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The Himalayan Glaciation : Myth and Reality

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ABSTRACT

The frequency, age and type of glaciation in the Himalayas remain a matter of controversy and uncertainty. In this paper, current knowledge of Quaternary glaciation on both the south and north sides of the Central Nepal Himalayan range is reviewed in the light of recent data dealing with the palaeoclimatic evolution of the Himalaya-Tibet ensemble during the Late Cenozoic. Besides the global climatic factor, the Himalayan glaciation was mostly generated and controlled, in its regional extent, by topographical factors.

INTRODUCTION

The Himalayas and the adjacent Tibetan Plateau are key areas for palaeoclimatic reconstructions and, in particular, for assessing the fluctuations of the Indian monsoon during the last 10^4-10^6 years (Ruddiman and Kutzbach 1989; Kutzbach et al. 1989, Prell and Kutzbach 1992). Glacier fluctuations and glacial history can provide, among other records such as lake sediments, ice cores, loess etc., useful data for identifying and evaluating palaeoclimatic changes. However, in the Himalayas, the frequency, the age and the type of glaciation remain a matter of controversy and uncertainty, despite numerous investigations carried out in the glaciated terrains. For a long time, the four-fold Quaternary glaciation proposed by Chinese authors, who have mostly worked in the northern, dry side of the Himalaya, has been the prevailing view (Zheng 1988; 1989a, Derbyshire et al. 1991), with climatic change and glaciation affecting the range during the Quaternary being caused chiefly by the uplift (about +3000 m) of the Tibet-Himalaya ensemble (Li et al. 1979, Zheng and Li 1981). No specific attention has been paid to possible differential uplift of the Himalayas with respect to Tibet. More recently, Kuhle (1985 1987) has argued that the Himalayas were invaded by ice overspilling from a huge ice-sheet covering the entire Tibetan plateau. This author maintains that the ice-sheet development had important implications on global climate (trigger of ice age, Kuhle 1988). Kuhle's theory has nevertheless been strongly rejected by several authors, mainly on the basis of field evidence (Zheng 1989b, Burbank and Kang 1991, Shi et al. 1992, Fort 1993, Derbyshire, in press). Recent studies on Himalayan glaciation differ from both Chinese or Kuhle's views in that they seek a more detailed chronological account by stressing the importance of the Late Pleistocene and Holocene periods. It is argued that a detailed history of the Last Glacial stage would provide a good framework for greater understanding and modeling of climate fluctuation, especially during glacial stages of the Pleistocene.

In this paper, field data on the extent of glaciation currently available on both sides of the Central Nepal Himalayan Range are presented. The continuous uplift of the Greater Himalayas with respect to Tibet, and the subsequent dissection of the mountain ranges to adjust to the Gangetic plain base level, have strongly controlled the Himalayan glaciation.

GLACIAL EVIDENCE AND CHRONOLOGY: METHODS AND PROBLEMS

Despite the magnificence of the present Himalayan glaciation, conditions in the Nepalese mountain ranges for assessing the history and chronology of glaciation are limited by several factors. On the south, monsoon-influenced side of the range, abundant vegetal cover, intensive erosion and frequent reworking of glacial sediments by mass-wasting processes do not favour the preservation or the recognition of glacial evidence. On the northern, dry side, the paucity of datable material, the frequent confusion between glacial and debrisflow diamictons, the degradation of glacial landforms by highly active periglacial processes and limited access to these remote areas, all explain the lack of a detailed glacial chronology.

The few ^{14}C dates available relate to the most recent, Late Pleistocene and Holocene stages of glaciation only. Most of the reconstructions of former glaciations, such as those referred to in this paper (Table 1), are therefore based on relative dating criteria, such as sharpness of morphology, degree of weathering (Schmidt hammer rebound value, weathering ring, % of clasts affected by oxidation, pit depth on the clast surface), soil development, and thickness of loess cover.

Equilibrium line altitudes (ELA) provide a good indication of climatic parameters (mainly temperatures and precipitation) which determines the distribution of glaciers. They are useful in comparing results obtained in different areas and in assessing the magnitude of climatic changes between the present and former periods of glaciation. ELAs employed here have been estimated using three methods (for a review of available methods, see Meierding 1982): the highest altitude of medial and lateral moraines, the altitude of changes in surface contours from concave to convex (Andrews 1975) and the altitude be-

Table 1: The "classical" glacial successions in the Mt Everest/Xixabangma region, north of the Himalaya (after various sources).

EPOCH	AREA				
	S.Everest	N. Everest	N. Xixa-Bangma	E. Xixa-Bangma	Langtang
Holocene	Thukhla 1-6	Rongpude Neoglacial	Neoglacial1 Neoglacial2	Minor glacial Yala II,I Neoglacial	Lirung
	Ghat	*Yali hypsithermal*			Langtang
Late Pleistocene	Lukla	Qomolangma II	New Glacial	Rongbusi	Gora Tabela Lama ?
		Interglacial			
		Qomolangma I		Jilongsi	Lama ?
		Gyarag Interglacial			
Middle and Early		Nyanyaxingla *Pagri Interglacial*	Old Glacial	Nyalam	
Pleistocene		XixaBangma	Older Glacial		

Sources : Williams 1983; Shi and al. 1986; Zheng 1988: Derbyshire et al. 1991; Shiraiwa and Watanabe 1991 low which lies 40% of the glacierized area (assuming an accumulation-area ration AAR of 0.60). Although these methods have been cross-checked as far as possible, uncertainty persists because of the poor chronological constraints on recognised glacial landforms and because of the pecularity of Himalayan glacier origins (avalanche-fed glaciers). Despite these limitations, a general increase of present and former ELA values has been assumed —from the tropical south to the dry north slopes— as formerly established by Williams (1983) (Fig. 1). This diagram reflects both the present climatic gradient of dryness and the existence of cold, dry conditions during the Last Glacial Maximum (LGM), as expected from global climate changes (Gates 1976, Van Campo 1986). It also provides a reference framework for distinguishing other potential controling factors, such as tectonics or topography, on Himalayan glaciation.

GLACIAL EVIDENCES ON THE SOUTH SLOPE OF THE HIMALAYA

Glacial evidence is best found in three geographical situations: (1) in small isolated massifs located in the foreground of the Greater Himalaya (i.e. Taunja, Gorkha or Shorung Himal), (2) in the deep valleys directly descending from the Greater Himalaya front (i.e. Modi, Seti, Madi khola valleys), and (3) in the wider valleys characteristic of the inner Himalaya (Marsyangdi, Buri Gandaki, Langtang and Khumbu valleys).

