The Quaternary glacial history of the Lahul Himalaya, northern India

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ABSTRACT: This paper presents the first glacial chronology for the Lahul Himalaya, Northern India. The oldest glaciation, the Chandra Glacial Stage, is represented by glacially eroded benches at altitudes greater than 4300 m above sea-level. This glaciation was probably of a broad valley type. The second glaciation, the Batal Glacial Stage, is represented by highly weathered and dissected lateral moraines, which are present along the Chandra valley and some of its tributaries. This was an extensive valley glaciation. The third major glaciation, the Kulti Glacial Stage, is represented by well-preserved moraines in the main tributary valleys of the Chandra valley. This represents a less extensive valley glaciation. Two minor glacial advances, the Sonapani I and II, are represented by small sharp-crested moraines, which are within a few hundred metres or few kilometres of the present-day glaciers. The change in style and extent of glaciation is attributed to an increase in aridity throughout the Quaternary, due either to global climatic change or uplift of the Pir Panjal mountains to the south of Lahul, which restricted the northward penetration of the south Asian summer monsoon.

Journal of Quaternary Science
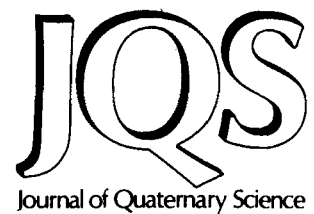
Introduction

The Himalayas and Tibetan Plateau have attracted much attention in recent years through the debate on the likely role of late Cenozoic uplift of the central Asian mountains in driving regional and global climate change during late Tertiary and Quaternary times (Ruddimann and Kutzbach, 1989; Prell and Kutzbach, 1992). In addition, the mountains of the western and central Himalayas and the Karakoram Mountains comprise the greatest concentration of glaciers outside of the polar regions. This makes the area particularly important in understanding environmental change with reference to the nature and timing of glacier fluctuations. Data associated with this are extremely important to global climate modellers, who need to consider albedo changes, weathering rates and meltwater fluctuations associated with the growth and decay of glaciers during the Quaternary in order to construct reliable models of climatic change. Accurate reconstructions of former glaciers are also important in resolving the contentious argument over the former extent of ice cover across the Tibetan Plateau and the adjacent Himalayas throughout Quaternary time (Zheng Benxing, 1989b).

   Despite these important issues little research has been undertaken on the nature of palaeoenvironmental change

within the high mountains of the Himalayas of northern India. Previous work has been concentrated in the Karakoram Mountains in Northern Pakistan (Derbyshire et al., 1984; Owen, 1989; Shroder et al., 1993), Kashmir (Holmes and Street-Perrott, 1989, Holmes, 1993), the central Himalaya in Nepal (Fort et al., 1981; Burbank and Kang, 1991) and the Tibet Plateau (Zheng Benxing, 1989a; Li Jijun et al., 1979). In this study, evidence is examined for palaeoenvironmental change in the Lahul Himalaya, Himachal Pradesh, North India (Fig. 1). This is an important area in palaeoenvironmental research because it marks the junction between the monsoon-influenced southern flank of the Pir Panjal (Lesser Himalaya) and the Greater Himalaya, and should therefore contain geological and geomorphological evidence for fluctuations in the northern limit of the south Asian palaeomonsoon through time. Furthermore, the area has undergone significant change in topography owing to uplift of the Pir Panjal during the Pleistocene, which may well have a control on environmental conditions. Well-preserved glacial landforms and sediments in the northern part of this region and along the lower valleys provide evidence for at least three major glaciations. In this paper, the styles and extent of glaciation are discussed, tentative correlations provided and theories for the changing styles of glaciation are examined.
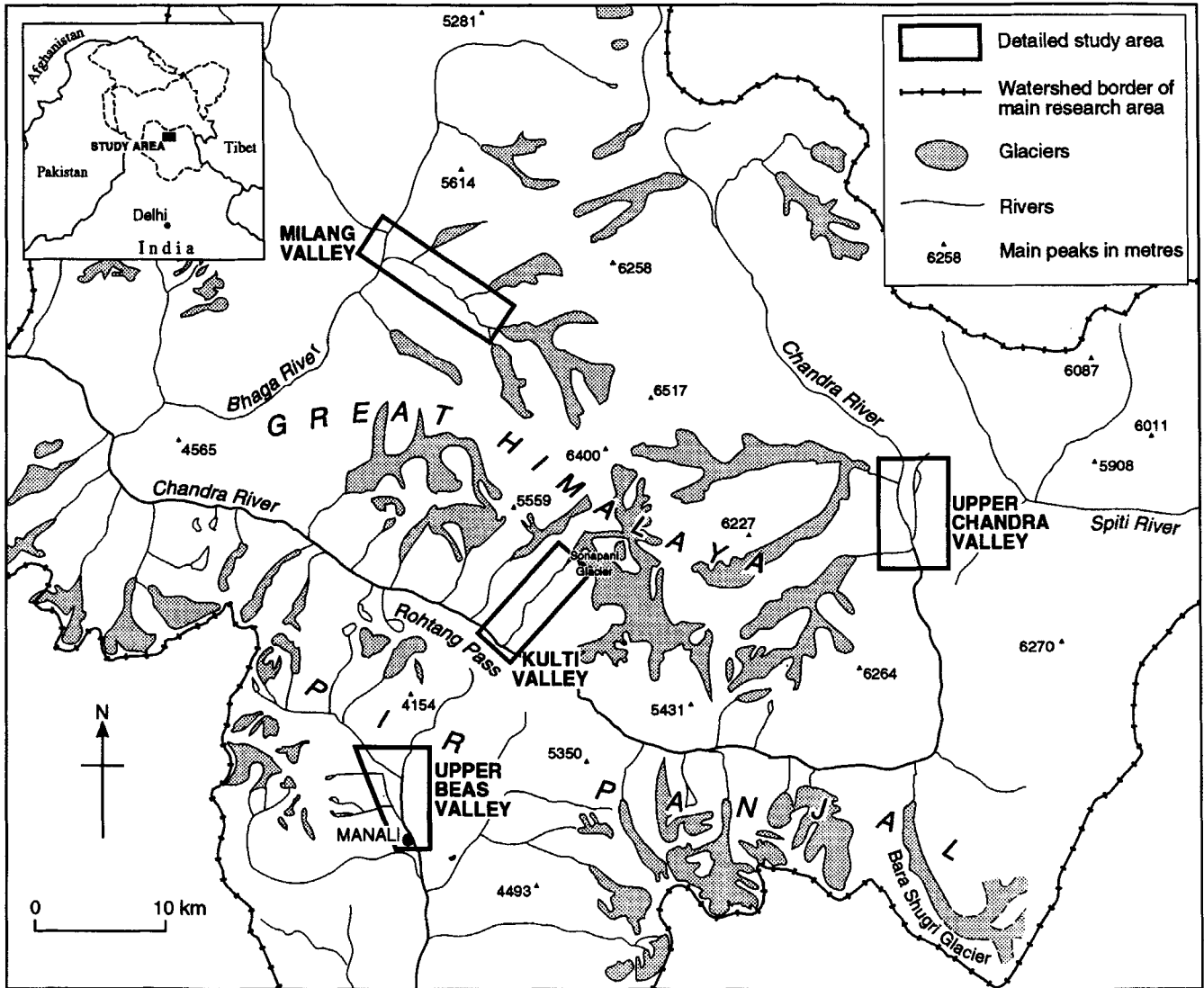
Figure 1 Location map of study area.

Geomorphological setting

The geomorphological background to this region is discussed in detail in Owen et al. (1995). The region comprises two mountain ranges, the Pir Panjal and the Great Himalaya, which trend NW–SE. The area is drained by the Chandra River, which flows south and then turns northwest near the Bara-Shugri Glacier, where it divides the Pir Panjal from the Great Himalaya (Fig. 1). The climate varies from the monsoonal influenced southern slopes of the Pir Panjal to semiarid valleys on the northern slopes of Pir Panjal and in the Great Himalaya.

The climate is dominated by a long winter season from mid-November to March, with a spring season that lasts until the end of May. Summer extends to the end of September, with October and early November being a short autumn season. Little data are available on precipitation, but Mamgain (1975) suggested that most of the precipitation falls as snow in winter north of the Pir Panjal with little during the monsoon months from June to September. On the southern slopes of the Pir Panjal there are heavy snow falls during the winter and intense heavy monsoon rains fall during July and August. Precipitation, however, is strongly controlled by aspect and altitude. The permanent snowline is above 4260 m, although the

lower limit of the snowline on the southern slopes of the Pir Panjal reaches as low as 1500 m (Sharma, 1986).

Vegetation varies with altitude, ranging from forest characterised by Juniperus, Pinus, Betula, Salix, Populus, Picea and Pyrus on the southern slopes of the Pir Panjal and in the lower reaches of the valleys north or the Pir Panjal, to alpine vegetation at altitudes of between 3550 and 4850 m. There is little vegetation above 4850 m.

The geomorphological system is dominated by steep, high-activity glaciers, which carry large amounts of supraglacial debris. The glacier margins indicate recent ice retreat, with complex moraine systems down-valley of the present-day terminal zone (Owen et al., 1995). Mass movements, particularly talus development and landsliding, have produced major remodifications of landforms within the area and paraglacial processes are regarded as an extremely important landscape-forming process (Owen et al., 1995).

