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QUATERNARY GLACIAL HISTORY OF THE KARAKORAM MOUNTAINS AND NORTHWEST HIMALAYAS: A REVIEW

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The style and extent of glaciation in the NW Himalayas and Karakoram Mountains of Pakistan, and the Himalayas in NW India are reviewed. At least three glacial events, progressively less extensive with time, can be recognised in most regions. The timing and status of these glacial successions is poorly known. This is partially due to poor dating constraints, but also arises from a lack of adherence to strict stratigraphic procedures. Recommendations are made for a more rigorous approach to the study of Himalayan Quaternary glacial histories.

INTRODUCTION

In recent years much attention has been focused on the potential influence of Himalayan and Tibetan Plateau uplift on climate change, yet little consideration has been given to the style and extent of glaciation within the Himalayas. This is partially due to difficulties of access, both physical and political, and to a failure to recognise the potential importance Himalayan glacial systems have for the study of global change. We consider that an understanding of the extent and style of glaciation is critical to the building of improved models of global change and is fundamentally important in reconstructing the evolutionary history of the high mountain landscapes of central Asia. This paper summarises present knowledge and recent work on the style and extent of glaciation in the NW Himalayas and Karakoram Mountains of Pakistan, and the Himalayas of NW India.

THE QUATERNARY GLACIAL SUCCESSIONS

On the basis of landforms and thick accumulations of glacial, glaciofluvial, mass movement, aeolian and lacustrine sediments, glacial chronologies have been produced for the Karakoram Mountains (Derbyshire *et al.*, 1984; Shroder *et al.*, 1993), and the Swat (Porter, 1970; Owen *et al.*, 1992), Nanga Parbat, Lahul (Owen *et al.*, 1995a, *in press)* and the Garhwal (Sharma and Owen, 1996) Himalayas (Table 1). These show at least three major glaciations which became progressively less extensive with time. However, their timing and status (e.g. whether they are full Glacials or Stadials) have not been determined because of the lack of suitable material for standard dating techniques such as ^{14}C, palaeomagnetism, Th/U and K/Ar. It is not yet known whether this diminishing series of Quaternary glacial extensions was the result of the global climatic changes induced by Milankovitch forcing or whether differential tectonic uplift of Himalayan mountain ranges played a critical role in reducing the supply of moisture to the Greater Himalayas. This question may be resolved in part by determining whether the glaciations were synchronous both within the Himalayan region and in relation to other mountain regions of the world. Each of these study areas will be considered in turn in order to examine the style of glaciation at the western end of the Himalayan mountain chain (Fig. 1).

SWAT HIMALAYA, NORTHERN PAKISTAN

The first modern detailed study in the Himalayas was undertaken by Porter (1970) in the Swat Himalayas. On the basis of drift mapping he recognised evidence of three Pleistocene glaciations in the northern part of the Swat River drainage basin. The extent and altitudinal distribution of three sets of deposits were determined on the basis of morphostratigraphy, relative weathering and the thickness of loess deposits on the surface of the moraines. From oldest to youngest, he called these the Laikot, Gabral and Kalam Stages. Each glaciation was progressively less extensive, and was confined within the valleys occupied by each preceding glaciation (Fig. 2). Porter (1970) calculated a maximum ELA depression of about 1000–1200 m for the Swat Himalayas.

Owen *et al.* (1992) re-examined Porter's chronology, using thermoluminescence dating (TL). Selected samples of loess resting on the surfaces of moraines were dated to help constrain the chronology. However, detailed sedimentological analysis of the loess showed it had been reworked by slope processes. Thus, the

TABLE 1. Tentative correlations of selected Quaternary glacial chronologies at the western end of the Himalayan Mountain Range

	Glacial Non-Glacial		Lahul	Middle Indus-Gilgit-Hunza Valleys			Upper Indus	Swat Kohistan	Gathwal	Tentative Dates
Series	Stage	Stade	Owen *et al.* (1995)	Derbyshire *et al* (1984)	Shroder *et al.* (1993)	Zang & Shi (1980)	Cronin *et al.* (1989)	Porter (1970)	Sharma and Owen (1996)	Years
Holocene			Sonapani II	Pasu II	Historical	Historical	Individual Moraines		Bhujbas	10^2
			Sonapani I	Pasu I	Little Ice Age	Little Ice Age				10^3
				Batura	Neoglacial	Neoglacial		Neoglacial	Shivling	
Pleistocene	Late Glaciation		Kulti	Ghulkin II	Darel-Shatial Moraine	Hunza Glaciation		Kalam Glaciation Late Stade	Bhagirathi	10^4
				Ghulkin I				Kalam Glaciation Intermed. Stade		
				Borit Jheel	Dainyor Moraine			Kalam Glaciation Early Stade		10^5
	M.I IG.		Batal II	Yunz	Valley Fill III	Yunz Glaciation	? Strong Erosion Alluviation	Gabral Glaciation Late Stade		
	Middle Glaciation	Late Stade			MS Tills		Satpura Till			
			Batal I		Valley Fill II		? Valley Fill			
		Early Stade			M1 Tills		Bunthang Till	Gabral Glaciation Early Stade		
	E.M. Inter G.		Chandra	Shanoz	Upper Jalipur valley Fill I	Shanoz Glaciation				10^6
	Early G.				Lower Jalip. Till			Laikot Glaciation		

TL dating provides only an approximation of the minimum ages of the deposits. Ages of between ca. 22,000 and 18,000 BP were obtained for loess covering the Gabral Stage moraines, while loess draping the Kalam Stage moraines gave ages of between ca. 3000 and 7000 years. These dates suggest that the Gabral stage may be correlated broadly with the last glacial maximum of the northern hemisphere ice sheets, while the Kalam Stage can probably be assigned to a Neoglacial advance. The older Laikot Stage, however, was more extensive and may represent an earlier advance during the last glacial cycle, in which case the last glacial maximum in the Swat Himalaya may have been much earlier than the maximum of the northern hemisphere ice sheets.

THE HUNZA, GILGIT AND MIDDLE INDUS VALLEYS, NORTHERN PAKISTAN

Much has been written about the Quaternary history of the Hunza, Gilgit and the middle Indus valleys as a result of numerous expeditions to North Pakistan. Good summaries of the early work are provided by Shroder *et al.* (1993) and Hewitt (1989). Of particular note is the work of Dainelli (1922, 1934, 1935) who attempted to correlate glaciations in the Karakoram with the classic four-fold glacial sequence of the European Alps according to Penck and Brückner (1909). A great deal of discussion has focused on the extent of glaciation in the Indus valley although, during the early part of this century, none of the protagonists had travelled up the

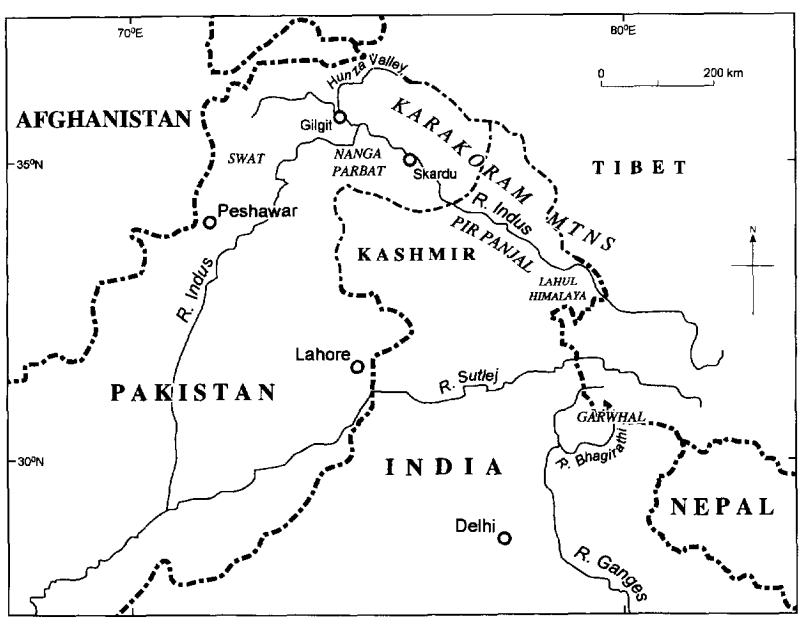

FIG. 1. Location map showing the areas mentioned in the text.