1) The Taunja Himal is an isolated massif representative of the first context. Lying south of the Lamjung Himal at altitudes between 4500-5300m, it appeared during the Last Glaciation as a local ice center, from which glaciers developped

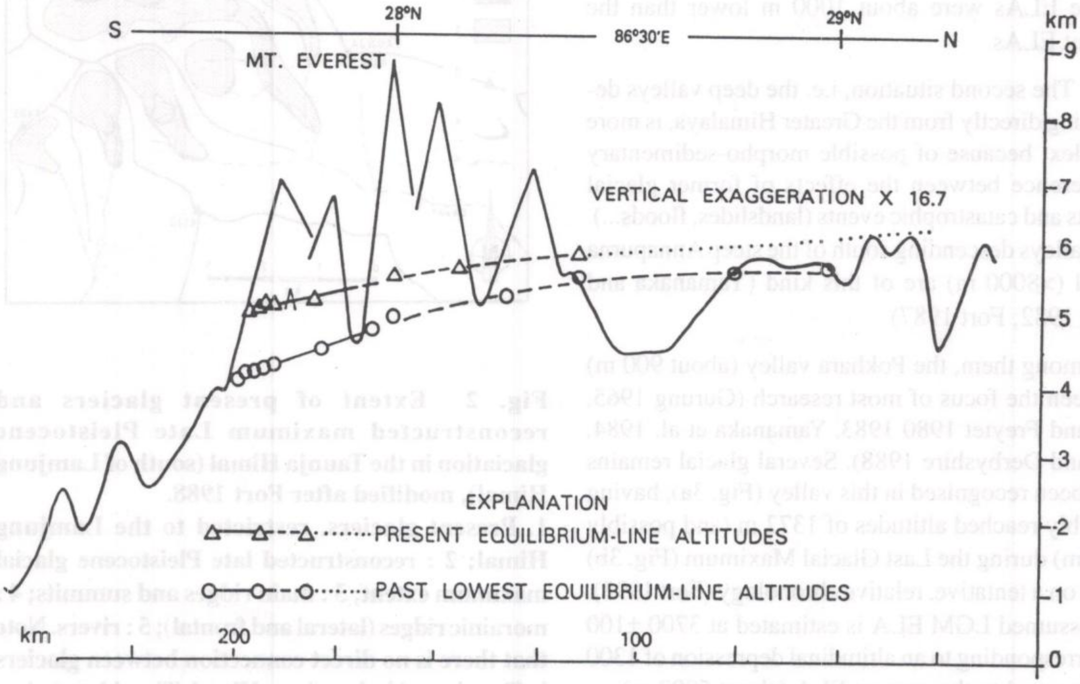

Fig. 1 Profile of present and lowest late Pleistocene equilibrium-line altitudes across the Himalayan Range, near Mount Everest (after Williams 1983)

independantly from the Greater Himalayan glaciation (Lamjung and Annapurna) (Fort 1993).

Besides a number of cirques and nivation hollows (sometimes still occupied by a lake), scoured bedrock and roches moutonnées and prominent systems of terminal and lateral morainic ridges are well preserved. They appear only below peaks or ridges exceeding 4300 m in altitude, a value which can be considered as the "glaciation limit" (as defined by Østrem 1966) in the Taunja Himal. Two morainic sets have been recognised and were inferred to be of Late Pleistocene and Holocene age (Fort 1988 1993). The assumed Late Pleistocene equilibrium line altitude (ELA) has been estimated close to 4150 ±140 m, which represents a about 1050 m snow-line depression compared to the present ELA (5200±100m). The longest glacial tongue was about 5 km long during this maximum (Fig. 2).

Observations made in comparable areas, i.e. Gorkha Himal (Miller and Marston 1989), Ganesh Himal (Thouret 1982), and Shorung Himal (Williams 1983), lead to similar conclusions : the Late Pleistocene ELAs were about 1000 m lower than the present ELAs.

2) The second situation, i.e. the deep valleys descending directly from the Greater Himalaya, is more complex, because of possible morpho-sedimentary interference between the effects of former glacial extents and catastrophic events (landslides, floods...). The valleys descending south of the steep Annapurna Himal (>8000 m) are of this kind (Yamanaka and Iwata 1982; Fort 1987).

Among them, the Pokhara valley (about 900 m) has been the focus of most research (Gurung 1965, Fort and Freytet 1980 1983, Yamanaka et al. 1984, Fort and Derbyshire 1988). Several glacial remains have been recognised in this valley (Fig. 3a), having probably reached altitudes of 1372 m (and possibly 1127 m) during the Last Glacial Maximum (Fig. 3b) based on a tentative, relative chronology (Fort 1993). The assumed LGM ELA is estimated at 3700 ±100 m, corresponding to an altitudinal depression of 1300 m compared to the present ELA (about 5000 m).

Rapid surveys in adjacent valleys give the same overall figure : ice probably reached about 1500 m in the Modi khola (confluence Modi/Kyumnyu khola), and it reached about 1200 m in the Madi khola near Taprang (Fig. 4). This exceptional Late Pleistocene ELA depression can be explained by the steep-

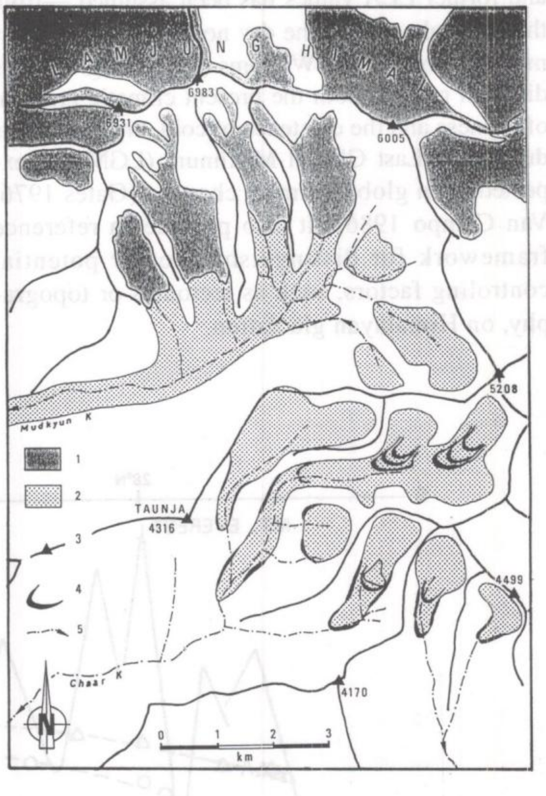

Fig. 2 Extent of present glaciers and reconstructed maximum Late Pleistocene glaciation in the Taunja Himal (south of Lamjung Himal), modified after Fort 1988.
1. Present glaciers, restricted to the Lamjung Himal; 2 : reconstructed late Pleistocene glacial maximum extent; 3 : main ridges and summits; 4 : morainic ridges (lateral and frontal); 5 : rivers. Note that there is no direct connection between glaciers in Taunja and in Lamjung Himal. The ridges below 4300 m were under the glaciation limit.