Methods

Mapping

Detailed base maps and aerial photographs are not available for this region. The best maps are at a scale of 1 : 250 000

Table 1 Tentative glacial chronology for the Lahul Himalaya compared with adjacent regions. Note that there is little or no dating control on these chronologies and dates that have been obtained are highly suspect because of reworking (cf. Owen et al. 1992) and glaciotectonism (cf. Owen and Derbyshire, 1988; Owen, 1989)

	Glacial Non-glacial		Lahul	Middle Indus-Gilgit-Hunza Valleys			Upper Indus	Zanskar	Swat Kohistan	Tentative Dates
Series	Stage	Stade	This Study	Derbyshire et al. (1984)	Shroder et al. (1993)	Zhang & Shi (1980)	Cronin (1982)	Osmaston (pers comm)	Porter (1970)	Years
Holocene			Sonapani Sonapani I	Pasu II Pasu I Batura	Historical Little Ice Age Neoglacial	Historical Little Ice Age Neoglacial	Individual Moraines	Drang-drung Neoglacial	Neoglacial	-10^2 -10^3
										-10^4
Pleisto-cene	Late glaciation		Kulti	Ghulkin II Ghulkin I Borit Jheel	Darel-Shatial Moraine Dainyor Moraine	Hunza Glaciation		Tepuk Glacial	Kalam Glaciation Late Stage Kalam Glaciation Intermed. Stade Kalam Glaciation Early Stade	-10^5
	M-L IG.				Valley Fill III		? Strong Erosion Alluviation	Thonde Glacial	Gabral Glaciation Late Stade	
	Middle glaciation	Late Stade Early Stade	Batal	Yunz	M2 Tills Valley Fill II M1 Tills	Yunz Glaciation	Satpura Till ? Valley Fill	Kilima Glacial	Gabral Glaciation Early Stade	
	E-M Inter G. Early glaciation		Chandra	Shanoz	Upper Jalipur Valley Fill I Lower Jalip. Till	Shanoz Glaciation	Bunthung Till		Laikot Glaciation	-10^6

(U502 Series) but they lack detail and are often unreliable. For example, the largest glacier, the Bara Shugri, is not shown on these maps. Base maps were constructed for selected valleys using reconnaissance survey techniques and a global positioning system (GPS) (Figs 2–4). A variety of scales were used, ranging from 1 : 10 000 to 1 :1000, in order to map moraines and important landforms.

Sedimentological analysis

A land-systems approach (Eyles, 1983), together with the detailed examination of available exposures, was used to distinguish sediments and landforms of different origins. The distinction between glacial and non-glacial diamicts proved particularly important in making accurate reconstructions of former ice positions. The criteria used to distinguish different types of diamict are discussed in Owen (1994).

Dating

No absolute dates are available for this region because there is an absence of fossils, artefacts, organic material for radiocarbon dating and sediments appropriate for palaeomagnetic dating. Therefore a relative chronology was established using morphostratigraphy, weathering criteria, rock varnishes, soil development, vegetation development and lichenometry. The main characteristics of each set of moraines are described in the sections below, along with details on the lichenometry.

Glaciations

Three major glaciations (the Chandra Glacial, the Batal Glacial and the Kulti Glacial) and two glacial advances (Sonapani I and Sonapani II) were identified on the basis of morphostratigraphy, weathering criteria, vegetation and soil development. Each will be discussed in turn from oldest to youngest. The chronology is listed in Table 1 and compared with chronologies for adjacent regions.

Chandra Glaciation

Evidence for this glaciation can be found along the upper Chandra valley near Chandra Tal and the North Dakka glacier. At altitudes above 4300 m a.s.l. (over 100 m above the present valley floor) rock benches are present, which have been glacially eroded to form extensive broad surfaces (Fig. 5) that can be traced across the upper Chandra valley (Fig. 6). Small outcrops of rock have whaleback and roche moutonnée forms. The rock surfaces have deeply abraded and well-preserved glacial striations. Deep, well-developed red-brown rock varnish is common on all these surfaces (Fig. 7). Immediately south of Chandra Tal the rock benches have striations that trend NW–SE, probably indicating the streaming of ice along the precursor Chandra valley during a broad valley glacial phase. Till veneers and blankets were also deposited at this time up to 4600 m in the Kunzon La (Pass) Therefore glacier ice almost inundated the local topography, leaving a few of the higher summits as nunataks.

Such extensive glaciated surfaces have not been identified in the southern part of Lahul and probably represent a glaci-
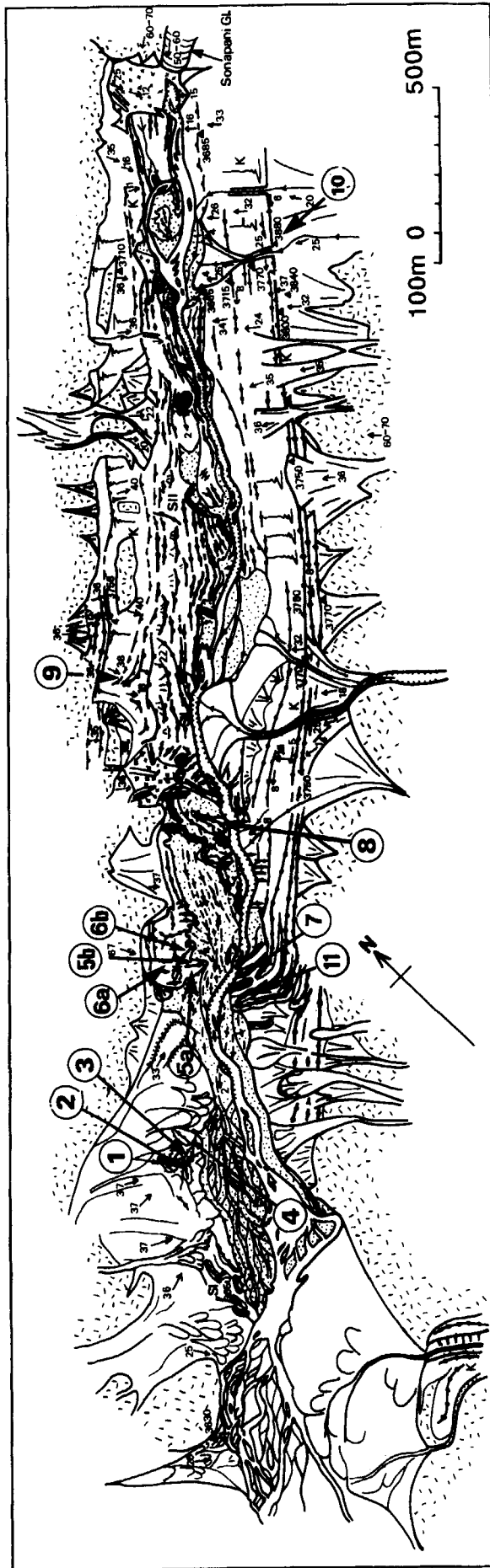
Figure 2a Geomorphological map showing the Quaternary moraines for: (a) the upper Kulti valley; (b) the lower Kulti valley. Note (a) and (b) overlap. K, Kulti Glacial moraines; SI, Sonapani Advance I moraines; SII, Sonapani Advance II moraines. Numbers enclosed by circles refer to lichen sites.
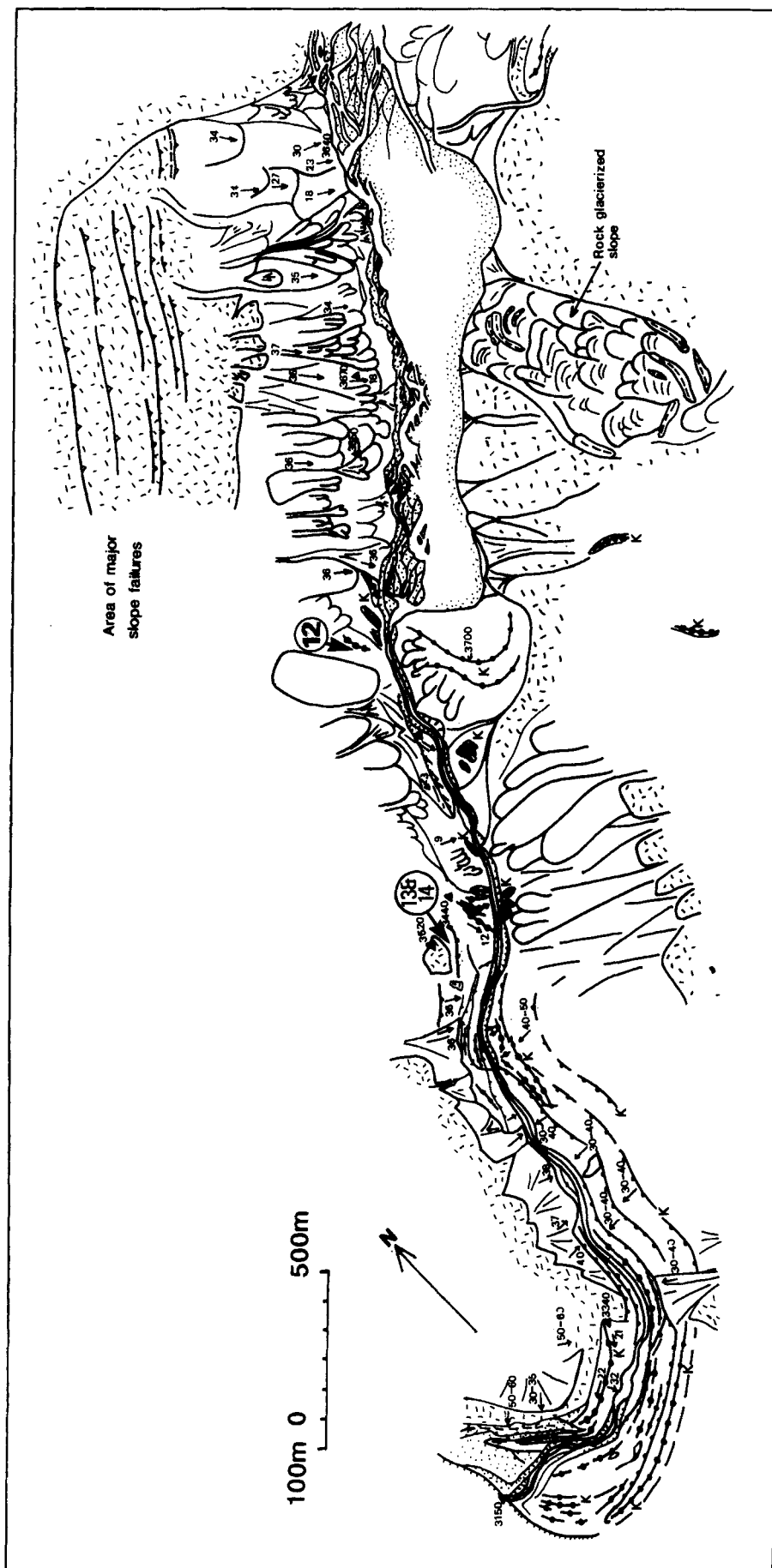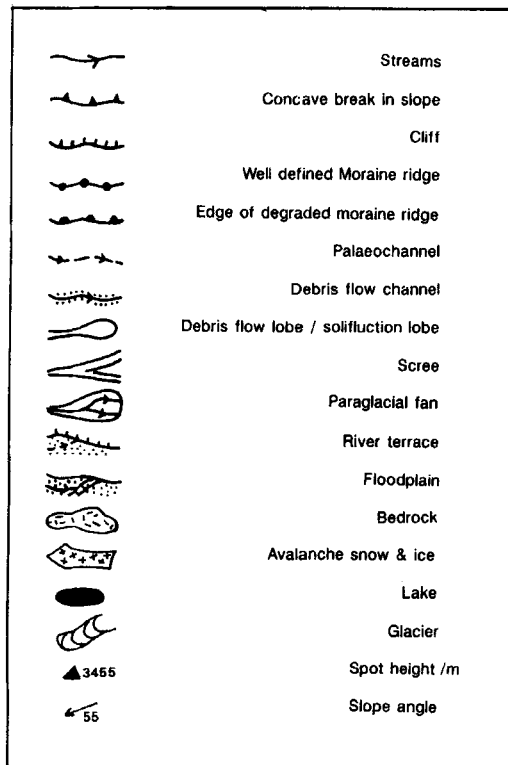
Figure 2b