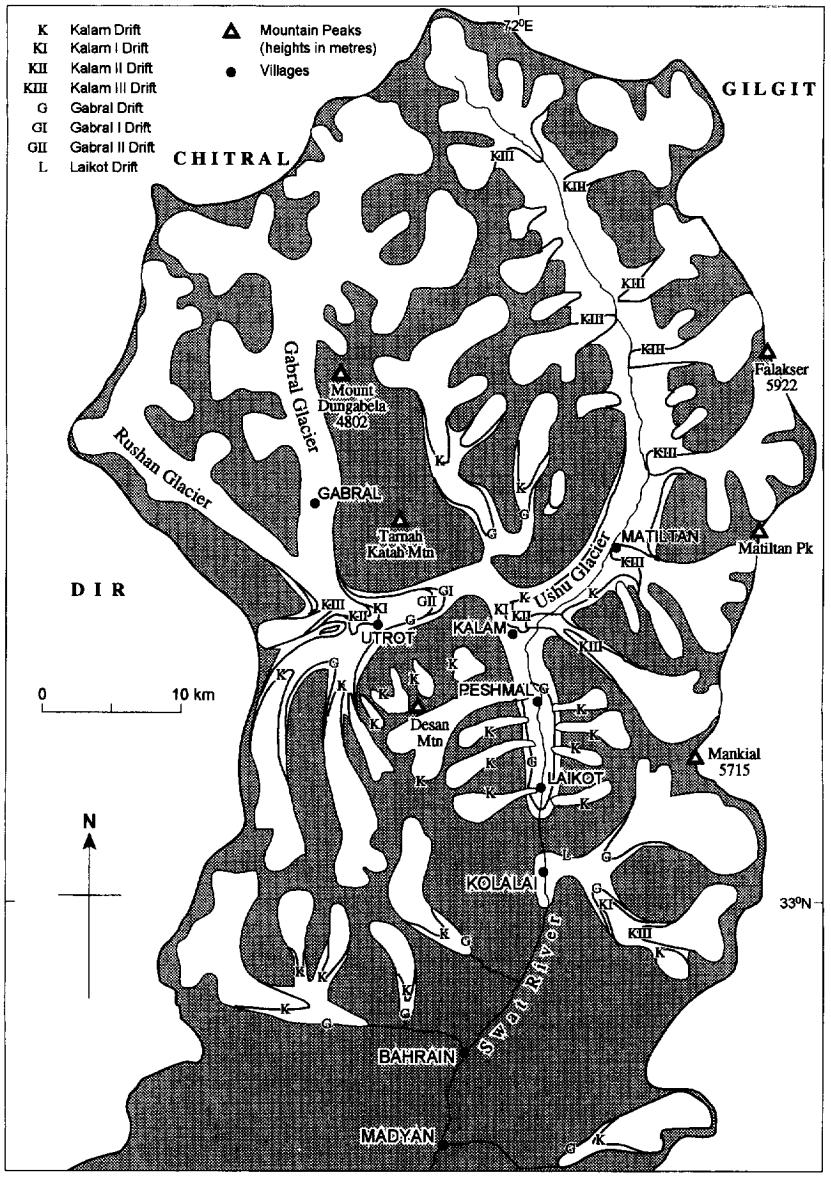

FIG. 2. Reconstruction of former ice limits in the upper Swat drainage basin. The shaded area represents nonglaciated areas (after Porter, 1970). L — Laikot Stage; G — Gabral Stage; K — Kalam Stage.

lower Indus gorge. For example, Norin (1925, 1946) suggested that, during the last glacial maximum, the whole of the Indus drainage system was filled with glacier ice which extended down to an altitude of ca. 1675–1830 m. He suggested that most of the valleys in Baltistan became filled with glacial sediments several hundreds of metres in thickness. Similarly, Cotter (1929) and Coulson (1938) favoured extensive ice and attributed large boulders on the Potwar Plateau to ice which extended down the Indus. These so called 'Punjab erratics' are now believed to have been carried down the Indus by catastrophic floods (Desio and Orombelli, 1983; Burbank, 1983; Butler *et al.*, 1988; Shroder *et al.*, 1989).

Misch (1935) was the first to describe the deposits in the middle Indus valley. He recognised faulted diamicts and diamictites which he called the '*Jalipur Sequence*', and believed they were tillites of late Tertiary–early Pleistocene age. Recently, there has been much debate regarding the origin and age of these deposits (Shroder *et al.*, 1993). On the basis of recent interpretations of sediments and landforms, the concensus is that ice did not extend farther down the Indus valley than Shatial (Owen, 1988a; Shroder *et al.*, 1989, 1993).

The best glacial successions occur in the Hunza Valley (Fig. 1). The first detailed work undertaken here was by Paffen *et al.* (1956) and Schneider (1959). They suggested a three-fold glacial sequence which included upper and lower terrace remnants, and a moraine sequence close to the present glacier fronts. Above 4000 m, they recognised a '*pre-Pleistocene relief*'. This was later reconfirmed by Derbyshire *et al.* (1984) at altitudes of between 4100 and 4200 m, and was called the *Patundas surface*. A higher planation surface at 5200 m on Mirschiken was also discovered. Derbyshire *et al.* (1984) indicated that these surfaces must be younger than 8.6 Ma, the age of the Karakoram

granodiorite (Desio *et al.*, 1964). The Patundas surface was broadly correlated with the Potwar Plateau at 500 m, which is of early Pleistocene age, and the higher surface in the Hunza valley was correlated with a higher surface on the Potwar Plateau, where the Murree Series of rocks is truncated. Owen (1989a) drew attention to the similarity of these surfaces to those described in Tibet by Li Jijun *et al.* (1979). In addition, Ambraseys *et al.* (1981) recognised abraded surfaces in the lower Indus gorge which they speculatively attributed to three distinct glacial advances. However, as there is no evidence of glacial deposits or glacial landforms in the lower Indus gorge, these surfaces could equally be the result of fluvial erosion and sporadic uplift. All these correlations, however, are highly tentative and there is little or no evidence to support them.

The construction of the Karakoram Highway in the late 1970s and the work of the International Karakoram Project in 1980 provided much impetus for the study of the Quaternary history of the Hunza valley (Batura Glacier Investigation Group, 1979, 1980; Zhang and Shi, 1980; Miller, 1984). The first significant work was by Zhang and Shi (1980) who identified evidence for at least three glacial stages in the region around the Batura Glacier. These were named the *Shanoz*, *Yunz* and *Hunza Stages*. This chronology was modified by Derbyshire *et al.* (1984) who identified eight glacial phases which they constrained by ^{14}C and preliminary TL dating. However, since details of the procedures followed in the Chinese laboratories were not provided, the reliability of these dates cannot be judged.