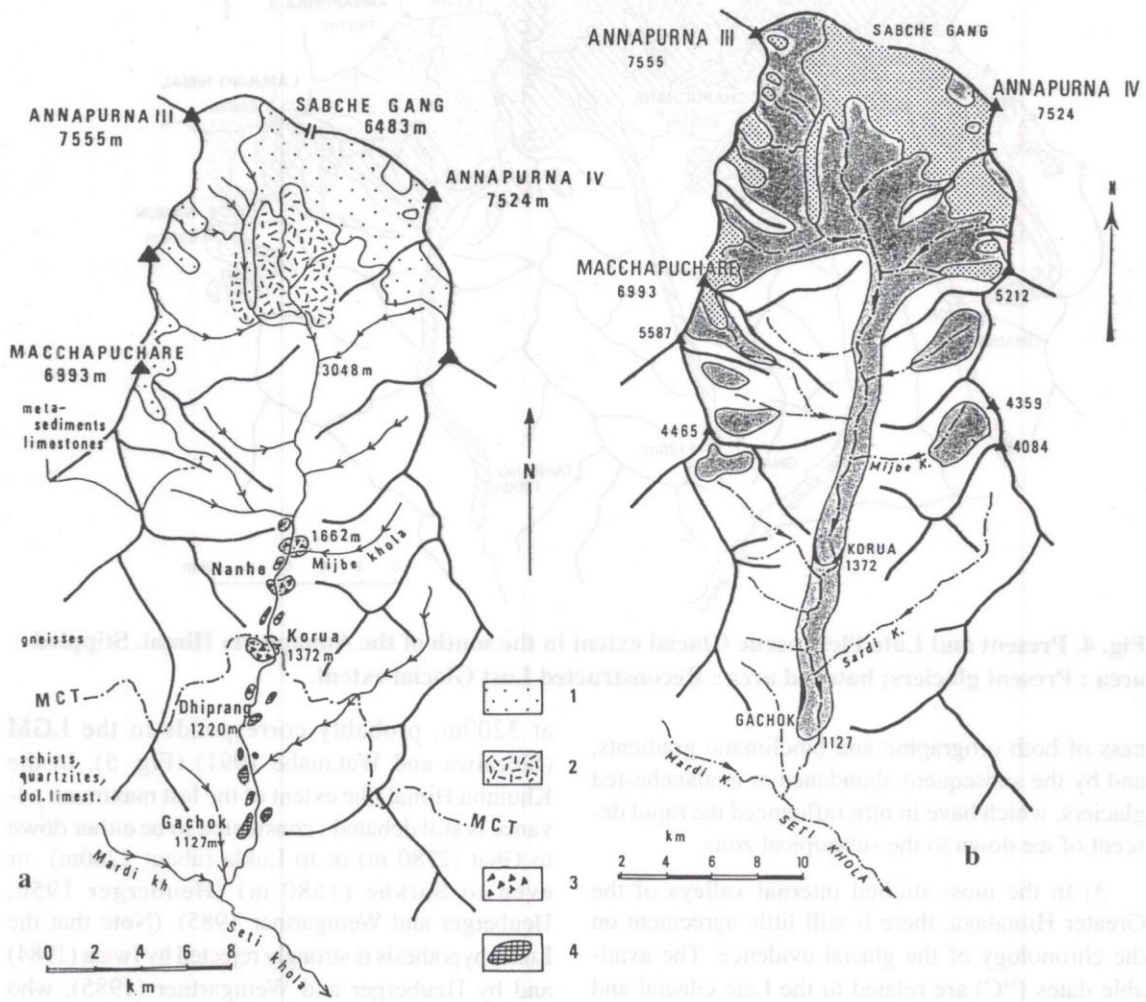

Fig. 3 Present and Late Pleistocene Glacial extent in the Seti khola watershed, north of Pokhara (after Fort 1988; and Fort and Derbyshire 1988). Note that the ages are only hypothetical, based on the degree of induration and/or superficial weathering, and in comparison with the only dated Pokhara event (500 y. B.P).

a). 1 : present glaciers; 2 : till (several hundred meters thick) probably belonging to the late Neoglacial; 3 : morainic frontal ridges and related till, probably belonging to Neoglacial stages (Mijbe and Nahne stages, and Korua stage, respectively younger and older than the Pokhara Formation, dated about 500 y. B.P.); 4 : calcareous, till-like breccia of Kahure-Gachok formation, which might represent the Late Glacial Maximum extent.

b) stippled area : present glaciers; shade : reconstructed Late Pleistocene glacial maximum extent.