~~	Streams
~~	Concave break in slope
~~	Cliff
~~	Well defined Moraine ridge
~~	Edge of degraded moraine ridge
~~	Palaeochannel
~~	Debris flow channel
~~	Debris flow lobe / solifluction lobe
~~	Scree
~~	Paraglacial fan
~~	River terrace
~~	Floodplain
~~	Bedrock
~~	Avalanche snow & ice
●	Lake
~~	Glacier
▲3455	Spot height /m
◄55	Slope angle

Figure 2c

ation of broad valley type that pre-dates the incision of the Chandra River to its present level.

Batal Glaciation

This glaciation is represented by highly weathered and dissected lateral moraines and paraglacial deposits that reach over 100 m in thickness. They are best preserved near Batal on the east side of the upper Chandra valley (Figs 8 and 9), along the north side of the Chandra valley between Kulti and Khoksar valleys and in the lower Milang valley (Figs 3 and 6). Opposite the Batal Glacier, the Batal Glaciation ice margin is dominated by a kame terrace at 4000 m. Hummocky lateral moraines also exist at 4000–4015 m on the east side of the Chandra valley at a point just south of the North Dakka Glacier tributary valley.

These landforms and deposits represent an extensive valley glaciation that deepened the river valleys, cutting into the Chandra glacial surfaces. At many locations, the Batal Glacial moraines have been eroded and resedimented by mass movement processes or have been transformed into rock glaciers (Fig. 10). The maximum advance of the Batal Glaciers is difficult to determine because of the fragmented remains of the moraines, but ice probably extended all the way down the Chandra and Bhaga valleys to at least their confluence at Tandi. The maximum extent down the Chandra valley northwest of Tandi awaits further investigation.

Kulti Glaciation

Evidence for this glaciation is found in most glaciated valleys in Lahul. It is represented by numerous well-preserved lateral and end moraines (Figs 9, 11 and 12). Boulders on these moraines have well-developed varnishes, and at low elevations are covered by mature vegetation. Figures 2 and 3 show the style and nature of Kulti Glacial moraines in the Kulti and Milang valleys. A series of well-developed moraine ridges can be traced in most tributary valleys, representing successive advances and retreats of valley glaciers. Within the Kulti valley a large recessional moraine (Fig. 13) is present, which has partially blocked the valley and allowed an extensive braidplain to develop up-valley (Fig. 2A and B).

These moraines can be traced a maximum distance of 12 km beyond the snouts of the present glaciers. On the basis of the height of these moraines, the ice was approximately 60 m thicker than at present. Where glaciers advanced into the main valleys (e.g. where the Sonapani glacier advanced into the Chandra valley, and where the Koa Rong Chu glacier advanced into the Milang valley) the valleys were partially blocked, diverting the main rivers and forming small glacial lakes (Fig. 3). At the mouth of the North Dakka valley a delta prograded into the lake produced by the advance of the Batal Glacier. This has an elevation of approximately 3960 m, with well-developed shorelines existing at the same altitude.

Moraines in the upper Beas valley are correlated tentatively with this glaciation on the basis of well-developed vegetation, weathering and their well-preserved morphology (Fig. 4). The moraines are best developed at Solang on the south side of the Solang valley, where a ridge 1 km long trends NNW–SSE and reaches 100 m above the present valley floor. Similar ridges are present along the Palchan valley, and a N–S trending moraine ridge, 250 m long and 30 m high, forms an inlier within the alluvial fan near Kulang (Fig. 14). This moraine has the lowest altitude in the Beas valley (2500 m). Glacially eroded bedrock can be traced up the upper Beas valley to sharp-ridged moraines within cirque-like basins above the Rohtang Pass. This suggests that ice flowed down from the Rohtang Pass as well as from the present glacial valleys of the upper Beas valley. On the basis of these moraines, we consider that glaciers probably extended no more than 12 km from their present position throughout the region.

Sonapani glacial advances

Sharp-crested moraines representing at least two glacial advances can be recognised within 5 km of the present glacier snouts. These have sparse vegetation, small lichens and poorly developed rock varnishes. In the Kulti valley two distinct sets of moraines were mapped and distinguished on the basis of relative dating (Fig. 2). The older moraines can be traced 4.3 km down-valley from the present snout of the Sonapani Glacier. These are attributed to the Sonapani I glacial advance. A younger group of moraines can be traced 2.75 km down-valley from the snout of the Sonapani Glacier and these are attributed to the Sonapani II glacial advance. Photographs published by Walker and Pascoe (1907) show that the Sonapani Glacier was within a few hundred metres up-valley from the lowest Sonapani II glacial moraines in 1905 (Fig. 15). Since then the Sonapani Glacier has retreated approximately 2.6 km, an average annual retreat of 29.5 m yr^{-1}, to a prominent rock bar on which there is now an impressive ice fall, with a vertical drop of 150 m. The present position of the glacier is thus constrained by ice avalanching. Post-1905 moraines contain buried ice and those on the valley sides are slowly slumping towards the centre of the valley.