The oldest stage, the *Shanoz*, is represented by ice-polished surfaces mantled with remnants of till and scattered erratics above 4000 m. Derbyshire *et al.* (1984) suggested that the ice extent was probably about twice that of today's cover. The second stage, the *Yunz*, is represented by till mantles along the valley sides and dissected moraines on benches at altitudes of between 3000 and 3650 m a.s.l. Derbyshire *et al.* (1984) suggested that the floor of the Hunza valley was probably about 800 m above its present level. This glaciation was extensive with much diffluent ice on surfaces which were approximately 1000 m below those produced during the Shanoz glaciation. A tentative TL age for lenses of lacustrine silts incorporated in the basal part of this till is 139 ka BP. The third stage, the *Borit Jheel*, deposited tills at altitudes of up to 3000 m. It is thought that these deposits represent an extensive valley glacier which was constrained by the topography, and that glaciers occupied many diffluence cols and tributaries so that the ice coalesced to fill the Hunza valley. Derbyshire *et al.* (1984) quoted TL dates of >50–65 ka BP for deposits of this advance, which implies that this glaciation occurred during the first half of the last glacial cycle. The fourth stage, *Ghulkin I*, formed moraines which were restricted to tributary valleys, with little coalescence in the Hunza valley. These deposits have an apparent TL age of 47 ka BP. This was followed by the *Ghulkin II* stage which was constrained within the Ghulkin I limits. Derbyshire *et al.* (1984) considered this to be a late still-stand in the retreat of the Ghulkin I advance. The final three stages, *Batura*, *Pasu I* (800–325 ^{14}C years BP) and *Pasu II*, were restricted advances and were considered to be of Holocene age.

Figure 3 shows the reconstruction of ice cover in northern Pakistan for the three full glacial stages. Derbyshire (1996) points out that although ice extent may have become less extensive with time, the total ice volumes may have shown less variation as valley systems enlarged in conditions of quasi-balance between uplift and incision.

The Hunza chronology has been examined and generally accepted by other workers (Owen, 1988a; Shroder *et al.*, 1989; Scott, 1992), and attempts have been made to extend this work into the Gilgit and Indus Valleys. Yet there are still no reliable dates with which to constrain these chronologies.

On the basis of geomorphological and sedimentological evidence in the lower Gilgit valley, Owen (1988a) and Derbyshire and Owen (1990) showed that major trunk valley glaciers extended down the Hunza and Gilgit valleys into the middle Indus valley during the Yunz and the Borit Jheel Stages (Figs 4 and 5). During the Yunz Glaciation, Hunza and Gilgit ice streams converged and were also fed by ice from the tributary valleys on the north side. A well-defined break in slope occurs about 300 m above the present river level. Polymictic diamictons containing striated clasts are preserved at a number of sites along this bench-like feature, which is considered to be a glacial trimline separating a zone of subaerial degradation above the surfaces of the glaciated trough below, and to mark the former upper surface of the Yunz ice. Derbyshire and Owen (1990) suggested that, soon after deglaciation, the combination of water-saturated tills, steep and long valley slopes, and the instability consequent upon the wasting of confining glacier ice, produced extensive debris-flows, substantially clearing the valley sides of till. Such resedimented till forms a major component of the alluvial fans, along with valley-floor tills preserved as inliers, and glaciofluvial outwash deposits from the retreating glaciers.

The Borit Jheel Glaciation produced a large glacier which extended down the Hunza valley, but ice was less extensive in the Gilgit valley and probably did not extend as far as the Gilgit basin (Fig. 5). The Borit Jheel ice eroded valley sediments deposited by the Yunz glaciation except for a few isolated till remnants on rock benches east of Gilgit and in the base of the Dainyor palaeovalley. Hunza ice blocked the Gilgit valley and produced a lake which extended at least 20 km up-valley. Lacustrine sediments up to 30 m thick occur as terrace inliers within the fans west of Gilgit. Marginal lakes also developed along the sides of the valleys: these are now represented by planar-bedded silts interbedded with tills. A ridge of till south of Dainyor trending NNW–SSE marks the former lateral margin of the Hunza glacier and a N–S ridge immediately west of Minawar Gah is a good terminal moraine.

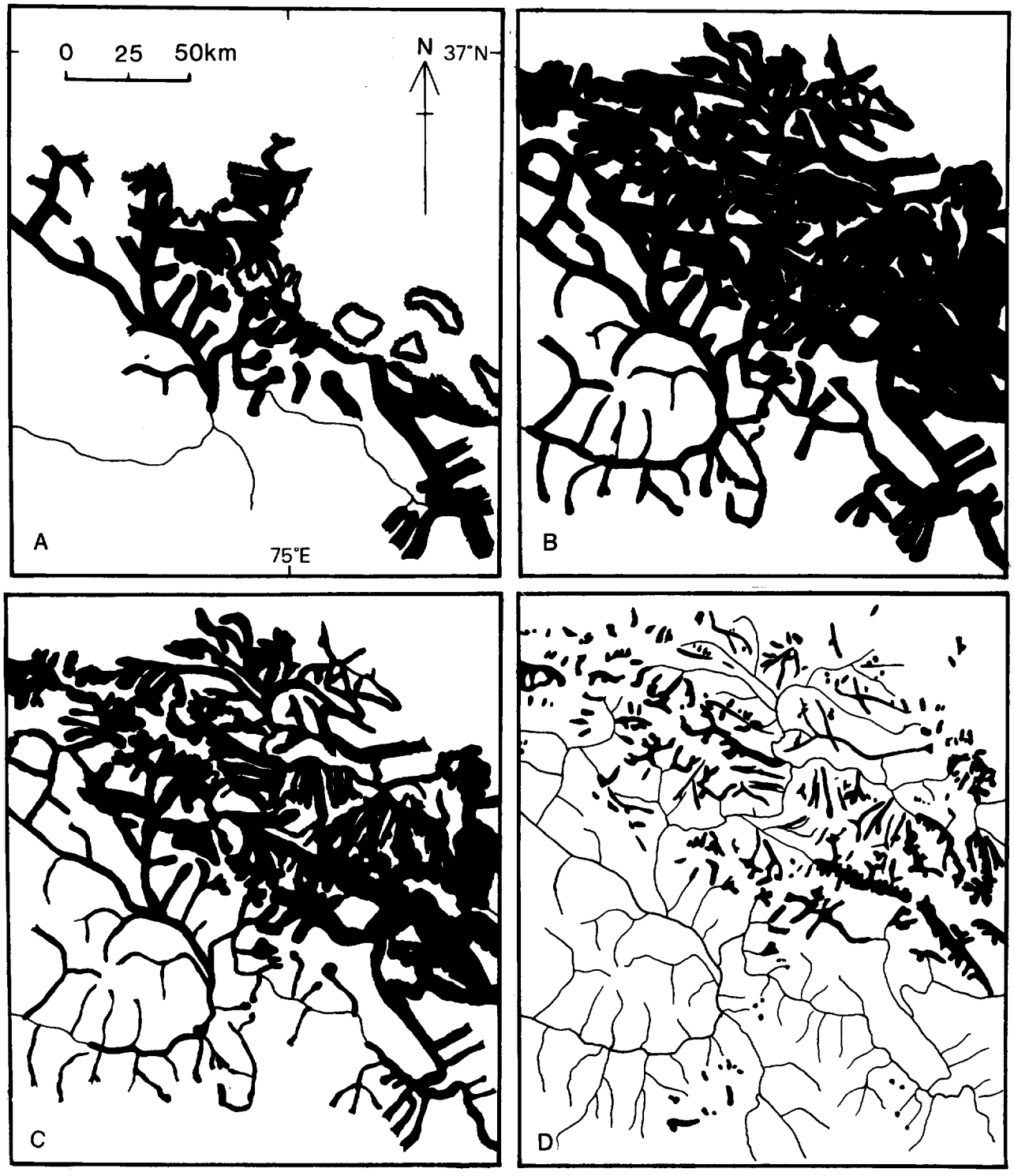

FIG. 3. Sequence and extents of Quaternary glaciations and the present day ice cover in northern Pakistan. (A) Shanoz Glaciation; (B) Yunz Glaciation; (C) Borit Jheel Glaciation; (D) Present (after Owen, 1989b).