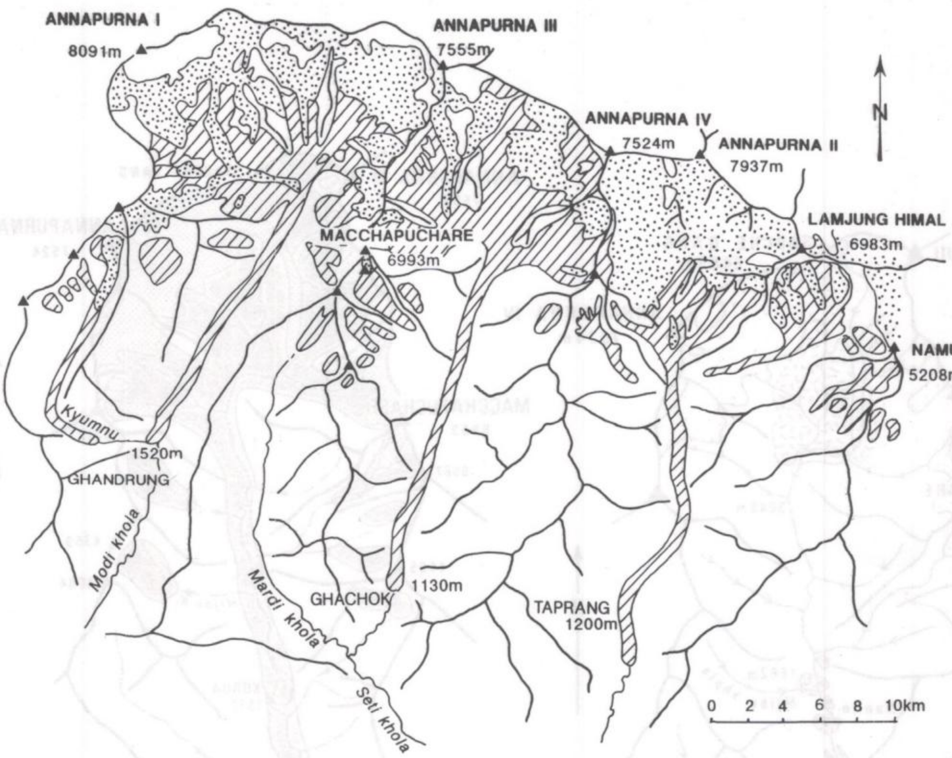

Fig. 4. Present and Late Pleistocene Glacial extent in the south of the Annapurna Himal. Stippled area : Present glaciers; hatched area : Reconstructed Last Glacial extent.

ness of both orographic and bioclimatic gradients, and by the subsequent abundance or avalanche-fed glaciers, which have in turn influenced the rapid descent of ice down to the subtropical zone.

3) In the most studied internal valleys of the Greater Himalaya, there is still little agreement on the chronology of the glacial evidence. The available dates (^{14}C) are related to the Late Glacial and Holocene stages of glaciation only, as shown in the Marsyangdi (Rothlisberger and Geyh 1985), in the Langtang (Shiraiwa and Watanabe 1991), and in the Khumbu (Iwata 1984, Williams 1983, Rothlisberger and Geyh 1985) valleys.

In the Langtang valley, two pre-Holocene glacial stages have been recognised (Heuberger et al. 1984, Shiraiwa and Watanabe 1991). An early last glacial advance reached probably 2600 m, as attested by the U-shape trough of the valley (Shiraiwa and Watanabe 1991), whereas the thick Gora Tabela till, at 3200m, probably corresponds to the LGM (Shiraiwa and Watanabe 1991) (Fig. 5). In the Khumbu Himal, the extent of the last maximum advance is still debated : considered to be either down to Ghat (2780 m) or to Lukla (about 2200m) or even to Surkhe (1580 m) (Heuberger 1956, Heuberger and Weingartner 1985). (Note that the Lukla hypothesis is strongly rejected by Iwata (1984) and by Heuberger and Weingartner (1985), who consider the Lukla terrace as the remain of a former landslide deposit).

These chronological uncertainties render the reconstructions of the LGM ELAs tentative at best. Following Shiraiwa and Watanabe's chronological assumptions, we can estimate the LGM ELA depression in the Langtang Himal to be about 510 m lower than the present ELA (5320 m). In the Khumbu Himal, this Last Pleistocene ELA depression has been estimated at 4250 m, i.e. about 600 m lower than the Present one (Williams 1983).

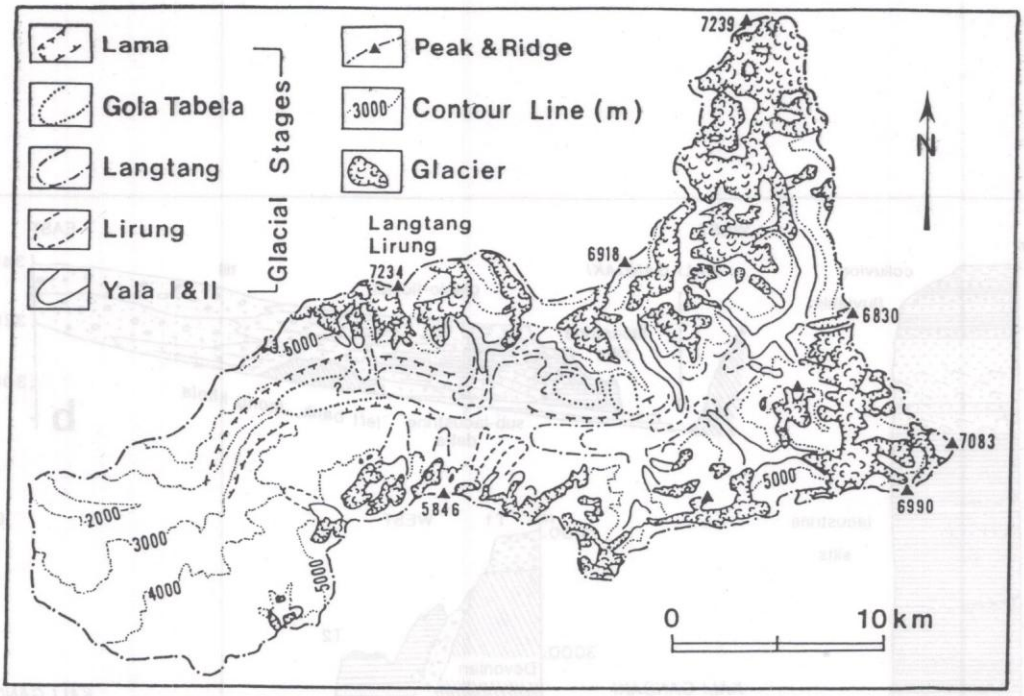

Fig. 5 Extent of the Late Quaternary glaciers in the Langtang valley (from Shiraiwa and Watanabe 1991). The Yala I and II, Lirung and Langtang stages have been ^{14}C dated and attributed to Holocene stages. Gora Tabela till might represent the L.G.M., whereas the U-shape Lama stage is older.

GLACIAL EVIDENCE ON THE NORTH SLOPE OF THE HIMALAYA

Along the northern side of the Himalayas, glaciation has also appeared in three distinct geographical situations : in very deep valleys, such as the Kali Gandaki and some of its tributaries, towered by the >7000 m peaks of the Greater Himalaya; in valleys issued from the Himalayas and southerly draining towards Tibet; in isolated massifs, ≤ about 6000 m, located north of the Greater Himalayan slopes.

