the Thado Khola (below the black ■ on the left) into the Arun Nadi (27° 37′ 59″ N/87° 21′ 08″ E, Figure 4, Panorama 40) from facing NNW (left margin) via part of the upper Thado Khola facing NNE up the Arun Nadi (□) facing NE via the mountain spur (third ■ from the right) with the Lunsun settlement, up to facing E looking to the orographic left side valley, the Amsuwa Khola (right margin). Most of the cross-profiles of the Arun Nadi are V-shaped valleys. On the cross-profile of the viewpoint the talweg with the Arun river runs at 950 m a.s.l. The highest occurrence of lodgement till (■) is at 1600 m a.s.l. (fourth ■ from the right) (cf. Photo 37). Further remnants of lodgement till are situated on the orographic right between ca. 1000 and 1200 m a.s.l. In these two cases (■ white and black on the very right) the moraine covers have been cut by a rill, i.e. by the talweg of the side valley of the Thado Khola, and, due to the discharge of precipitation water, dispersed into forms related to earth-pyramids on the walls of the exposure (below ■ white and black on the very left). (■ third from the right) is also exposed moraine material preserved as a remainder in the form of a small sharp crest running downward (above the third ■ from the right); below, the tipped over ground moraine material has settled as a steep debris cloak on the outcropping edges of the gneiss which are still visible (below the third ■ from the right). (■ on the very right and on the left beside it) are ground moraine covers about 1000–1350 m a.s.l., superficially reworked by the development of rills and slope rinsing since the deglaciation. The Amsuwa Khola joins the Arun main valley as a hanging valley with a very narrow gorge stretch (↓), which during the interglacial periods, i.e. when the High Glacial main glacier was lacking, has been cut. (◓) are glacigenic flank abrasions relatively well preserved up to 1640 m a.s.l. They have polished back the mountain spur of Lunsun as a triangle-shaped slope. (–––) is the corresponding highest verifiable Ice Age Arun glacier trim-line. Cf. Figure 11 below No. 49. Analogue photo M. Kuhle, 14/12/1994.

← *Photo 41.* At 1390 m a.s.l. from the orographic right flank of the Arun Nadi, ca. 0.5 km S of the side valley talweg of the Ekuwa Khola (27° 37′ 10″ N/87° 20′ 50″ E, Figure 4, Photo 41) looking diagonally down-valley across the Arun Nadi facing ESE. (■ black) is a ca. 200 m-wide complex of ground moraine, lying on a rock pedestal as far down as 1280 m a.s.l. This ground moraine cover is 380 m above the current talweg in which the Arun river flows. On both sides of (■ black) slope ravines have been regressively cut down into the old trough valley bottom with its ground moraine overlay. The division into an upper trough- and a lower V-shaped valley profile has already been developed syngenetically by glacier ground scouring above and subglacial meltwater erosion below. In the foreground (■ white) on the orographic right valley flank ground moraine also lies ca. 450 m above the talweg. It contains far-travelled, partly round-edged gneiss boulders, metres in size, in a clayey matrix. (– – –) is the High Glacial glacier trim-line about 1550 m a.s.l. (Stage 0; Table 1); (– – – on the right) is the glacier trim-line on a rock spur (⏶) polished at an angle by the ice, which is situated in the junction area of the Ikhuwa Khola. Cf. Figure 11, No. 50. Analogue photo M. Kuhle, 12/12/1994.

↓ *Photo 42.* Panorama at 1550 m a.s.l. from the orographic right flank of the Arun Nadi, ca. 1.0 km S of the side valley talweg of the Ekuwa Khola (27° 36′ 49″ N/87° 20′ 46″ E, Figure 4, Panorama 42) from facing ESE looking at the ground moraine in the Ikhuwa Khola-junction (■ black near the left margin) via facing S diagonally down across the main valley, the Arun Nadi, up to facing SW along its orographic right valley flank (∩) seen down-valley. (∩) are gneiss banks cleared and abraded by the flank polishing of the High Glacial (Stage 0; Table 1) Arun Glacier (band polishing of the outcropping edges of the banks; cf. Photo 43). (First and second ■ from the left) are ground moraines which in the junction area of the Ikhuwa Khola make up the trough-like concave slopes of the bed of the High Glacial Arun Glacier up to ca. 1550 m a.s.l. (■ on the right) is an orographic right moraine remnant. (▽) is a mudflow fan heaped up by dislocated Ice Age moraine material from an orographic right talweg. On it terraces have been established belonging to the farmland of the Uwa settlement. (□) is a river-terrace of the Arun classified as neoglacial glacier mouth gravel floor terrace of the Nauri Stage (No. −0) (cf. Table 1). (– – –) is the High Glacial upper abrasion limit indicating the Arun glacier trim-line at ca. 1550 (– – – on the left) up to 1500 m a.s.l. (– – – on the right). (⏶) is an accompanying glacigenically polished-back triangle-shaped face with a moraine cover. Cf. Figure 11, No. 50. Analogue photo M. Kuhle, 14/12/1994.