Bagrot valley ice produced an end moraine at the junction of the Bagrot and the Gilgit valleys. Unstable tills along the valley sides were resedimented as debris-flows, leaving the more compact till and lacustrine sedimentary outcrops as inliers. Derbyshire and Owen (1990) suggested that debris-flow and fan development occurred quite soon after glacial retreat and, in many cases, glacier ice may have been in close proximity to the developing fans.

NANGA PARBAT HIMALAYA

Nanga Parbat is a relatively isolated massif at the western end of the Great Himalaya, and comprises a series of peaks which exceed 8000 m in altitude. Tectonically, it is bounded by the Main Mantle Thrust (MMT) and, although it has attracted much attention from structural geologists, little work has been undertaken on the glacial geology (e.g. Owen, 1988a, 1989a; Shroder *et*

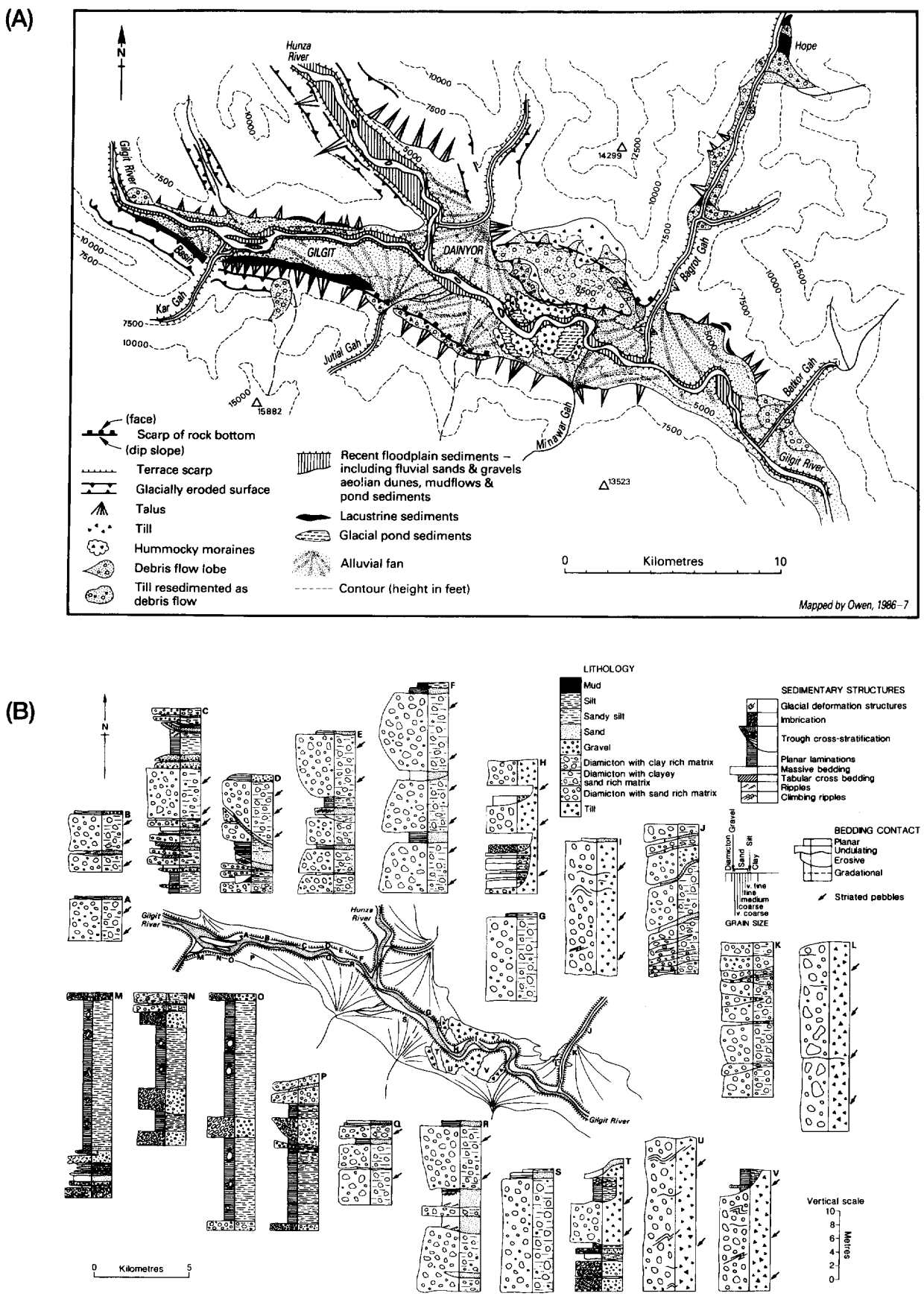

FIG. 4. The Gilgit area. (A) Sedimentological and geomorphological map; (B) Simplified sedimentary logs (after Owen, 1989b and Derbyshire and Owen, 1990).