1) The upper Kali Gandaki valley (i.e. the Thakkhola area) offers an interesting succession of complex features, involving true glacial deposits together with fluvio-glacial, alluvial, landslide and periglacial slope deposits. Their relative chronology has been assessed by using chiefly morphostratigraphical methods, in relation to the key lacustrine formation of Marpha (Fort 1980). This >300-m-thick Marpha Formation, normally magneto-polarized , corresponds to the filling of a large lake, which flooded the main Kali Gandaki valley from Tukuche downstream to the north of Kagbeni. This lake was the local base level for all the sediments derived from the adjacent valleys (Fig. 6). The Marpha Formation is locally underlain by a consolidated till ("Syang diamicton"), the presence of which suggests that, at the time of the flood, the Kali Gandaki was already dissected down to its present floor. The depth of this dissection lead us to assume, in the absence of better chronological confirmation, that all the sediments recorded in this valley floor laterally interfingered into the lake deposits are likely to belong entirely to the Last Glacial period.

Glacial evidence is preserved along the Kali Gandaki and its tributary valleys. The best succession can be observed in the upper Muktinath valley, bordered by the two North and South Thorung Peaks

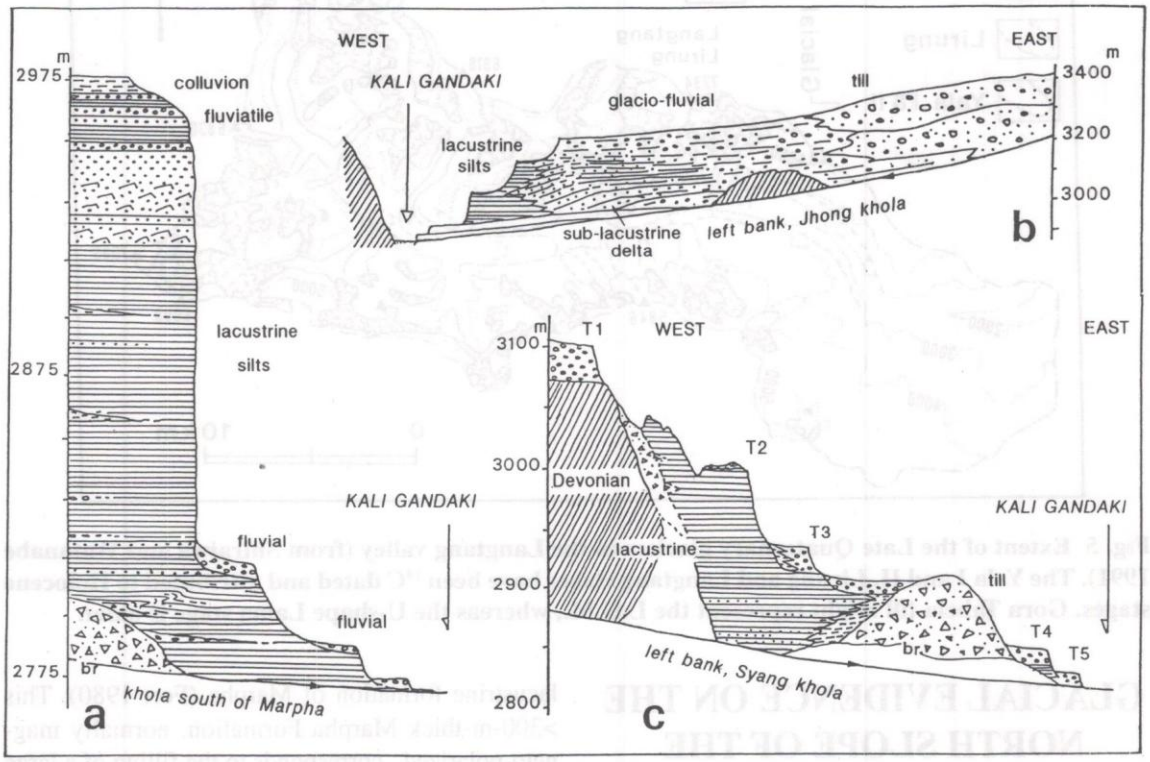

Fig. 6 Marpha palaeolacustrine Formation, Thakkhola area, Kali Gandaki valley (from Fort 1980). (Note that the distances are not to scale)
a) section of lacustrine sediments observed south of Marpha (right bank of the Kali Gandaki). Calcareous silts and fine sands are predominant. The sediments are thinly layered, with a few coarser detrictic inputs from the slopes at the origin of intraformational slumps. The top of the section (end of the lake filling) has been reworked by colluvial and alluvial deposition.
b) Series of sedimentary facies laterally prograding in lacustrine silts, as observed along the valley of Jhong khola (a left bank, tributary of Kali Gandaki), upstream Kagbeni : till, glacio-fluvial, deltaico-lacustrine and lacustrine facies.
c) Recent dissection of the lacustrines deposits, north of Syang. Five thin alluvial accumulations are stepped (cut-and-fill) in the former lacustrine sediments, underlying terraces levels. The basal breccia represent the Syang Formation, interpreted as consolidated till material which might belong to an early stage of the Last Glacial.

culminating around 6500 m. Four glacial stages have been individualized (Iwata et al. 1982, Fort1980), namely the Thorung III, II, I (=Tukuche), and Dzong (=Khingar) stages (names in bracket refer to Iwata's terminology). Both authors agree on considering that the two first stages are probably Holocene in age, while the two other stages have been respectively attributed either to the late and early stages (Iwata 1984) or to the late and middle stages of the Last Glaciation (Fort 1993). In Iwata's hypothesis, Syang till (Fig. 6c) is thought to predate the last Intergla-cial, whereas it is more likely that it belongs to an early stage of the Last Glaciation.

Other tributary valleys of the Kali Gandaki, such as the Shokang and the Langpoghyun valleys (north flank of the Nilgiri Peak, 7223 m), present a similar succession though it is less clearly preserved down-stream due to later reworking of glacial remains by catastrophic, glacially-derived, debris flows issuing from the steep north face of Nilgiri North. The topo-graphic conditions for glaciation may sometimes impose strong influence on ice extent and morphol-ogy, as shown in the Chokopani watershed, a left bank tributary of the Kali Gandaki (Fig. 7). Fig. 8 indicates the limits of reached by the glaciers during the Last Maximum.