← *Photo 43*. At 1350 m a.s.l. from the orographic right flank of the Arun Nadi near the Jar Khola locality (27° 36′ 12″ N/87° 20′ 14″ E, Figure 4, Photo 43) looking into the orographic right flank above the Uwa settlement facing NNE up the main valley. (◠) are glacigenic flank abrasions on the massive gneiss bank-edges reaching up to 1550 m a.s.l. (cf. Photo 42). The flank polishings show a vertical extension of 250 m. It follows that during the last glacial period (Stage 0; Table 1) the surface level of the Arun glacier (– – –) has reached at least up to this altitude, i.e. up to 1550 m a.s.l. Cf. Figure 11, No. 50. Analogue photo M. Kuhle, 12/12/1994.

↓ *Photo 44*. Panorama at 1440 m a.s.l. from the orographic right flank of the Arun Nadi ca. 1 km W above the Simma settlement (27° 35′ 49″ N/87° 19′ 29″ E, Figure 4, Panorama 44) from facing NNE the orographic right Arun valley flank diagonally up-slope (left margin) via facing ENE to the Ikhuwa Khola-junction (on the left of the left ■) across the Arun Nadi facing ESE looking into its orographic left valley flank. (◠) are gneiss faces smoothed by glacigenic flank abrasion. (●) is a pothole filled with rainwater, situated ca. 580 m above the Arun river (far below ■ on the right). It cannot have been developed by the water flowing down here only periodically and away from a talweg worth mentioning. Accordingly, a subglacial pothole is concerned. The smooth rock roundings (e.g. close to the person with the two sticks) also point to the fact that subglacial meltwater has contributed to the glacier polishing. (○) are angular gneiss boulders, partly or completely round-edged, facetted and rounded. They have been superficially flushed free or embedded into a fine substrate of ground moraine. Boulders from rock avalanches up to hut-size are also scattered on these moraine-covered slopes. They can be diagnosed by their fresh breaking edges. (■) are remnants of ground moraine at 880 m a.s.l., 300–400 m above the talweg of the Arun valley. They have been preserved on jutting out rock ribs on the orographic left valley flank near the Sirutar settlement (■ on the left) and above Dhodeni (■ on the right) since the Late Glacial deglaciation (probably since Stage II; Table 1). Cf. Figure 11, No. 50. Analogue photo M. Kuhle, 12/12/1994.