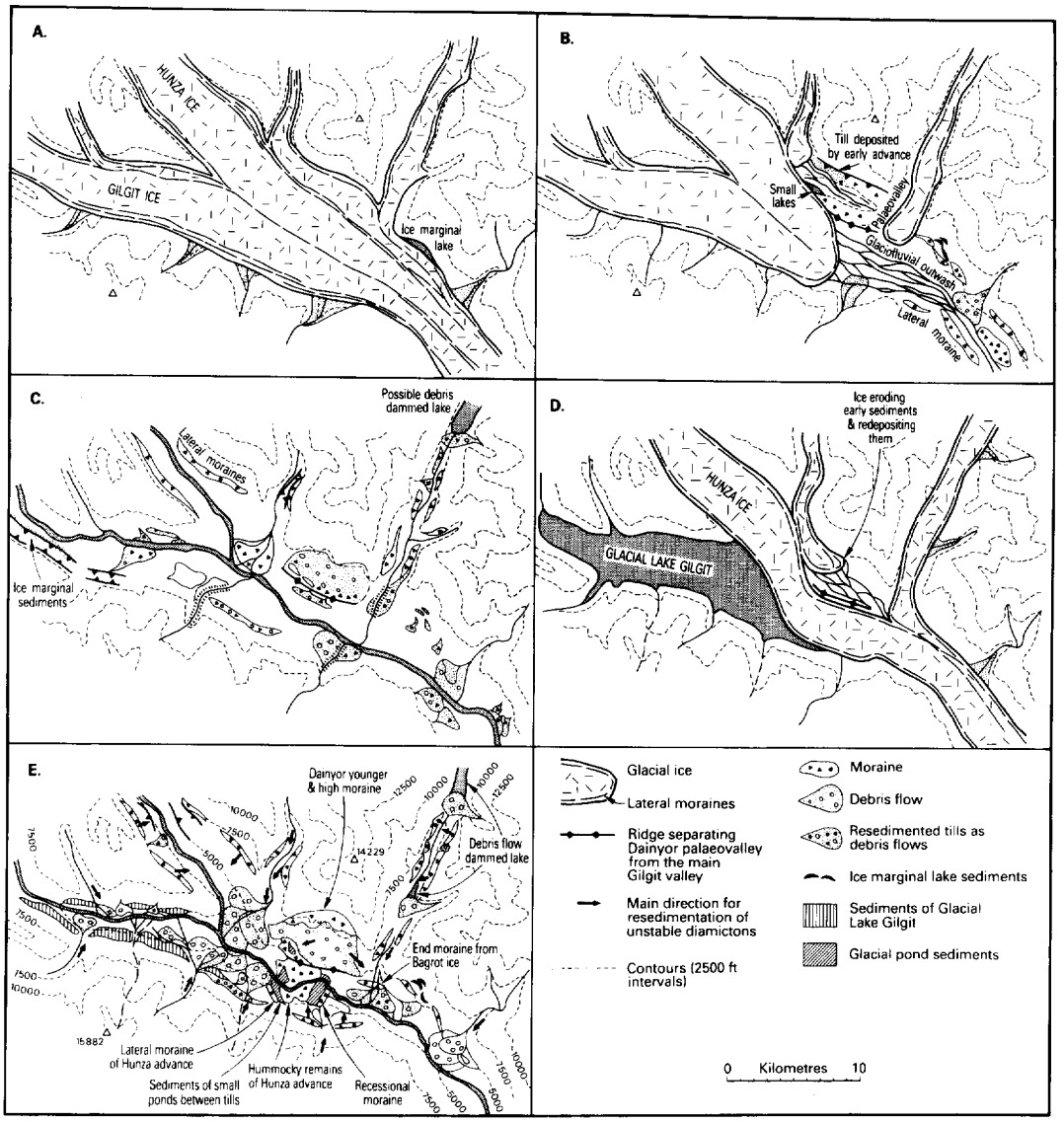

FIG. 5. Sequential development of the Gilgit area. (A) Yunz Glaciation; (B) Ice retreat at the end of the Yunz Glaciation; (C) Ice free valley between the Yunz and Borit Jheel Glaciation; (D) Borit Jheel Glaciation; (E) Post-Borit Jheel Stage (after Owen, 1989b and Derbyshire and Owen, 1990).

al., 1989, 1993). The only modern detailed study is that undertaken by Scott (1992).

Scott (1992) suggested that during one or more times in the Pleistocene, an extensive glacier system occupied the valleys of the Nanga Parbat massif with ice advancing more than 15 km down-valley beyond the present termini (Fig. 6). The only strong evidence for distinct Pleistocene glacial advances lies in the glacial landforms of the Astor valley, where two separate glacial advances were identified. Scott argued that such an advance of ice into this valley would have required a substantial lowering of regional temperatures and that this would have been in line with Pleistocene events in other parts of the northwest Himalaya. Elsewhere in the massif, Scott recognised evidence suggesting less extensive glaciation, where glaciers advanced no more than 12 km beyond their present snouts. This accords with other evidence from the northwest Himalayas (Derbyshire *et al.*, 1984; Owen, 1988a; Holmes, 1988; Shroder *et al.*, 1989) and these ice limits correspond well with the those stages which followed the maximum known Pleistocene ice extent. Scott argued that depositional evidence for earlier Pleistocene glaciations had been destroyed by subsequent erosion and that truncated spurs, hanging valleys, steep valley sides and over-deepened trunk valleys provide evidence of a more extensive earlier glaciation.

The work of Scott (1992) includes detailed sedimentological analysis which demonstrated that the sequence of glacial deposits is consistent with deposition in a waning series of glacial advances, and that the distinct ice front accumulations mark either still-stands or pulsed advances. On the basis of inter-valley comparisons of relative age, it was suggested that a broadly synchronous series of events of regional status was responsible for the glacial deposits. In addition, wastage of all the glaciers up-valley implies at least two still-stands or readvances in each valley system, followed by further glacier retreat. However, there is a lack of unequivocal evidence for glacier

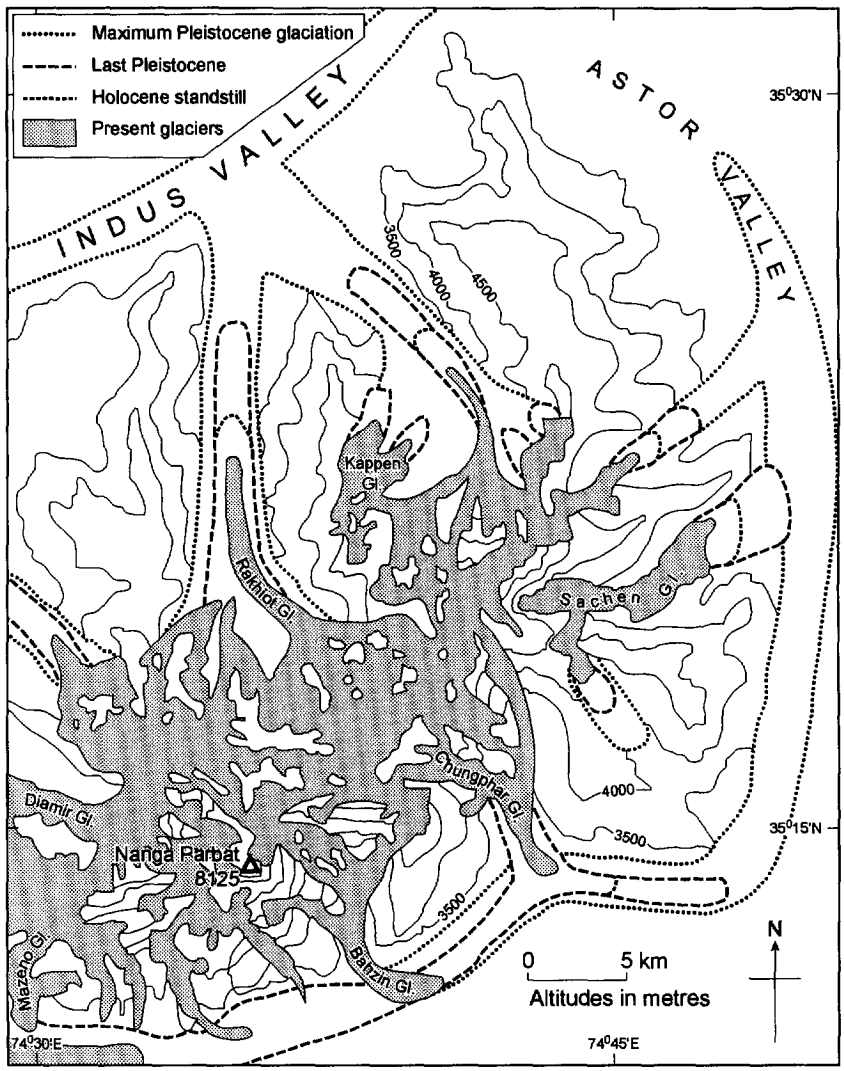

FIG. 6. Reconstuction of former ice limits on Nanga Parbat (after Scott, 1992).

advances during episodes of general retreat, such as push fabrics in the glacial deposits, further supporting the likelihood that the deposits represent still-stands. In addition, Scott argued that clasts within the extensive meltout tills that formed during wastage events show similar degrees of weathering throughout. This, in turn, suggests that retreat between stages was relatively rapid. In contrast, the thickness of the still-stand deposits implies that these deposits took a relatively long time to form.