Landforms and sediments associated with the Batal Glacier provide good geomorphological evidence that can be correlated with these advances (Fig. 16). Lateral moraines formed
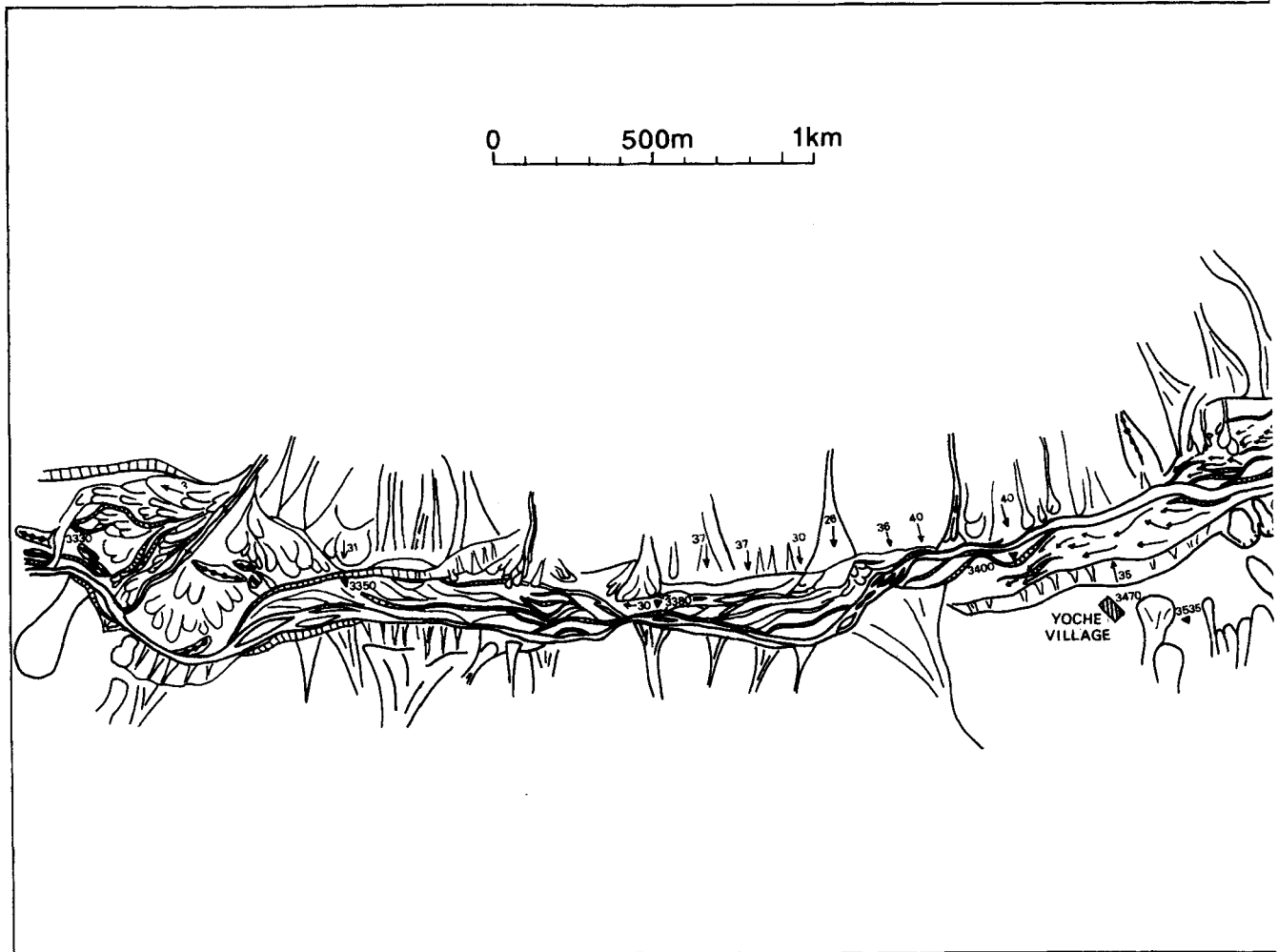
Figure 3   Geomorphological map of the Milang valley showing the Quaternary moraines. K, Kulti Glacial moraines; S, Undifferentiated Sonapani I and Sonapani II moraines. The key to the geomorphology is shown in Fig. 2. Letters enclosed by circles refer to lichen sites.

during the Kulti Glaciation trend southwards along the upper Chandra valley, although the easternmost moraine is associated with a landslide block and probably transported the moraines on the landslide. Two main sets of sharp-crested moraines are inset within the Kulti moraines, and these trend eastward across the valley. These clearly can be related to the present Batal Glacier, and may be correlated with the Sonapani I and II glacial advances. A younger set of moraines are inset into the older moraines but they are higher in elevation. This suggests that ice thickened more during the Sonapani II advance because the Sonapani I moraines restricted lateral ice flow. Unfortunately, it is not possible to trace in detail the extent of these moraines down-valley because of extensive erosion by the Chandra river. A third set of moraines is inset within the Sonapani II moraines. These form a small end moraine approximately 400 m from the present snout of the Batal Glacier. This may be attributed either to a third advance or it may be a recession stage during the Sonapani II. Fresh moraines are also found within a few hundred metres of the Koa Rong Chu and Mulkilla glaciers (Milang valley).

Lichenometry

On the basis of a reconnaissance traverse across the Kulti valley, a lichen, subsequently identified as belong to the genus *Aspicilia* (V. Winchester, pers. comm.), was found to the have

a down-valley gradient in its mean diameters. Figure 17 summarises the data obtained from the Kulti valley. Both the graphs of lichen diameters on boulder surfaces of different aspect (Fig. 17a) and the mean maxima and minima lichen diameters (Fig. 17b) show three clear populations: (i) sites 12, 13 and 14 some 6.5 to 7.5 km downstream of the Sonapani Glacier (and regarded as the retreat moraine of the Kulti Stage) (Fig. 2); (ii) sites 5–11 (but excluding 10) lying between 2 and 3 km from the glacier; and (iii) sites 1–4 and site 10. Site 10 is located on the highest lateral moraine remnant on the southeastern valley-side about 1.2 km below the Sonapani Glacier: it is clearly contemporaneous with the end moraine series sampled at sites 1–4 inclusive, its slightly smaller lichen diameters probably reflecting its distinctly higher altitude (3820 m). The sharp break in mean lichen diameter values between sites 4 and 5 (Fig. 17b) marks the change from Sonapani I to Sonapani II moraines.

The evidence is not so clear-cut in the Milang valley, where the data consist of only maximum and minimum lichen diameters from three sites on moraines considered, on morphological grounds, as dating from the Kulti Stage, and from two sites on a rock glacier about 1.5 km down-valley of these moraines (Figs 3 and 18). The maximum diameter values for the lateral moraines (LM series on Fig. 18) are similar to absolute maxima for sites 12–14 in the Kulti valley, interpreted as a retreat series of the Kulti glaciation. Lichen diameters for the up-valley site (M1 series), however, are distinctly smaller, being comparable to those for the moraines of Sonapani I age in the Kulti valley.
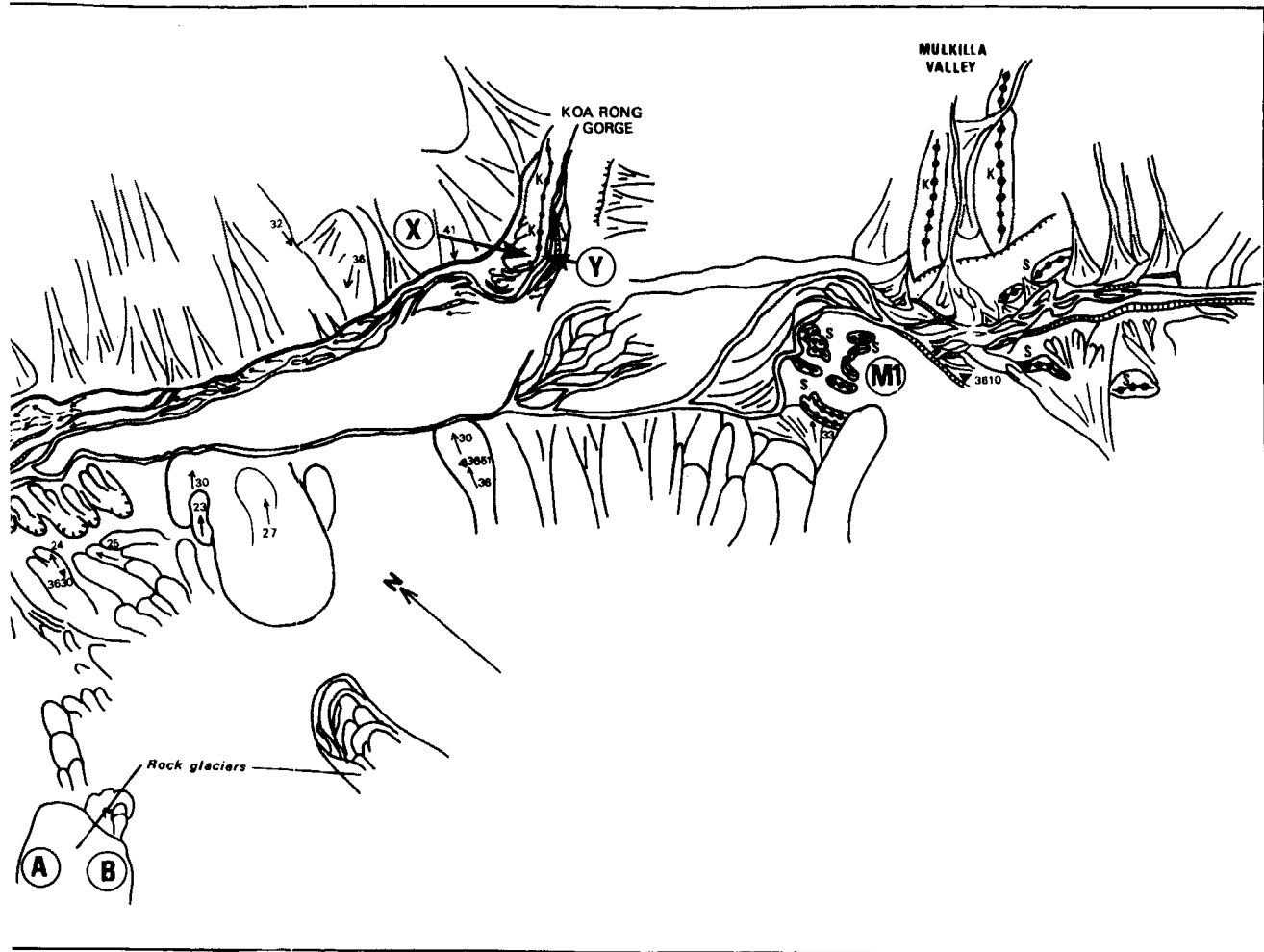
Figure 3b

They are also similar to the values obtained for the lichens on the rock glacier, which may indicate that the transition from valley-side glacier to rock glacier occurred in the Sonapani I glacial advance.