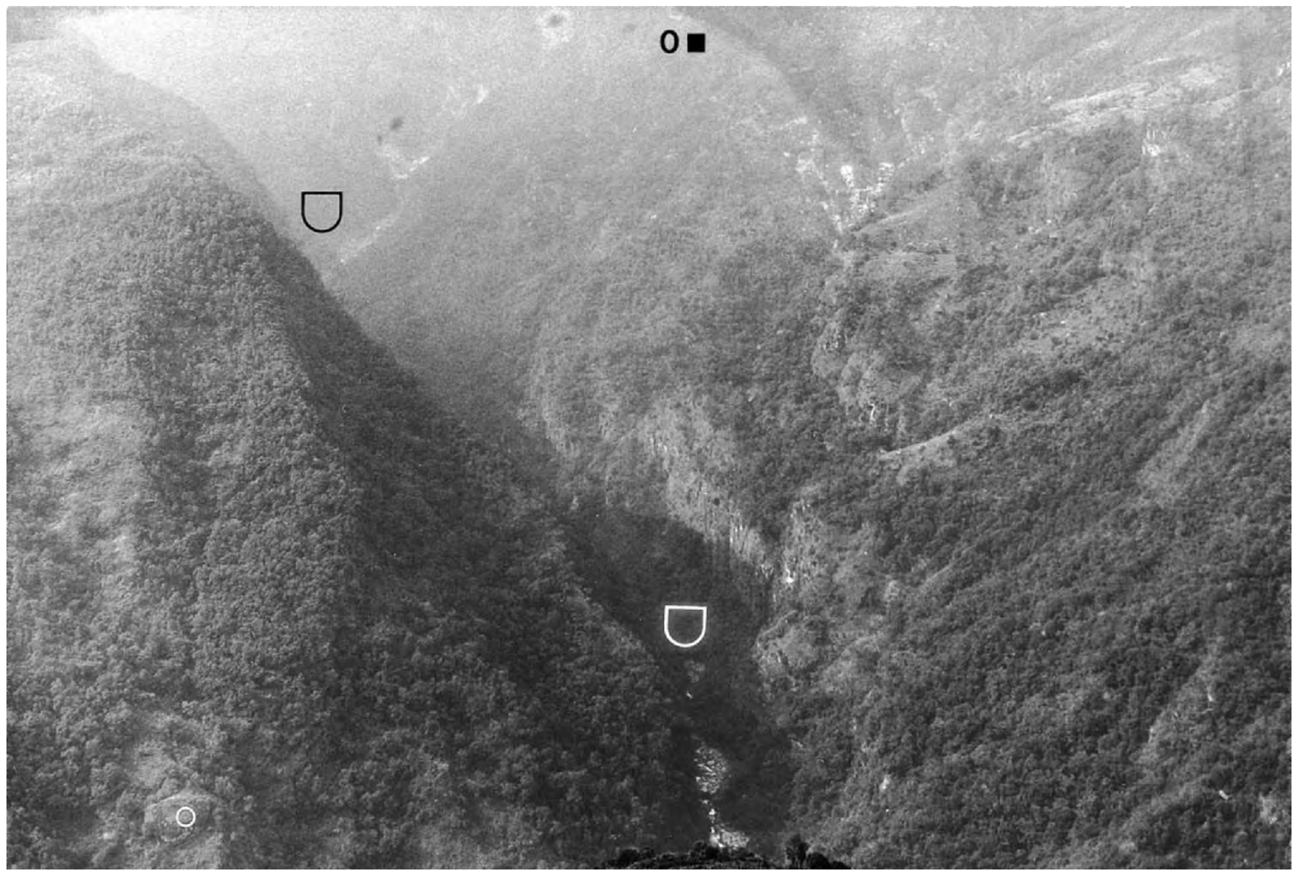
← *Photo 45*. At 1430 m a.s.l. on the orographic right flank of the Arun Nadi ca. 1 km W above the Simma settlement (27° 35′ 46″ N/87° 19′ 30″ E, Figure 4, Photo 45) looking steeply up-slope facing NW. (∩) marks a classic band polishing of edges of the banks in the outcropping gneiss. The banks, which are dissected by nearly horizontal release joints (▽), are ca. 1.5–3 m-thick (for scale: person with burden on the left below ∩). The glacigenic abrasion roundings (∩) are still clear, but the rock polishing has already been splintered and roughened. In the younger Holocene and historical time now crumblings (⇩) take place, destroying the glacier polishing. The material of ground moraine in the foreground contains edged and round-edged gneiss boulders in size of 1–2 m at a maximum. There are farm-terraces. Cf. Figure 11, No. 50. Analogue photo M. Kuhle, 12/12/1994.