Additional information is provided by the mid-dle reach of the Kali Gandaki valley, just across the Greater Himalaya. A few remains of older till mate-rial (identified on the basis of their petrographic con-stituents, and clearly attributed to formerly glaciated ridges) are preserved, perched above the main ter-race level of the Kali Gandaki (Fig. 8) : on the flat ledge (+400 m) NE of Dhumpu (left bank of the Kali Gandaki), and on the spur between Kaiku and Ghasa (right bank of the Kali Gandaki). These are accom-panied by consolidated glacio-fluvial gravels, which can be traced discontinuously from the north of Kaiku down to the confluence of the Miristi Khola, at Banskot, Narcheng and above Dana (about +600-650 m relative to the present Kali Gandaki bed). Without doubt, a major phase of dissection has fol-lowed their deposition, confirming their status as remains of a former, undated glaciation.

2) The large northern valleys, which slope gen-tly down to the semi-arid high Tibetan plateau (about 4500 m), are important areas where the most exten-sive and longest records of glacial remains have been observed so far. Detailed studies by Chinese scien-tists have inferred the existence of three to four qua-ternary glaciations in the northern side of Xixabangma-Everest (Table 1) (Shi and Liu 1964, Li et al. 1979, Shi et al. 1986, Zheng 1988, 1989a). There is general agreement on the extent of the LGM moraines and on the related Late Pleistocene ELA lowering, estimated ≤450 m (Williams 1983, Osmaton 1989, Burbank and Kang 1991, Fort and Dollfus 1992).

In these areas, evidence for older glaciations is limited to the highest areas (>7000 m). Recently, the classical chronology has been partly rejected on the grounds of the imprecise diagnosis of glacial related sediments. Glacial diamicton allows possible con-vergent characteristics with syntectonic types of de-posits (cf. with Gongba conglomerates; Fort 1989), with periglacial debris-flow (Osmaston 1989) and with mass-wasting features; (Burbank and Kang 1991). Nevertheless, despite these uncertainties, true glacial remains certainly exist (see the discussion), indicating an interplay of true climatic parameters and tectonic/orographic parameters. North of Xixabangma, the oldest glacial evidence (the "morainic plateau") lies perched above the remains of more recent valley glaciers (Shi and Liu 1964, Zheng 1988), and the relative palaeo-snowline has been lifted above the modern one (Shi and Liu 1964). These facts can be interpreted as evidence of Himalayan uplift with respect to Tibet, addi-tionally demonstrated by the northward tilting of the Plio-Pleistocene Thakkhola-Mustang graben filling (Fort et al. 1982).

3) To date, little work has been carried out in the northernmost, isolated massifs. These areas (Mus-tang, Lhagoi Kangri, Zangma...), nowadays very dry and little glaciated (present ELA around 6000-6200 m), display on satellite images a characteristic gla-cial morphology of cirques and U-shaped valleys. In fact, most of these massifs have been identified as former independant centres of glaciation (small ice-caps) from which glacial outlets radially flowed down and deposited frontal moraines, these latter being thought to belong to the Last Glacial (Williams 1983;