Correlation with other regions

The glacial chronology in Lahul is remarkably similar to the chronologies established by Zhang and Shi (1980), Derbyshire et al. (1984), and Shroder et al. (1993) (Table 1) in the Hunza and middle Indus valleys, where three major glaciations followed by several minor advances have been recognised. The earliest glaciation (Shanoz) in the middle Indus valley was of broad valley type, producing high benches and leaving scattered erratics, whereas later glaciations were of valley type and became less extensive with time (Shroder et al., 1993). It is interesting to note that Zheng's (1989a) model for glaciation driven by Milankovoitch climate change and tectonic uplift predicts three major glaciations for the Himalayas, with minor advances during Holocene time. It must be remembered, however, that evidence for mountain glaciations is fragmentary, because later and more extensive glaciations are always likely to destroy the evidence of earlier glaciation. In the mountains of the Himalayas, however, the high uplift rates provide higher preservation potential of early glacial features because they may be left stranded on high benches as uplift

and river incision change the influence of geomorphological activity. It is also worth noting that Gibbons et al. (1984) used probability modelling to show that the likely number of surviving moraines from previous glaciations will vary considerably given a total number of 32 possible glaciations during the Quaternary: with a 32% chance for three and a 90% chance for between one and four. Therefore, interpretation of glacial histories and correlation of glacial stages in the Himalayas must be treated with great care. Until absolute dates are available, correlations must be based on relative dating. Such tentative correlations are listed in Table 1.

Mayewski and Jeschke (1979) examined the historical records for glacier fluctuations throughout the Trans-Himalayan region and showed that in a gross regional sense glaciers have been on the retreat since about 1850. There are no historical records for the Lahul Himalaya back to this period except for the Bara Shugri Glacier, back to 1860, and the Sonapani Glacier, back to 1905 (Egerton, 1864; Walker and Pascoe, 1907). Contrary to this regional view the Bara Shugri Glacier advanced between 1860 and 1893, and it crossed the Chandra valley to block the Chandra River and produced a lake (Egerton, 1864). Lake silts and delta sands and gravels onlap the southern lateral moraine of the Bara Shugri Glacier. This advance can be correlated broadly with the Sonapani II Glacial Advance in the Kulti valley. Since 1893 the Bara Shugri Glacier has retreated progressively at rates varying from 62.5 m yr^{-1} to 20 m yr^{-1}. This compares favourably with a 29.5 m yr^{-1} retreat for the Sonapani Glacier from 1905. The age of the older Sonapani I glacial advance is not known, but
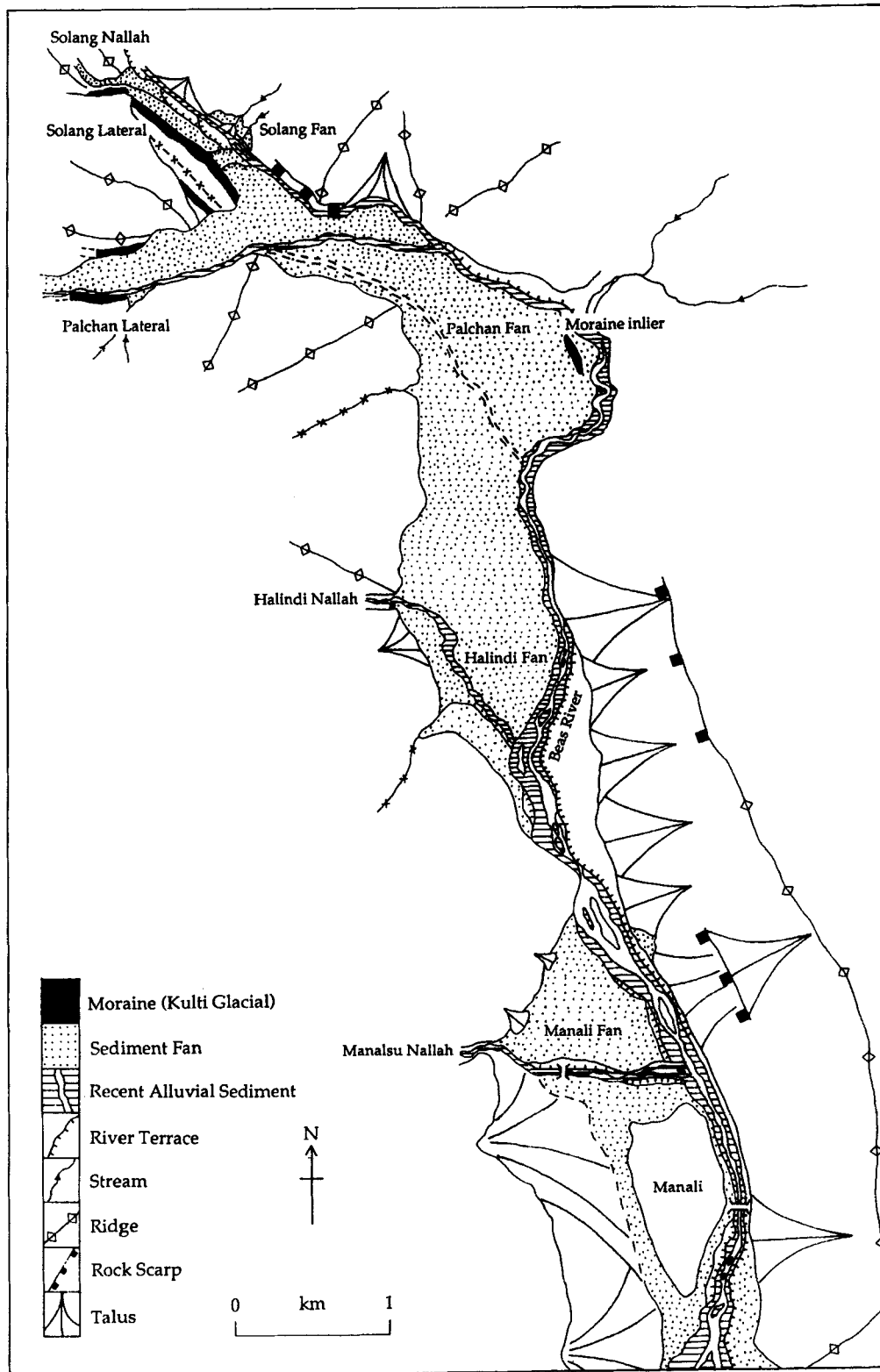
Figure 4 Geomorphological map of the upper Beas valley showing the positions of Kulti Glacial moraines.

the moraines can be attributed to the Little Ice Age and correlated with the Shroder *et al.* (1993) and Zhang and Shi (1980) Little Ice Age moraines in the Hunza valley.

Discussion

This new chronology provides a framework for the study of palaeoenvironmental change in the Lahul Himalaya. It is clear that styles of glaciation have changed through time, from an extensive, broad-valley glaciation during the Chandra Glacial, to progressively less extensive valley glaciations. This may be a result of several factors. Firstly, it may be related to preservation, because evidence for less extensive older glaciations is not likely to be preserved. Secondly, it may be due to global climatic conditions becoming progressively less favourable to the development of mountain glaciers during the late Quaternary. Thirdly, it may be a consequence of uplift influencing local climate.

Figure 5 View looking westward from Chandra Tal at the glacially eroded surfaces (C) formed during the Chandra Glaciation.
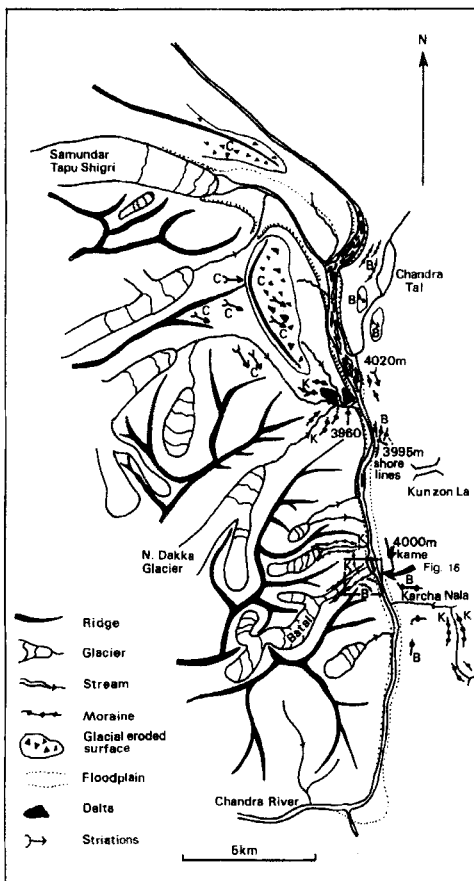

Figure 6 Geomorphological map of the upper Chandra valley showing the Quaternary moraines. The original base map was prepared by McArthur (1955). C, Chandra Glacial moraines; B, Batal Glacial moraines; K, Kulti Glacial moraines. The inset shows the area covered by Fig. 16.