↓ *Photo 46*. Panorama at 1430 m a.s.l., a good 700 m above the Arun river (Figure 16, Pro. 9), from the orographic left flank of the Arun Nadi near the Num settlement (27° 33′ 50″ N/87° 17′ 24″ E, Figure 4, Panorama 46) from facing NNW (left margin) up the Kasuwa Khola, via facing NE up the Arun Nadi, up to ENE (right margin) looking into the orographic left flank of the Arun Nadi. (■) are High Glacial accumulations of lateral- and ground moraine. (■ black) is a plate of lateral- to ground moraine, the highest reaches of which are situated a good 700 m above the Arun river in the talweg of the Arun Nadi (cf. Photo 49 □). Due to the extended area of the lateral moraine plate (see also Photo 47, which shows the continuation of this lateral moraine face) the moraine material is decametres-thick, covering the unevennesses of the outcropping rock spur in the underground. (○) are edged, round-edged i.e. facetted and – with regard to their overall form – slightly rounded augengneiss boulders up to 2.5 m in length, which, isolated from each other, are embedded into a clayey matrix. 80.1% of the quartz grains of the fraction 0.2–0.6 mm contained in the matrix, consist of glacially crushed grains (see Figure 6, No. 1). (On the left of ■ white above) is the corresponding deposit of ground moraine on the orographic right Arun main valley flank, the matrix of which even contains 89.6% glacially crushed quartz grains of this fraction (see Figure 6, No. 2). This moraine remnant at 1550 m a.s.l. near the Murmidada settlement even lies 830 m above the current talweg of the main valley. Both the moraines (upper white and ■ black) are classified as being synchronous lateral moraines of the Arun parent glacier during the last glacial period (Stage 0, Table 1) with the corresponding highest glacier trim-line preserved at (– – – and – – –0). (■ white below) is a further ground moraine remnant. (*) are High Glacial cirques in a S-exposition, the bottoms of which lie between 3300 and 3600 m (cf. Photo 26). Cf. Figure 11, No. 51. Analogue photo M. Kuhle, 22/11/1994.

→ *Photo 48*. At 990 m a.s.l., ca. 270 m above the Arun river, taken from the orographic right flank of the Arun Nadi (27° 34′ 19″ N/ 87° 16′ 33″ E, Figure 4, Photo 48) E of the Mulgau settlement facing SSW across glacigenic flank polishing on the orographic right side (∩), looking down the Arun Nadi. The locality is shown in Photo 47 below (∩). (∩) is a freshly preserved polishing on the crystalline schist bedrock (phyllite) diagonally to the cleft face. (▼) is a breaking edge, developed since the deglaciation and arranged along a stratification surface. See Figure 11 on the right below No. 52. Analogue photo M. Kuhle, 22/11/1994.

↓ *Photo 47*. Panorama at 1430 m a.s.l. a good 700 m above the Arun river, taken from the orographic left flank of the Arun Nadi near the Num settlement (27° 33′ 50″ N/87° 17′ 24″ E, Figure 4, Panorama 47) from facing SSE (left margin) via the lateral moraine terrace (○ white) in the SSW, via facing SW (centre) down the Arun Nadi, via facing NW into the orographic right flank of the Arun Nadi (■ black on the right up to - - on the right), up to facing N (right margin) looking up the Kasuwa Khola. (■) are High Glacial accumulations of lateral- and ground moraines. (■ black on the left and white on the very right) is a lateral- to ground moraine plate, situated with its upper reaches a good 700 m above the Arun river in the talweg of the Arun Nadi (cf. Photo 49 □). Due to the extended area of the lateral moraine plate (it is therefore used as extraordinarily good farmland) (see also Photo 46 showing the continuation of this lateral moraine face) the moraine material is decametres-thick and covers the unevennesses of the outcropping rock spur in the underground. (○) are edged, round-edged, i.e. facetted and – with regard to their overall form – slightly rounded augengneiss boulders up to 3 m in length (two children and a grown-up with burden for scale). They 'swim' isolated from each other in a clayey matrix. 80.1% of the quartz grains of the fraction 0.2–0.6 mm contained in the matrix consist of glacially crushed grains (see Figure 6, No. 1). There is no catchment area above the accumulation of loose rocks concerned, from which the augengneiss boulders could have come as local slope debris (cf. Figure 16, Pro. 9, on the right below point 1690 m). Accordingly, this is rather a mountain spur with a sharpened crest (on the left above – – –0) along which transport of debris is impossible. (Second ■ white from the right) is the corresponding ground moraine deposit on the orographic right Arun main valley flank, the matrix of which even contains 89.6% glacially crushed quartz grains of this fraction (see Figure 6, No. 2). This moraine remnant lies at 1550 m a.s.l. near the Murmidada settlement, 830 m above the current talweg of the main valley (Figure 11, No. 52). Both the moraines (■ black on the left and second ■ white from the right) are classified as being synchronous lateral moraines of the Arun parent glacier during the last glacial period (Stage 0, Table 1) with a corresponding highest glacier trim-line at (– – – 0 and – – –). An accumulation ledge extends the orographic right moraine from the Murmidada settlement (second ■ from the right) down-valley from 1550 to ca. 1400 m a.s.l. (left of – – – on the right, up to above ■ black). (◓) is a glacigenic flank polishing (below is the locality shown in Photo 48). (*) are High Glacial cirques in a S-exposition, the bottoms of which lie between 3300 and 3600 m (cf. Photo 26). See Figure 11, No. 51. Analogue photo M. Kuhle, 22/11/1994.