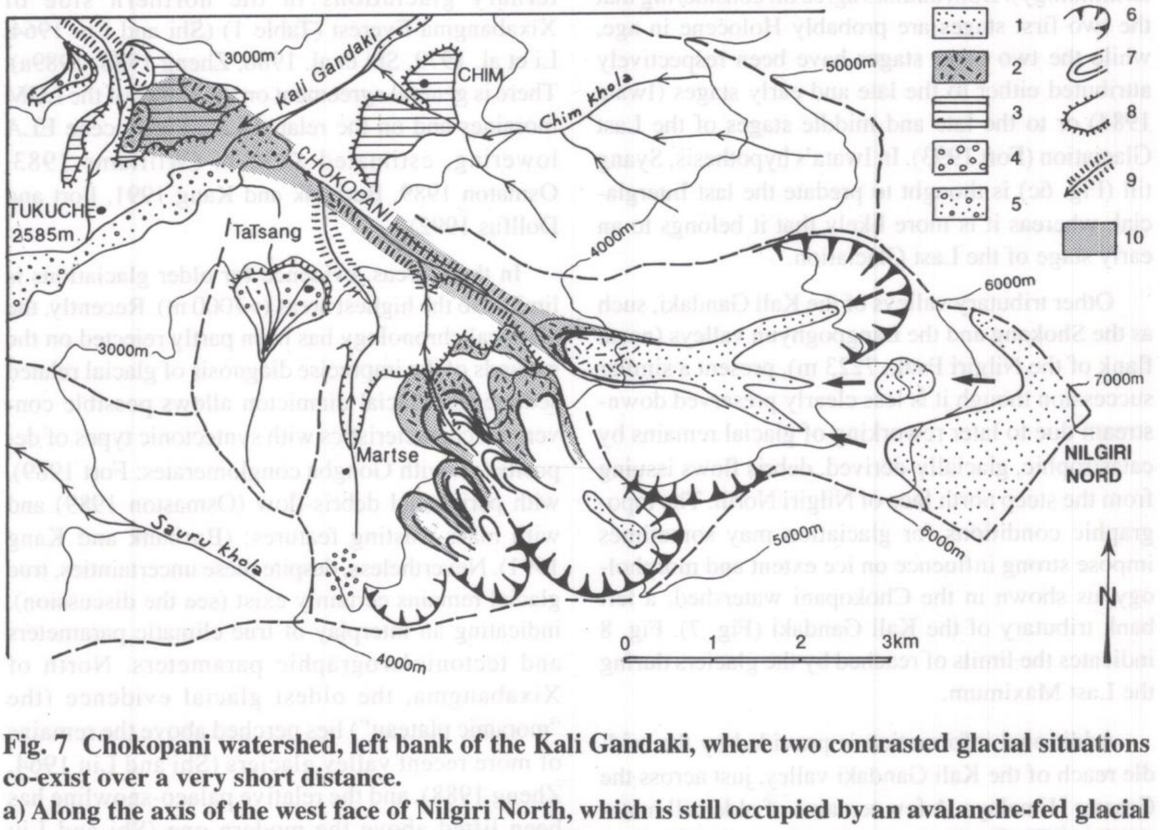

Fig. 7 Chokopani watershed, left bank of the Kali Gandaki, where two contrasted glacial situations co-exist over a very short distance.
a) Along the axis of the west face of Nilgiri North, which is still occupied by an avalanche-fed glacial tongue; Late Pleistocene, glaciers flowed directly down the Chokopani gorge across the Kali Gandaki valley bottom (4 km distant only). They deposited the frontal moraines that are now emerging as hills above the middle terrace level (debris-flow material) of Tukuche (2500 m).
b) Along the WSW oriented spur (alt. decreasing from 6000 m to 4000 m) branching out of the Nilgiri West peak, three small, formerly glaciated cirques are well preserved on the north side of this spur. They are externally bounded by a series of arcuated frontal moraines resting upon a rocky ledge (3900 m) which overlooks the Chokopani gorge. We have related the outer morainic crests to the Last Glacial Maximum (cf. brown podzolic, 50-cm-deep, soils). No glacial evidence can be found where the spur lowers below 4200 m; we therefore consider this altitude as a good approximation of the local glaciation limit during the LGM.
The large difference in altitude reached by the two types of glaciers during the LGM influences consequently the reconstructed ELA values : along the main Chokopani valley, the LGM ELA was 730 m lower than the present one (5200 m), whereas in the cirques it was 430 m lower only.
1. Present glaciers; 2 : till attributed to the Last Glacial Maximum; 3 : +150 m and +100 m terraces; 4 : +400 m cones and terraces; 5 : Kali gandaki flood plain; 6 : glacial cirques; 7 : morainic ridges; 8 : terrace edge; 9 : gorges; 10 : reconstructed LGM advance of the Chokopani glacier, descended from the Nilgiri North.

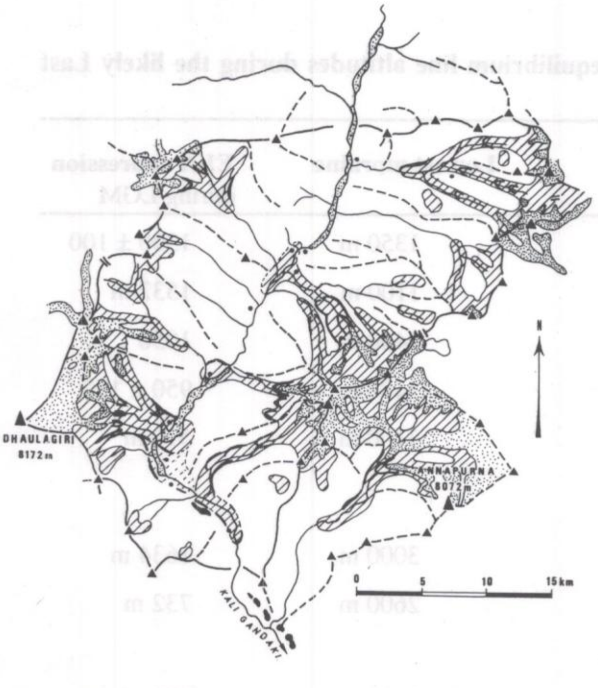

Fig. 8 Present (stippled) and Late Pleistocene (hatched) Glacial extent in the upper Kali Gandaki valley.

Armijo et al. 1986). Field evidence suggests the glacial advance did not expand far beyond the foot of these reliefs (Armijo et al. 1986, Fort and Dollfus 1992), thus giving an ELA depression estimated to be about 400 m ±100 m. In these areas also, the role of recent uplift cannot be omitted, since most of these massifs are active-fault bounded ; any deposit produced by an older, larger glaciation would therefore have accumulated in the adjacent graben, as recognised in the Thakkhola-Mustang graben (Fort, unpubl.).

DISCUSSION

The preceding account draws attention to the following points : the outer limits reached by the Last Glacial extent, the variations of this extent compared to the reference frame (Fig. 1), and the evidence for the former glaciation.

LAST GLACIAL EXTENSION

A strong contrast exists between the northern and the southern faces of the Himalaya. On the southern slopes, the glaciers thought to belong to the Last Glacial Maximum were able to reach relatively low altitudes, particularly in those cases where their source massifs were at high altitudes, where preexisting valleys were well developed and where the mountain front lay close to basin areas (Fig. 9B). The southern glaciers of Annapurna are perhaps the most extreme example displaying a topographic drop of >6000 m over 35 kms. More generally, these considerations lead us to assume that any glacial evidence found in the present valley bottoms can be attributed to the former stages of the Last Glaciation rather than to older glaciations (see below).

On the northern slopes, the degree of dissection being lower, the dominant factors controlling appear to have been the altitude of the surrouding ridges/ summits together with the surface of upper terraines situated above the snow-line. This explains the exceptional glacial succession recorded in the Xixabangma-Mt Everest area (Fig. 9D).

GRADIENT OF GLACIATION

The depression value (= difference between the present and former ELAs values) is quite variable depending on the chosen area (Table 2) : high to the south of the Annapurna (>1300 m), intermediate (about 950-1000 m) in isolated massifs (Taunja or Shorung), and low (500-00 m) in internal valleys. Further to the north, it lowers even more (400 ±100 m). The intermediate values correspond to an average and accord with values obtained in other parts of the Himalayan Range (Paffen et al. 1956, Porter 1970, Burbank and Fort 1985). They can be considered as climatically significant. Variations from the average can be explained by several factors : (i) the general dryness gradient which can be observed all along the Himalayan Range and which steepens when crossing over the Himalayan crest (Williams 1983), (ii) a high number of avalanche-fed glaciers, which tend to increase the ELA depression value (Chokopani example) (Fig. 9C), (iii) the amplitude of the topogradient and the degree of dissection of preexisting valleys, which also tends to increase the ELA depression values (as observed in the south flank of Annapurna, or the West face of Nilgiri).

Table 2 : Available data on lowest moraines and equilibrium line altitudes during the likely Last Glacial Maximum

Author	Area	Lowest moraine	ELA depression during LGM
Fort (1993)	Seti khola	1350 m	1300 ± 100
Kuhle (1982)	south Dhaulagiri	1100 m	1532 m
Williams (1983)	east Shorung Himal	3400 m	1050
Fort (1993)	west Shorung Himal	3480 m	950 ± 150
Fort, from the interpretation of Shirauwa and Watanabe's data (1991)	Langtang	3100 m	510 m
Kuhle (1982)	north Dhaulagiri	3000 m	1634 m
Fort (unpubl.)	southwest Nilgiri	2600 m	732 m
Fort (unpubl.)	south Chokopani		
West Nilgiri		2600 m	730 m
Fort (unpubl.)	Martse	3900 m	432 m
Fort (unpubl.)	Muktinath valley	3900 m	650 m
Burbank and Kang (1991)	Rongbuk valley, north Everest	3100 m	≥450 m