Although no absolute dates have been obtained for the Nanga Parbat deposits, Scott (1992) compared her stratigraphies with the dated sequences in the Hunza valley (Derbyshire *et al.*, 1984). On the basis of morphology and relative weathering characteristics, she suggested that the Nanga Parbat deposits are of late Pleistocene age. Those in the middle Astor valley are assigned a Middle to Upper Pleistocene age, and two distinctive levels within these are correlated with the Yunz and Borit Jheel Stages of the Hunza valley. The large glacial accumulations in the lower reaches of the Rupal, Rakhiot and Rama valleys are assigned an Upper Pleistocene age, correlating with the Ghulkin I Stage in the Hunza valley. The glacial still-stand deposits in each valley are correlated by Scott with the Ghulkin II Stage at the end of the Pleistocene, while the ice-contact deposits nearest to the present glaciers are considered to be correlative with the Batura deposits, representing a glacial advance during early Holocene times. The largest lateral ridges are regarded as equivalent to the Pasu I and Pasu II Stage moraines of the Hunza valley. However, none of these correlations is constrained by dates, and unique (local) stratigraphic names for each of the glacial events described in this region by Scott (1992) have not been provided.

In the view of Scott (1992), field evidence from the Nanga Parbat massif indicates that no glacial readvances took place after the glacial maximum of late Pleistocene times. Rather, glacial retreat from this maximum was merely punctuated by periods of still-stand. She suggests that this was caused by factors other than a reversal of the regional warming trend, such as increases in glacial accumulation resulting from increases in precipitation brought about by a changing regional wind system, including fluctuations in the monsoon. In addition, she points out that uplift resulting from tectonism or isostatic

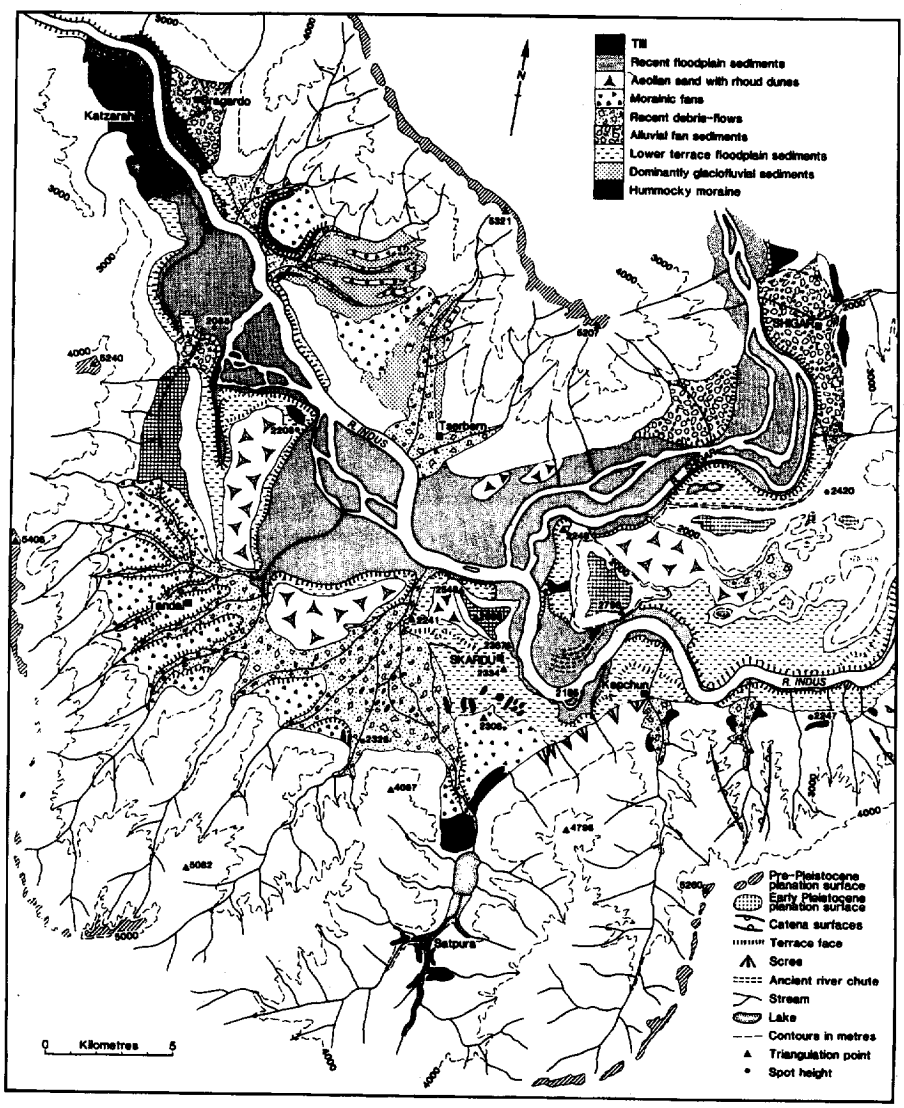

FIG. 7. Geomorphological and sedimentological map of the Skardu area (after Dainelli, 1922; Cronin, 1982; Owen, 1988b).

rebound could have increased ice accumulation by the promotion of orographic rainfall and the provision of more topographically efficient accumulation areas. It was argued that such changes in glacier accumulation might have caused a halt in glacier wastage.

SKARDU BASIN

The Skardu basin, some 30 km long and 15 km wide, lies at the confluence of the Indus and Shigar Rivers. Dainelli (1922) was the first to map the superficial deposits in this area. He suggested that it had been extensively glaciated. Little detailed work followed until Cronin *et al.* (1989) published a palaeomagnetic stratigraphy for the 1300 m thick sedimentary sequence at Bunthang, situated in the NW corner of the basin. This sequence comprises a basal diamicton overlain by lacustrine and glaciofluvial sediments. Cronin *et al.* (1989) showed the sequence to be magnetically reversed, and suggested that the base of it began to accumulate towards the end of the Matuyama chron (ca. 0.72 Ma). The diamicton at the base of the section was interpreted as a till and is correlated with till exposed on a butte, Karpochi Rock, near the centre of the Skardu basin (Drew, 1873; Lydekker, 1883; Conway, 1894; Oestreich, 1906; De Filippi, 1912; Dainelli, 1922). Owen and Derbyshire (1988), however, showed that the base of the Bunthang sequence has been glaciotectonised, casting doubt on the palaeomagnetic interpretation of this section.