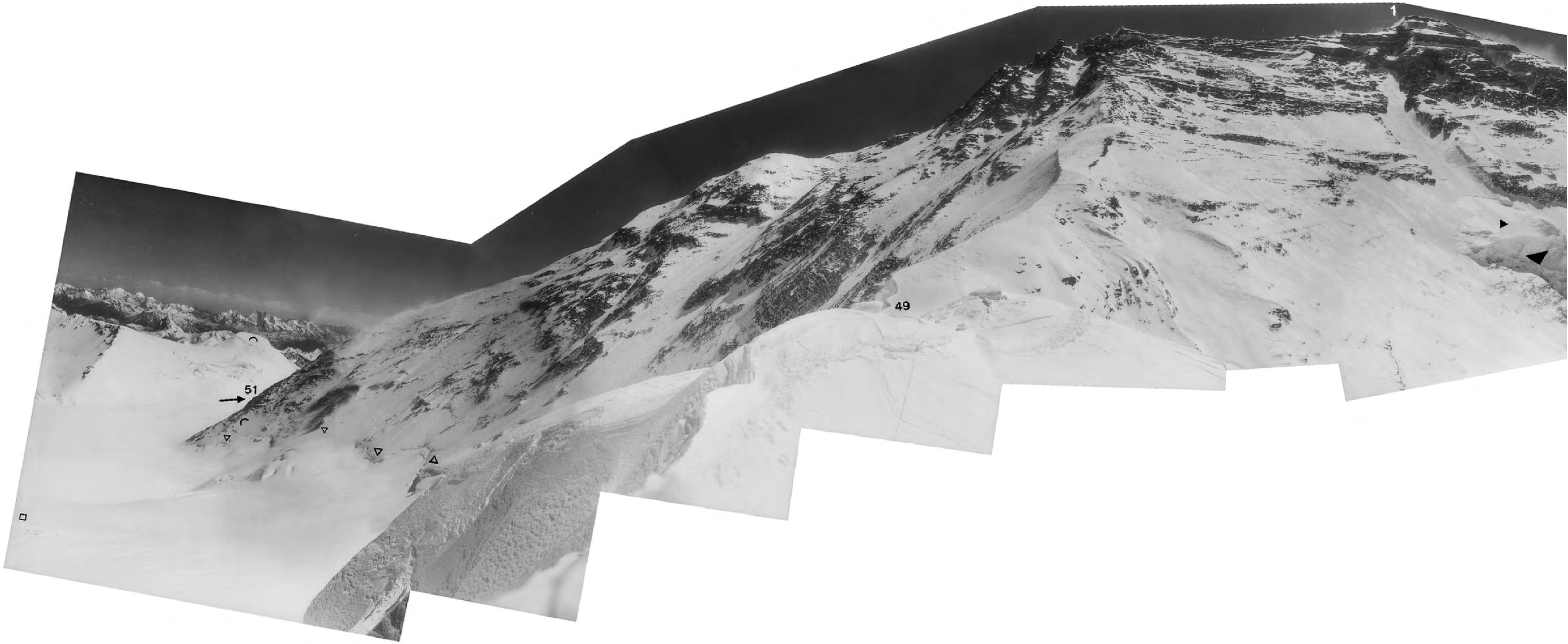
↑ *Photo 49*. Panorama at 1360 m a.s.l., 660 m above the Arun river, from the orographic left flank of the Arun Nadi (27° 33′ 15″ N/87° 16′ E, Figure 4, Panorama 49) N of the Amran settlement, from facing W (left margin) across the junction of the Irkhuwa- or Isuwa Khola (▽) which leads down from the Chamlang S-flank, facing N across the orographic right flank of the Arun main valley (centre), via facing NE up the Arun Nadi, up to ENE looking onto the orographic left flank toward the Num settlement (right margin) (Photos 46 and 47). (■) are sporadic ground moraine remnants in the two main valley flanks with a maximal extension of 700–830 m above the Arun river (□). They probably suggest the Last Glacial (Stage 0, Table 1) Arun glacier level (– – –). (■ on the right of ▽) is a remnant of lateral moraine, i.e. a bank kame at 1120 m a.s.l. which, a good 420 m above the talweg as an abutment, has been accumulated against the valley glacier, which had already melted down during the early Late Glacial. (⏶) shows a truncated spur, further polished back by the Arun glacier. A flattened moraine remnant (Photos 46 and 47) occurs at the same level on the orographic left valley side (■ on the left of ▽). This suggests a synchronous development of the two accumulations by the same glacier level. (⌒) is an orographic right band polishing of outcropping edges of the strata. (▽) is the Irkhuwa or Isuwa Khola which shows a trough profile up to its inflow into the Arun Nadi (for further details see Photo 50). See Figure 11, Nos. 51 and 52). Analogue photo M. Kuhle, 16/12/1994.