The influence of preservation potential has been discussed above. Some support for the global climate model is provided by the fact that the pattern of glaciations in Lahul is similar to that in many montane areas throughout the world. Although data are often fragmentary, there is growing evidence for progressively less extensive mountain glaciations through the late Quaternary in all continents, many glaciers having reached their maximum extent prior to the last ice sheet maximum of ca. 20 ka BP (Gillespie and Molnar, 1995). Mountain glaciers in many regions in both hemispheres appear to have been less extensive since 20 ka BP than at earlier times (e.g. Porter, 1979; Clapperton, 1990; Seret et al, 1990; Sturchio et al., 1995; Gillespie and Molnar, 1995). Given the apparently world-wide distribution of this pattern, the evidence for progressively more restricted glaciation in Lahul may well reflect a global climatic signal, perhaps reflecting expansion of the large mid-latitude ice sheets and their effects on global temperature and moisture availability.

However, the possibility that the glacial history of Lahul was influenced by uplift of the Pir Panjal to the south cannot be ruled out. Growth of the Pir Panjal during the Quaternary would have increased local monsoon storminess while progressively reducing the supply of moisture to the northern slopes of the Pir Panjal and the Great Himalayas. On the basis of palaeomagnetic dating of sediments within the Kashmir, Burbank (1982) argued that uplift of the Pir Panjal was slow until about 1.7 Ma BP and then accelerated to approximately $3.4–10.0$ mm yr^{-1} by 0.4 Ma BP. This interpretation suggests that at about 0.4 Ma, the Pir Panjal was probably 1400–4000 m lower than at present. Prior to this uplift, moisture-bearing winds would have penetrated much further north into Lahul and so considerably influenced the style of glaciation. As the Pir Panjal rose, the glaciers would have been progressively starved of moisture making them less extensive. In complementary fashion, the Pir Panjal would have become glaciated only later in the Pleistocene, with glaciation on its southern flank becoming more extensive with time. This may account for the lack of preservation of glacial sediments and landforms older than the Kulti Glacial in the upper Beas val-

Figure 7 Striated cleaved phyllites with a deep brown-red rock varnish at approximately 4300 m north of the North Dakka Glacier. There were also striations on the higher ridge shown in the background. This erosion is attributed to the Chandra Glaciation.
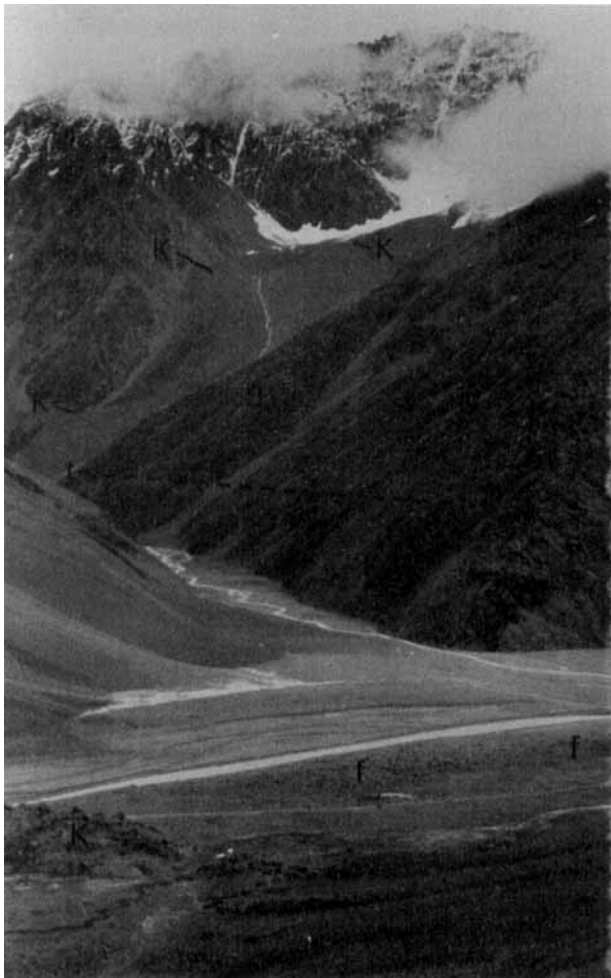

Figure 8 Deeply eroded thick lateral moraines of the Batal Glaciation (B) and fresh moraines of the Kulti Glacial Stage (K) at Batal. t–t marks the trimline of the Kulti Glacial and f marks the extent of glacial flood deposits, which probably occurred as waters burst through the Batal glacier when it dammed the upper Chandra valley during the Kulti Glacial.
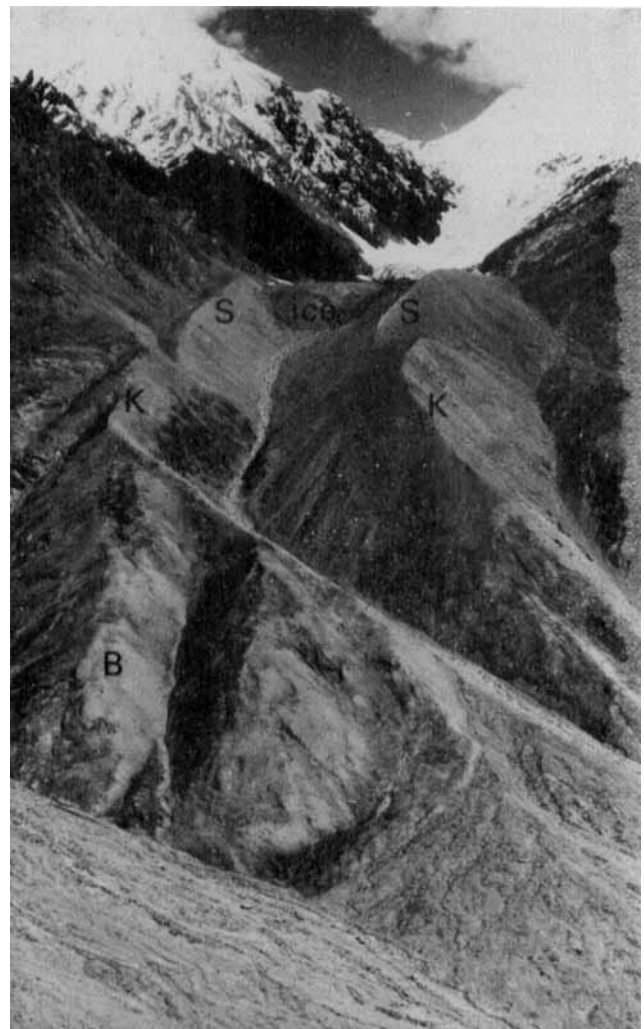
Figure 9 View looking west at the first glacier north of the Batal glacier, showing the chronology of moraines (B, Batal Glacial moraines; K, Kulti Glacial moraines; S, Sonapani I or/and Sonapani II moraines).

Figure 10 Rock glacierized slopes in the lower Kulti valley. These are possibly reworked lateral moraines of the Batal Glacial. See Fig. 2a for the location and plan of this rock glacierized area.
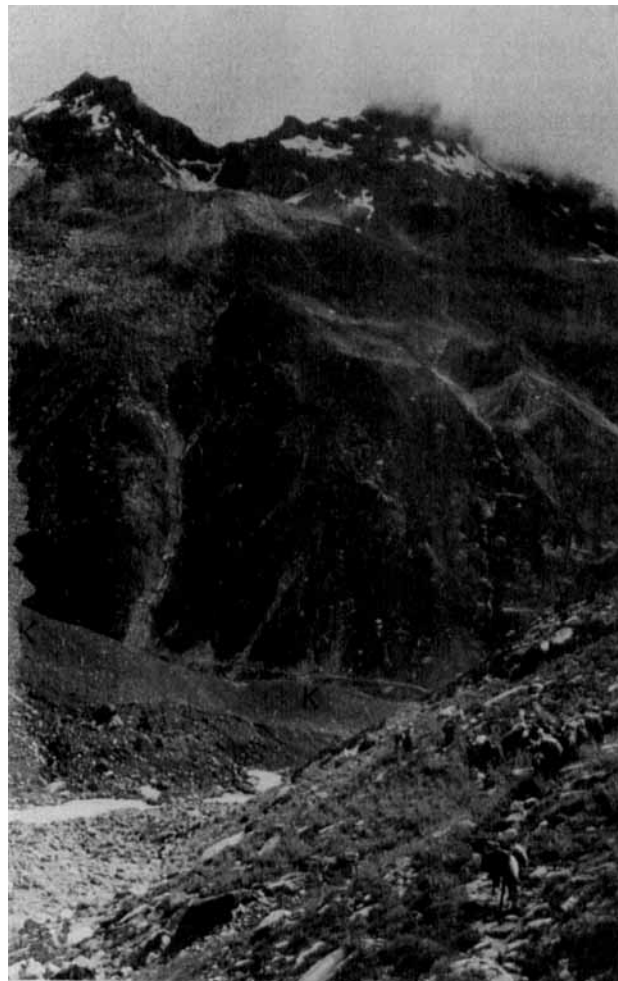
Figure 11 End moraines of the Kulti Glacial (K) at the confluence of the Kulti and Chandra valleys.

Figure 12 Thick lateral moraines of the Kulti Glacial in the middle Kulti valley. K marks the crests of the moraines.

Figure 13 Large recessional moraine of the Kulti Glacial in the middle Kulti valley.