The most detailed study of the glacial history of the Skardu basin is that by Owen (1988a, b). He recognised a number of planation and glacial surfaces throughout the Skardu basin and the Shigar valley (Figs 7 and 8). The highest of these is at an altitude of 5000–5400 m, suggesting that it is probably pre-Pleistocene in age. This surface may be correlated with a surface at a corresponding altitude in the Hunza valley (Derbyshire *et al.*, 1984). Along the Shigar valley, at 3200–3500 m altitude, glacially eroded benches with a cover of till were also recognised. Owen (1988b) suggested that these glaciated surfaces probably correlate with surfaces at a similar height on the southern side of the Skardu basin, representing an early extensive glaciation of the basin and the Shigar valley, although the possible effects of

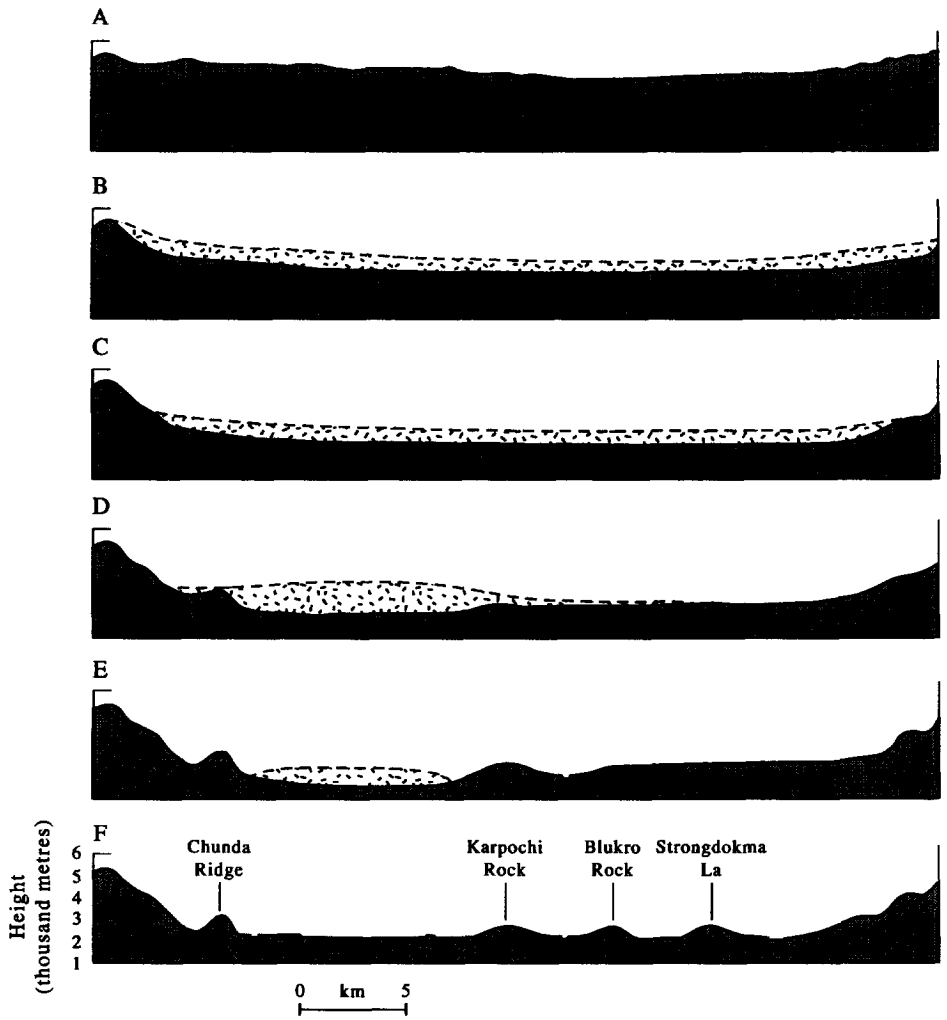

FIG. 8. Cross-section across the Skardu Basin showing stages of planation, and glaciation surfaces (after Owen, 1988b). (A) Pre-glaciation; (B) Earliest broad valley glaciation (Shanoz Glaciation); (C) Second glaciation (Yunz Glacial); (D) Third glaciation (Borit Jheel); (E) Restricted valley glaciation; (F) Present topography.

differential uplift due to the active tectonics across this region remain to be evaluated. A subsequent glaciation eroded this glaciated surface, deepening the Shigar valley and producing an extensive surface of erosion. A later glacier advance incised this landscape to produce a large mesa making up what is now Karpochi Rock, Blukro Rock, and Stronodoka Ridge. Ice over-topped this mesa depositing tills against its cliffs and on its summit surfaces. The deepened valleys were then infilled with sediment. Owen (1988b) suggested that the basal till in the Bunthang Sequence of Cronin *et al.* (1989) may be the equivalent of till deposited in such a deep palaeovalley during this glaciation.

Owen (1988a, b) showed that valley glaciers from tributary valleys advanced into the Skardu basin during Holocene times. These blocked the Indus and diverted its course over the Karpochi–Blukro–Stronodoka mesa, producing deep rock-cut channels, and so dissecting the mesa into three blocks. As yet, no absolute age determinations have been undertaken on any of these sediments but a very dark desert varnish on surface boulders in the tills suggests that they are at least early Holocene or possibly late Pleistocene in age.

KASHMIR (PIR PANJAL AND GREAT HIMALAYA)

The most recent and comprehensive study of the Quaternary glacial history of Kashmir is that of Holmes and Street-Perrott (1989) and Holmes (1988, 1991). Holmes and Street-Perrott (1989) re-evaluated the original work of de Terra and Paterson (1939) which had long been regarded as the 'type' sequence for Himalayan glaciation. They suggested that the older work misinterpreted the origin of a number of deposits, particularly those mapped as moraines, many of which are now regarded as mass movement deposits. Holmes and Street-Perrott showed that the lower limit of glaciation was much higher than that proposed by de Terra and Paterson and that no more than two phases of ice advance can be recognised in Kashmir as compared to the four phases originally suggested.

Holmes and Street-Perrott take the argument further by comparing modern glacial thresholds and mean equilibrium line altitudes (ELAs) with cirque altitudes and maximum ELA depressions. On the basis of such data, they argue in favour of a reversal of glaciation gradient

during the Quaternary. They believe that a change in the major precipitation source region can be ruled out and that the apparent reversal was a consequence of greater uplift of the Pir Panjal relative to the Great Himalaya since the onset of glaciation. It is argued that this would have had the effect of raising cirque altitudes and lowering observed Quaternary ELA depressions in the Pir Panjal.

LAHUL HIMALAYA, NORTHERN INDIA

The Lahul Himalaya in northern India marks the junction between the monsoon-influenced southern flanks of the Pir Panjal (Lesser Himalaya) and the Greater Himalaya, which today is influenced mostly by the westerlies. In addition, it is likely that the Pir Panjal underwent rapid uplift during the Quaternary, thereby influencing the style of glaciation in this region. For this reason, the Lahul Himalaya has great potential for the study of fluctuations in both the SW monsoon and the Westerlies, as well as the effects of tectonics on climate change. On the basis of detailed mapping, morphostratigraphy and relative dating, Owen *et al.* (1995b, *in press*) and Owen *et al.* (*in press*) have recognised three major glaciations in the Lahul Himalaya (Figs 9 and 10). 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 (Fig. 10A). Evidence for the second glaciation, the *Batal Glacial Stage*, is in the form of highly weathered and dissected drumlins and lateral moraines and drumlins. Two phases of glaciation can be recognised within the Batal Glacial Stage, termed here *Batal I* and *Batal II*. This was an extensive valley glaciation interrupted by an oscillating regression or a readvance (Fig. 10B). It produced a series of superimposed drumlins and inset moraine ridges. The third major glaciation, the *Kulti Glacial Stage*, is evidenced by well preserved moraines in the main tributary valleys of the Chandra valley. This was a less extensive valley glaciation during which ice advanced no more than 5 km beyond the present ice fronts (Fig. 10C). Two minor glacial advances, the *Sonapani I and Sonapani II*, are marked by small sharp crested moraines which are within a few hundred metres or a few kilometres of the present glaciers. Owen *et al.*, in press attribute the change in style and extent of glaciation in this region to topographic controls produced by fluvial incision and increased aridity throughout the Quaternary. Such progressive aridity is regarded as a product either of 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.