→ *Photo 50*. At 1360 m a.s.l., 660 m above the Arun river, taken from the orographic left flank of the Arun Nadi (27° 33′ 15″ N/87° 16′ E, Figure 4, Photo 50) facing WNW, looking into the valley exit, i.e. the inflow of the Irkhuwa- or Isuwa Khola (▽), coming down from the Chamlang S-flank. Up to its inflow into the Arun main valley the valley shows a ca. 500 m-wide trough valley cross-profile (▽ black). Into this upper trough profile a second, still narrower trough profile has been set in (▽ white). (0 ■) is the orographic left lateral moraine ledge of the Ice Age (Table 1 No. 0) Irkhuwa glacier during the last phase of the confluence with the Arun parent glacier. (○) is a huge moraine boulder larger than a house, preserved in an unstable slope-position. See Figure 11 on the left below No. 52. Analogue photo M. Kuhle, 16/12/1994.

← *Photo 51.* Panorama at 2165 m a.s.l., ca. 1565 m above the Arun river, taken from the orographic left flank of the Arun Nadi (27° 30′ 17″ N/87° 15′ 50″ E, Figure 4, Panorama 51) E of the Hururu settlement, from facing WSW (left margin) along the orographic left flank of the Arun Nadi down-valley, via facing NW the Rate Khola (foreground) down to the Arun river (▼) and into its right flank (centre) across the inflow of the Apsuwa Khola in the NNW (v) – which in the course of its lower ca. 13 km is V-shaped – up to facing NNE along the left flank of the Arun Nadi main valley looking up-valley. In the background the crests of the 6208 and 6213 m-high double-summit of the Ekrate Dada (No. 47, cf. Figure 11, No. 48) are visible between clouds; (*) are several High Glacial cirques and short troughs (short trough-shaped hanging valleys) in a S-exposition, the bottoms of which lie between 3300 and 3600 m (Figure 11 on the right of No. 46; cf. Photo 26). Here, the Arun river (▼) flows at 600 m a.s.l. On the orographic right side a classic glacigenic triangle-shaped slope has been developed (☗) (Figure 11, No. 35), formed by the truncation of a mountain spur due to the back-polishing by glacier abrasion. The rounded polishing face of the triangle-shaped slope is undercut and wasted away by a steep outer-slope and crumbling away ▽ caused by the Arun river. On the triangle-shaped slope as well as up- and down-valley, typical band polishings of outcropping edges of the strata are preserved (∩), preformed by the banking structure of the rock. On the triangle-shaped slope (––– above ☗) the polish line runs at 1040 m, a good 400 m above the talweg of the Arun Nadi (▼). It marks the High Glacial glacier trim-line (–––). (⇓) indicates a typically fluvial landscape of slope ravines with a rock crumbling. It has collapsed during the monsoon in 1994. Cf. Figure 11, No. 53. Analogue photo M. Kuhle, 21/11/1994.