Figure 14 A lateral moraine formed during the Kulti Glaciation in the upper Beas valley forming an inlier within an alluvial fan. K marks the crest of the moraine.

Figure 15 (A) The 1905 position (after Walker and Pascoe, 1907) (the small A and B are the original triangulation points of Walker and Pascoe, 1907). (B) the 1993 position of the Sonapani Glacier in the Kulti valley. X marks the corner of a rock bar that can be seen in both photographs. The snout position of the 1907 ice was located with the aid of the 1907 plate and by field mapping.
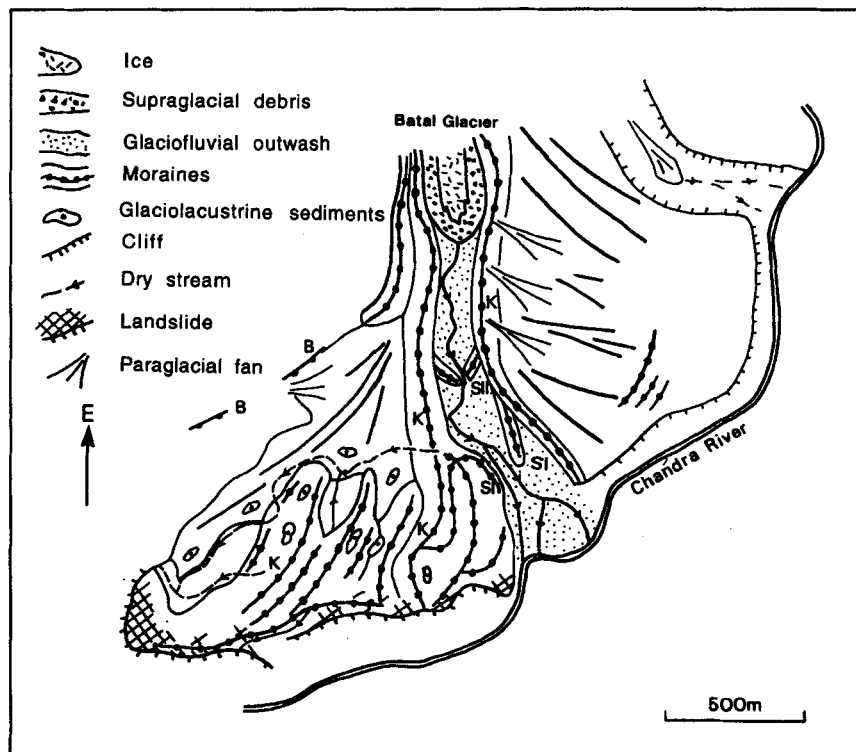
Figure 15b

Figure 16 Geomorphological map of the area around Batal showing the main Quaternary landforms (see Fig. 6 for location). C, Chandra Glacial moraines; B, Batal Glacial moraines; K, Kulti Glacial moraines; SI, Sonapani Advance I moraines; SII, Sonapani Advance II moraines.
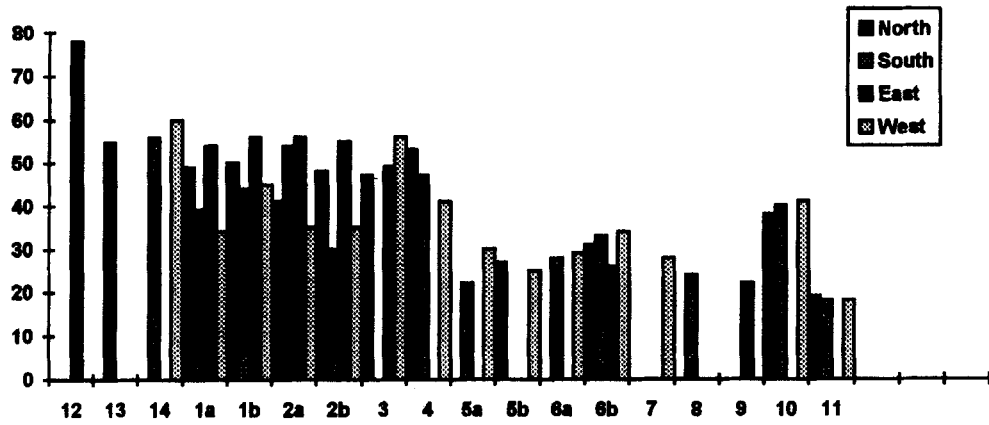
Figure 17 (a) Lichen diameter (in cm) on boulder surfaces of different aspects; (b) mean maxima and minima lichen diameters for sites in the Kulti valley (Fig. 2(a and b) shows the sample sites).
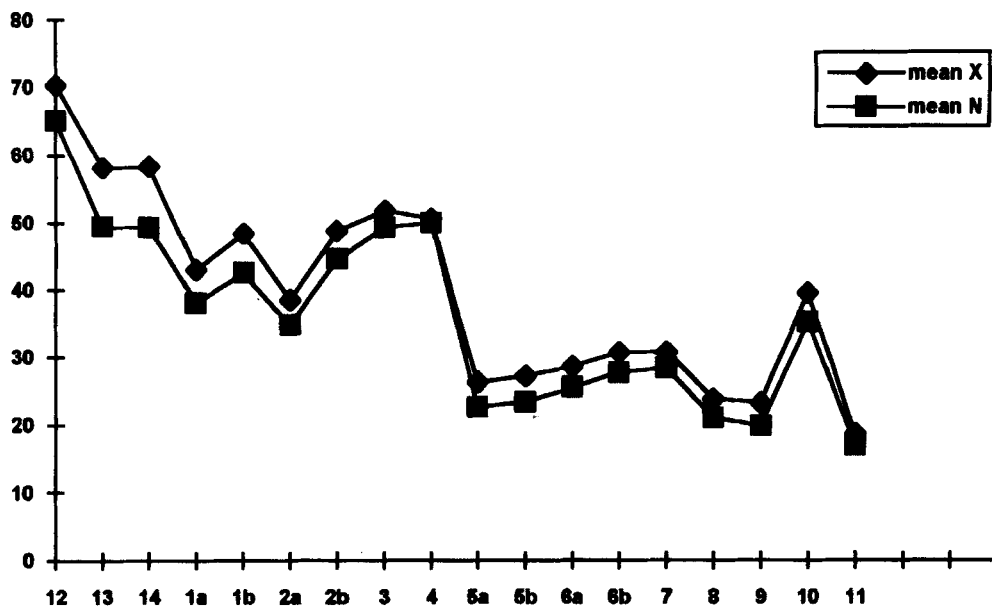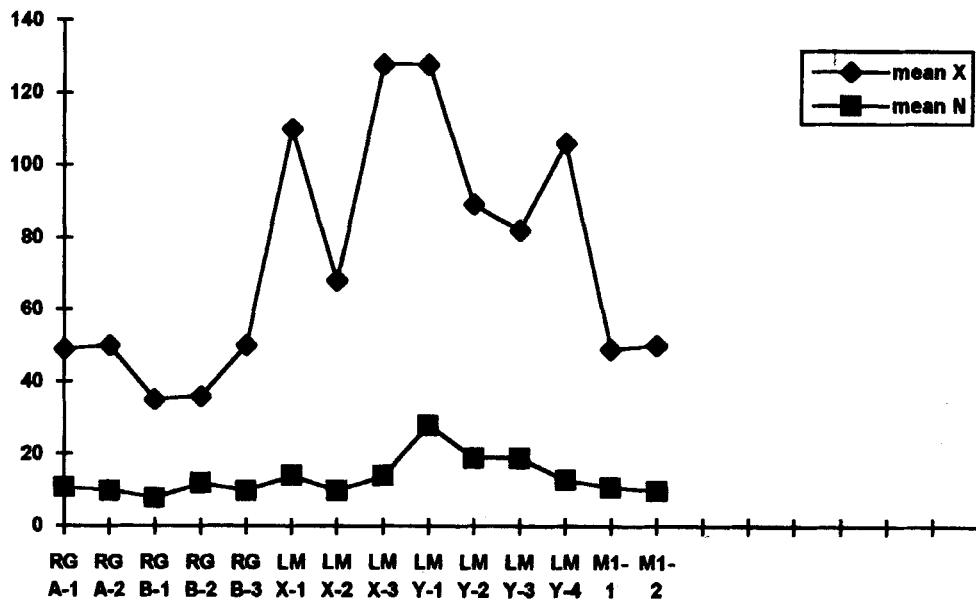

Figure 17b

Figure 18 Absolute maxima and minima lichen diameters for sites in the Milang valley (Fig. 3 shows the sample sites). RG, rock glacier; LM, lateral moraine; M, hummocky moraine; Mean X, mean maxima lichen diameters; Mean N, mean minima lichen diameters.

ley. The lack of evidence for the Chandra glaciation in the southern part of Lahul, particularly on the Pir Panjal, also may be attributed to this differential uplift. Either this region was not high enough for glaciation or the high uplift rates and consequently intense denudation have destroyed the glacial evidence.

The work of Holmes and Street-Perrott (1989) supports the view that rapid uplift of the Pir Panajal may influence glacial style. They showed that the height of cirques in the Pir Panjal and Great Himalayas, to the south and north of the Kashmir basin respectively, are sufficiently different in elevation that their altitudes cannot be explained by a climatic gradient. They suggest that, as a consequence of differential uplift of the Pir Panjal, the cirques in the Pir Panjal have risen by as much as 250 m in elevation since their formation.