FORMER GLACIATION

Evidence for former glaciation is either quite rare or very contentious. However, there is no serious reason to think that the Himalayas were not glaciated during the Quaternary. In fact, at the beginning of the Quaternary, the Tibetan Plateau had already reached an altitude close to its present one, as it has been confirmed by various studies, based on tectonic controls and physical constraints (Armijo et al. 1989, Harrison et al. 1992 1993, Molnar et al. 1993), on records of Himalayan molassic sediments (Curray 1991, 1994; Copeland and Harrison 1990), on variations in the mineralogical and chemical composition of oceanic waters (Edmond 1992, Richter et al. 1992), and on loessic sedimentation of Central China (Liu 1985, Kukla 1987, An et al. 1990, 1991, Rutter et al. 1991). The general cooling which characterized the climates of the last 3 Myr (Savin 1977, Shackleton and Opdyke 1993) also affected the Tibet-Himalaya ensemble. In these regions, the Quaternary climatic changes also varied according to the global, planetary scheme.

As a consequence, there is no doubt about the existence of older glaciations in the Himalayas. Presently, the question is not so much about the number of glacial ages than about their age and the probability of remains being preserved. On the south slopes, these remains are very frequently reworked by dissection and/or mass-movements. When they are preserved, however, they should probably be sought in a perched position rather than in the bottom of the present valleys (cf. in the Kali. Gandaki valley, Fig. 9F). On the northern slopes, the situation is more complex. The continuous uplift of the Great Hima-

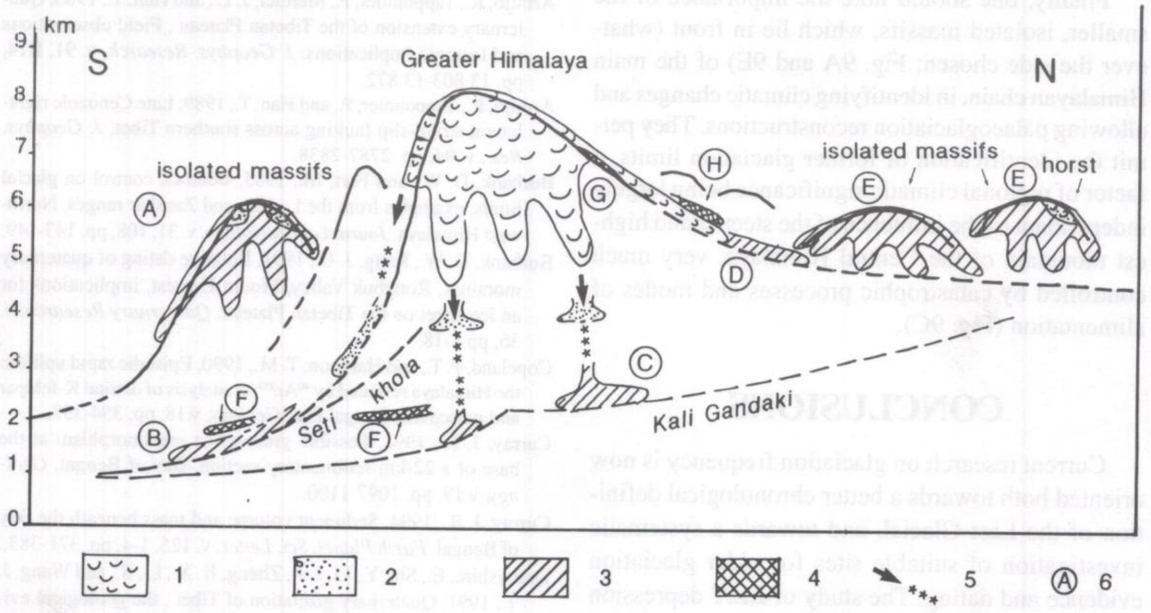

Fig. 9 Various configurations (synthetic) of present and Late Pleistocene glaciation across the Greater Himalaya : a key to assess older glaciation evidence and dating.
1 : present glaciers; 2 : avalanche-fed, present glaciers; 3 : extent of Late Pleistocene glaciers; 4 : older glacial remains (either perched or buried); 5 : avalanche tracks, and Late Pleistocene avalanche fed glaciers. A,B,... mains types of glaciation configurations : A : isolated massifs on south side, the best climatically sensitive areas, also allowing assessment of former glaciation limits; B : glacial tongues in very deeply dissected valleys, derived from avalanche inputs, reconstructed ELAs abnormally low ; C : avalanche-fed glaciers : the lowest altitudes are controlled by the steep topography; D : high altitude and low dissection on north slope : ice tongue can expand, with the dryness as a limiting factor; E : isolated massifs on north side, also good indicators for glaciation (same as A); E' correspond to horst; F : perched remains of glaciation (continuous uplift of the Greater Himalaya), to be sought above the present valley bottoms; G : buried older glacial remains (the continuous uplift causing the expansion of more recent glaciation to overide the limits of the former ones); H : perched remains of glaciation (same as F, but on north slope), to be sought upon the deglaciated interfluves

laya with respect to the adjacent Tibetan plateau during the Quaternary has generally caused the overriding, and/or the erosion, of older glaciogenic deposits by more recent ones (Fig. 9G). Because of further entrenchment by more recent glaciation, only at the foot of the highest peaks (>7000 m) which fed the largest ice bodies, could the glacial remains have been preserved in the interfluves. In such cases, they also appear in a perched position (cf. Xixabangma area) (Fig. 9H).

Finally, one should note the importance of the smaller, isolated massifs, which lie in front (whatever the side chosen; Fig. 9A and 9E) of the main Himalayan chain, in identifying climatic changes and allowing palaeoglaciation reconstructions. They permit the identification of former glaciation limits, a factor of regional climatic significance being largely independant of the influence of the steeper and highest mountain of the Central Himalaya, very much controlled by catastrophic processes and modes of alimentation (Fig. 9C).

CONCLUSIONS

Current research on glaciation frequency is now oriented both towards a better chronological definition of the Last Glacial, and towards a systematic investigation of suitable sites for older glaciation evidence and dating. The study of ELA' depression with respect to older glaciations should indirectly lead to an improved assessment of the extent of the Greater Himalayas' elevation for a given period, this elevation being a forcing parameter on monsoon fluctuations, and on the nature and the intensity of erosion affecting the Himalayan reliefs; issues which are at the heart of current debates.

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