← *Photo 52.* Panorama at 1880 m a.s.l., 1360 m above the Arun river, from the orographic left flank of the Arun Nadi (27° 27′ 46″ N/87° 13′ 58″ E, Figure 4, Panorama 52) near the Chichila alpine pasture from facing WSW (left margin) straight across the lower Arun Nadi, via facing NW across the Arun Nadi and its upper glacier catchment area from the Himalaya main ridge between Chamlang (No. 12, 7290 m) and Makalu (No. 3, 8481 m) (centre), up to facing NE along the orographic left flank of the Arun Nadi looking up the main valley (right margin). Below No. 12 the Irkhuwa- or Isuwa Khola and on the right below No. 3 the Kusawa Khola are running down to the S, flowing into the Arun Nadi. In the background several High Glacial cirques and short troughs (short, trough-shaped hanging valleys) are visible in a S-exposition (*). Their bottoms lie at an altitude between 3300 and 3600 m (cf. Figure 11 on the right of No. 46 and Photo 26). No. 37 is the ca. 6600 m-high Iswa Peak standing between the Irkhuwa Khola and Barun Nadi. The Kaguwa Khola (foreground) leads from the viewpoint down to the Arun river (▼). On the opposite side the Bendaksuwa Khola (on the left of ∩) and the Pikhuwa Khola (between the two ■) run down to the Arun talweg (▼). Here, the Arun river (▼) flows at only just 520 m a.s.l. Immediately above, loose rocks, which are suspiciously like moraine material, are preserved (■). In places they have been cut by fluvial rills (→) and superficially altered by field terraces. (∩) is an area with small-scale, exposed and abraded rock faces. (–––) is the approximate course of the High Glacial glacier trim-line orientated according to an indistinct upper abrasion limit and a remnant of planation (↓) which is like a lateral formation (kame terrace?) near the Simle settlement about 800 m a.s.l., ca. 280 m above the Arun Nadi talweg. Cf. Figure 11 below No. 53. Analogue photo M. Kuhle, 21/11/1994.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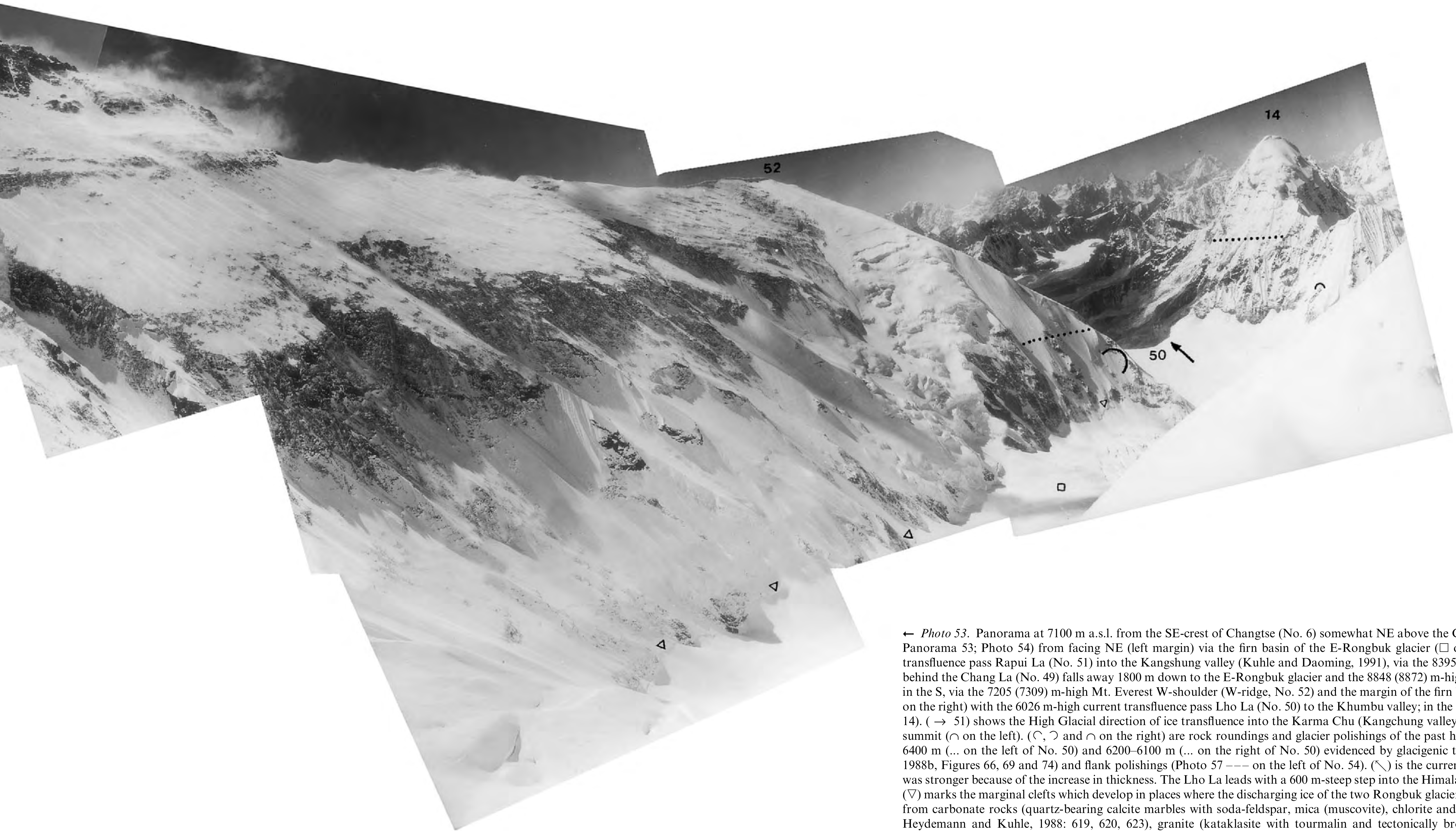

← *Photo 53.* Panorama at 7100 m a.s.l. from the SE-crest of Changtse (No. 6) somewhat NE above the Chang La (No. 49) (28° 01′ 06″ N/86° 55′ 08″ E, Figure 3, Panorama 53; Photo 54) from facing NE (left margin) via the firn basin of the E-Rongbuk glacier (□ on the left) (Kuhle, 1988b) with the 6548 m-high current transfluence pass Rapui La (No. 51) into the Kangshung valley (Kuhle and Daoming, 