If uplift did modify the climate of the Great Himalayas, it would be inadvisable to correlate the glacial sequence in Lahul with similar sequences elsewhere in the world, or even adjacent regions such as the Hunza valley. Indeed, the similarity of the Lahul and Hunza sequences may simply reflect similar tectonic histories, because the glacial history of the Hunza could be attributed to the differential uplift of the Himalayas with respect to the Karakoram Mountains. In short, the relative influence of global climatic change and local uplift on the glacial history of Lahul remains very uncertain, and cannot be tested until an accurate means of dating glacial landforms and sediments is available, and until uplift rates for Lahul and the Pir Panjal can be determined.

Fluctuations in the Holocene glacial record (Sonapani I and II glacial advances) may be attributed to perturbations in climate, variations in the intensity of the monsoon (Mayewski *et al.*, 1980) or even human-induced global warming (Houghton *et al.*, 1990).

Conclusion

This study provides the first Quaternary chronology for the Lahul Himalaya. Three main glaciations and two minor glacial advances have been recognised. These became less extensive with time and ranged from a broad-valley glaciation, the Chandra Glacial Stage, to valley glaciations, the Batal and Kulti Glacial Stages.

This study poses several important questions that need to be addressed by further mapping, absolute dating and refining of the preliminary chronology for this region. Specific objectives include definition of the full extent of all three glaciations; the reconstruction of ice dynamics and ice flow paths; a comparison of equilibrium line altitudes (ELA) throughout the region in order to define climatic gradients and to examine the influence of uplift on ELAs, using an approach similar to that of Holmes and Street-Perrott (1989); and the examination of evidence for the number and style of glaciations on the southern slopes of the Pir Panjal. Answers to such questions will clarify the role of uplift on the palaeomonsoon, and hence on glacial style.

References

BURBANK, D. W. 1982. The chronologic and stratigraphic evolution of the Kashmir and Peshawar Intermontane Basins, Northwestern Himalaya. Unpublished PhD thesis, Dartmouth College, 291 pp.

BURBANK, D. W. and KANG JIAN CHENG 1991. Relative dating of Quaternary moraines, Rongbuk Valley, Mount Everest, Tibet: implications for an ice sheet on the Tibetan Plateau. *Quaternary Research*, **36**, 1–18.

CLAPPERTON, C. M. 1990. Quaternary glaciers in the southern hemisphere: an overview. *Quaternary Science Reviews*, **9**, 299–304.

CRONIN, V. S. 1982. The physical and magnetic polarity stratigraphy of the Skordu Basin, Baltistan, northern Pakistan. Unpublished Master's thesis. Dartmouth College, Hanover,. NH.

DERBYSHIRE, E., LI JIJUN, PERROT, F. A., XU SHUYING and WATERS, R. S. 1984. Quaternary glacial history of the Hunza valley Karakoram Mountains, Pakistan. *IN*: Miller, K. (ed.), *International Karakoram Project*, 456–495. Cambridge University Press, Cambridge.

EGERTON, P. H. 1864. *Journal of a Tour through Spiti*. Cundall Downs, London.

EYLES, N. 1983. Glacial geology: a landsystems approach. *IN*: Eyles, N. (ed.), *Glacial Geology*, 1–18. Pergamon Press, Oxford.

FORT, M., FREYTET, P. and COLCHEN, M. 1981. The structural and sedimentological evolution of the Thakkhola–Mustang graben (Nepal Himalaya) in relation to the uplift of the Himalayan Range. *IN*: *Geological and Ecological Studies of Qinghai-Xizang Plateau*, Vol. 1, 307–313. Science Press, Beijing.

GIBBONS, A. B., MEGEATH, J. B. and PIERCE, K. L. 1984. Probability of moraine survival in a succession of glacial advances. *Geology*, **12**, 327–330.

GILLESPIE, A. and MOLNAR, P. 1995. Asynchronism of mountain and continental glaciations. *Reviews of Geophysics*, in press.

HOLMES, J. A. 1993. Present and past patterns of glaciation in the northwest Himalaya: climatic, tectonic and topographic controls. *IN:* Shroder, J. F. (ed.), *Himalaya to the Sea*, 72–90. Routledge, London.

HOLMES, J. A. and STREET-PERROTT, F. A. 1989. The Quaternary glacial history of Kashmir, North-West Himalaya: a revision of de terra and Paterson's sequence. *Zeitscrift für Geomorphologie*, **76**, 195–212.

HOUGHTON, J. T., JENKINS, G. T. and EPHRAUMS J. J. (eds) 1990. *Climate Change: the IPCC Scientific Assessment*. Cambridge University Press, Cambridge.

LI JIJUN, WEN SHIXUAN, ZHONG QINGONG, WONG FUBAO, ZHENG BENXING and LI BINGYUAN 1979. A discussion on the period, amplitude and type of uplift of the Qinghai Xizng Plateau. *Scientia Sinica*, **22** (11), 1314–1328.

MAMGAIN, M. D. 1975. *Himachal Pradesh District Gazetteers—Lahul and Spiti*, 32–33. Greater Punjab Press, Chandigarh.

MAYEWSKI, P. A. and JESCHKE, P. A. 1979. Himalayan and Trans-Himalayan glacier fluctuations since AD 1812. *Arctic and Alpine Research*, **11** (3), 267–287.

MAYEWSKI, P. A., PREGENT, G. P., JESCHKE, P. A. and AHMAD, N. 1980. Himalayan and Trans-Himalayan glacier fluctuations and the south Asian Monsoon Record. *Arctic and Alpine Research*, **12** (2), 171–182.

McARTHUR, H. 1955. *Central Lahul Expedition 1955*. Unpublished Report, Royal Geographical Society, London.

OWEN, L. A. 1989. Neotectonics and glacial deformation in the Karakoram Mountains, Northern Pakistan. *Tectonophysics*, **163**, 227–265.

OWEN, L. A. 1989. Terraces, uplift and climate in the Karakoram Mountains, northern Pakistan: Karakoram intermontane basin evolution. *Zeitscrift für Geomorphologie*, **76**, 117–146.

OWEN, L. A. 1994. Glacial and non-glacial diamictons in the Karakoram Mountains. *IN*: Croots, D. and Warren, W. (eds), *The Deposition and Deformation of tills*, 1–20. A. A. Balkema, Rotterdam.

OWEN, L. A. and DERBYSHIRE, E. 1988. Glacially deformed diamictons in the Karakoram Mountains, northern Pakistan. *IN*: Croot, D. (ed.), *Glaciotectonics: Forms and Processes*, 149–176. A. A. Balkema, Rotterdam.

OWEN, L. A., BENN, D. I., DERBYSHIRE, E., EVANS, D. J. A., MITCH-
ELL, W., THOMPSON, D., LLOYD, M. and RICHARDSON, S.
1995. The geomorphology and landscape evolution of the Lahul
Himalaya, Northern India. *Zeitscrift für Geomorphologie*, in press.

OWEN, L. A., WHITE, B. J., RENDELL, H. and DERBYSHIRE, E. 1992.
Loessic silt deposits in the western Himalayas: their sedimentology,
genesis and age. *Catena*, **19** (6), 493–509.

PORTER, S. C. 1979. Hawaiian glacial ages. *Quaternary Research*,
12, 161–187.

PRELL, W. L. and KUTZBACH, J. E. 1992. Sensitivity of the Indian
monsoon to forcing parameters and implications for its evolution.
Nature **360**, 647–652.

RUDDIMANN, W. F. and KUTZBACH, J. E. 1989. Forcing of Late
Cenozoic Northern Hemisphere climate by plateau uplift in sou-
thern Asia and the American west. *Journal of Geophysical Research*,
94 (18), 409–427.

SERET, G., DRICOT, E. and WANSARD, G. 1990. Evidence for an
early glacial maximum in the French Vosges during the last glacial
cycle. *Nature*, **346**, 453–456.

SHARMA, M. C. 1986. *Regional geomorphology of Lahul (Central
Himalayas)*, MSc Dissertation, Jawaharlal Nehru University,
Delhi, 125 pp.

SHRODER, J. F., OWEN, L. A. and DERBYSHIRE. E. 1993. Quaternary
glaciation of the Karakoram and Nanga Parbat Himalaya. *IN*:
Shroder, J. F. (ed.), *Himalaya to the Sea*, 132–158. Routledge, Lon-
don.

STURCHIO, N. C., PIERCE, K. L., MURRELL, M. T. and SOREY, M.
L. 1995. Uranium-series ages of travertines and timing of the last
glaciation in the northern Yellowstone area, Wyoming–Montana.
Quaternary Research, in press.

WALKER, H. and PASCOE, E. N. 1907. Notes on certain glaciers in
Lahaul. *Records of the Geological Survey of India*, 35 (4), 139–147.

ZHANG XIANGSONG and SHI YAFENG 1980. Changes of Batura
Glacier in the Quaternary and recent times. *Professional Papers on
the Batura Glacier, Karakoram Mountains*, 173–190. Science
Press, Beijing.

ZHENG BENXING 1989a. The influence of Himalayan uplift on the
development of Quaternary glaciers. *Zeitscrift für Geomorphologie*,
76, 89–115.

ZHENG BENXING 1989b. Controversy regarding the existence of a
large ice sheet on the Qinghai-Xizang (Tibetan) Plateau during the
Quaternary Period. *Quaternary Research*, **32**, 121–123.