1991), via the 8395 m-high Mt. Everest NE-spur, the northern wall of which behind the Chang La (No. 49) falls away 1800 m down to the E-Rongbuk glacier and the 8848 (8872) m-high Mt. Everest (also Chogolungma or Sagarmatha, No. 1) in the S, via the 7205 (7309) m-high Mt. Everest W-shoulder (W-ridge, No. 52) and the margin of the firn basin of the central Rongbuk glacier (Rongphu glacier, □ on the right) with the 6026 m-high current transfluence pass Lho La (No. 50) to the Khumbu valley; in the background in the W the 7145 (7165) m-high Pumori (No. 14). (→ 51) shows the High Glacial direction of ice transfluence into the Karma Chu (Kangchung valley) at an ice thickness which was able to round the 6835 m-summit (∩ on the left). (◠, ◝ and ∩ on the right) are rock roundings and glacier polishings of the past higher ice level. (...) is the maximum past ice level at 6500–6400 m (... on the left of No. 50) and 6200–6100 m (... on the right of No. 50) evidenced by glacigenic traces of undercutting (Photo 54 ... below No. 52; Kuhle, 1988b, Figures 66, 69 and 74) and flank polishings (Photo 57 – – – on the left of No. 54). (↖) is the current direction of ice flow over the Lho La, which in the past was stronger because of the increase in thickness. The Lho La leads with a 600 m-steep step into the Himalaya S-slope (Photo 55 ◠ ; 56↘ on the left below No. 52). (▽) marks the marginal clefts which develop in places where the discharging ice of the two Rongbuk glaciers has been separated from the ice frozen to the steep walls from carbonate rocks (quartz-bearing calcite marbles with soda-feldspar, mica (muscovite), chlorite and epidote modified tectonically and metamorphosed: after Heydemann and Kuhle, 1988: 619, 620, 623), granite (kataklasite with tourmalin and tectonically broken quartz- and feldspar crystals: ibid.: 620, 623) and sedimentary series (fine-grained biotite mica-schists with hornblende, epidote and apatite: ibid.: 621, 623). (▶) is a hanging glacier situated between 7660 and 7250 m a.s.l. in the 2450 m-high Mt. Everest-N-wall below the Norton couloir (wall gorge), which due to its stable lee position, is nourished by drift snow (Kuhle, 1986i, 1986j; Kuhle and Jacobsen, 1988). (◢) is the ice break-off of this glacier, the ice avalanches of which have eroded the wall gorge below into the bedrocks (see above) of the Mt. Everest-N-wall. Analogue photo M. Kuhle, 21/10/1984.