NW GARHWAL HIMALAYA, NORTHERN INDIA

The NW Garhwal Himalaya, northern India, is strongly influenced by the Indian monsoon and forms the upper catchment area of the Ganges. Sharma and Owen (1996) presented the first Quaternary glacial history for northwest Garhwal in the Central Himalayas. On the basis of sediments and landforms, they recognised one glacial stage, the *Bhagirathi Glacial Stage*, during which extensive valley glaciers advanced down the Bhagirathi valley to Jhala, 40.5 km from the snout of the Gangotri Glacier (Fig. 11). The ELA depression during this stage was ca. 640 m. The age of this Bhagirathi Glacial Stage is constrained by optically-stimulated luminescence dates of ca. 63 ka and 5 ka BP. The maximum extent of ice occurred ca. 63 ka BP and was not coincident with the Last Glacial Maximum of the northern hemisphere ice sheets (20 and 18 ka BP). A series of sharp crested moraines occurs 1–3 km beyond the snouts of the present glaciers. These moraines formed during the mid Holocene (<5 ka BP), in the *Shivling Glacial Advance*. Small moraines are inset into these features and, on the basis of dendrochronology, lichenometry and relative weathering, they were dated at about 200–300 BP. This event is termed the *Bhujbas Glacial Advance* and is considered equivalent to the Little Ice Age. ELA depressions of 40–100 m, and 20–60 m occurred during the Shivling and Bhujbas Glacial Advances, respectively. Since the Bhujbas Glacial Advance, the glaciers have undergone progressive retreat, initially by downwasting and retreat, and then by simple retreat. Sharma and Owen (1996) have shown that glacier retreat has accelerated during the last few decades. Impressive paraglacial fans were associated with deglaciation, representing very rapid resedimentation during and soon after ice retreat.

DISCUSSION AND CONCLUSIONS

The western Himalayas and Karakoram Mountains demonstrate a recurrent pattern of three or fewer major glacial stages and several minor ice advances that were progressively less extensive with the passage of time. The timing and status of these events, however, is poorly known because of a lack of suitable dating material essential to the establishment of an absolute chronological framework. Only with reliable chronological data will it be possible to determine whether glacial events were synchronous both throughout the region and in relation to mountains elsewhere in the world.

The glacier fluctuations of the terminal stages of the Pleistocene in the Hunza Karakoram appear to have been a diminishing series of stillstands or readvances, none of which is tightly constrained by sets of dates. The Ghulkin II advance of Derbyshire *et al.* (1984) remains undated, although it appears to be younger than 47 ka BP. The succeeding advance, the *Batura*, is also undated. However, indirect evidence in the form of weathering profiles and rock varnish led Zhang and Shi (1980) to suggest an age of 5–3 ka BP. The Pasu Glacier advanced 2.5 km downstream of its 1980 snout position between 800 and 325 ^{14}C years ago (*Pasu I*), and a little less than 1 km below the 1980 terminus at a later, but undated time (*Pasu II*). A similar waning series of stillstands/advances characterises the Nanga Parbat massif. Some of the

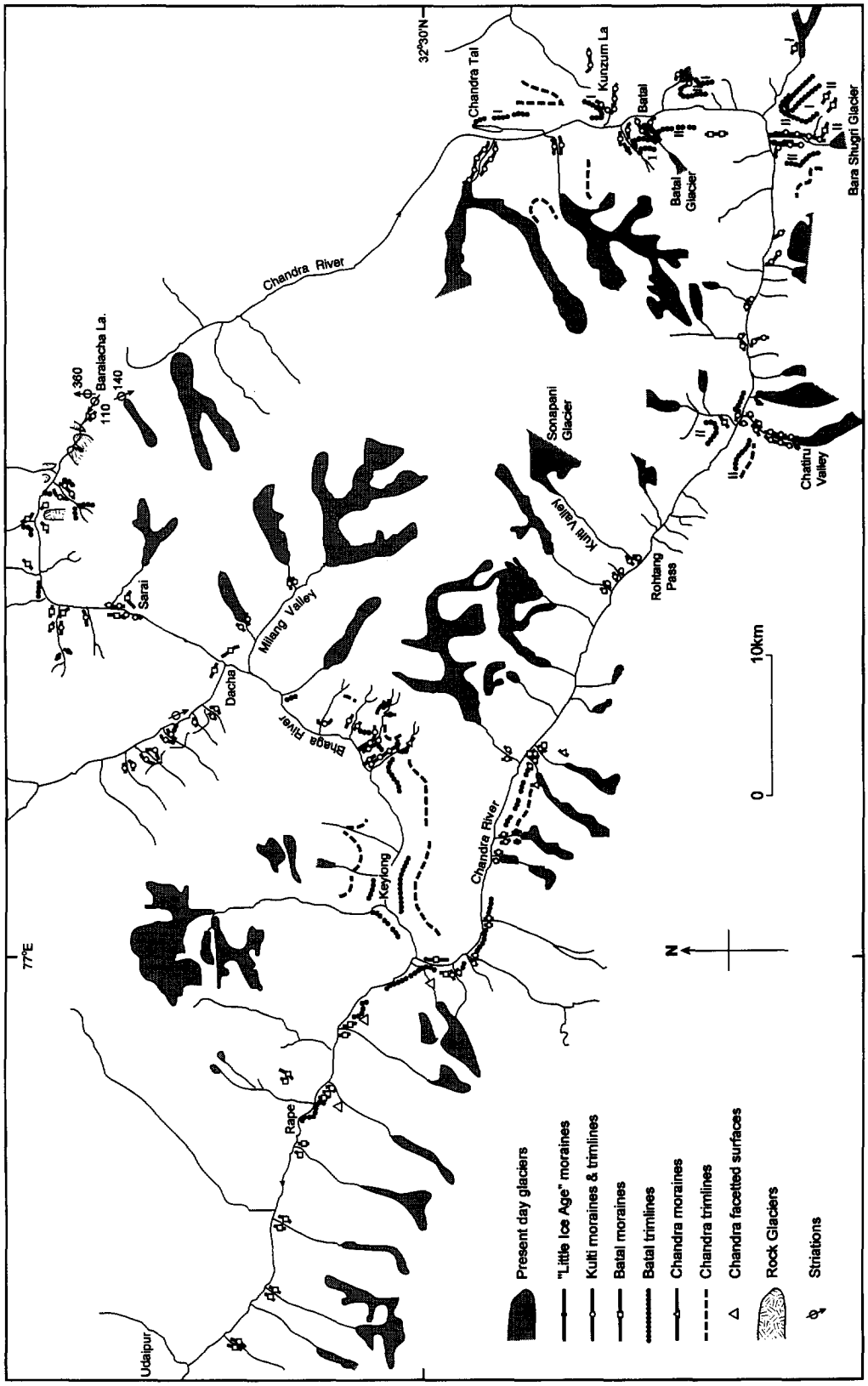

FIG. 9. Map of the Lahul Himalaya showing glacial moraines, trimlines and present glaciers (after Owen *et al.*, *in press*).

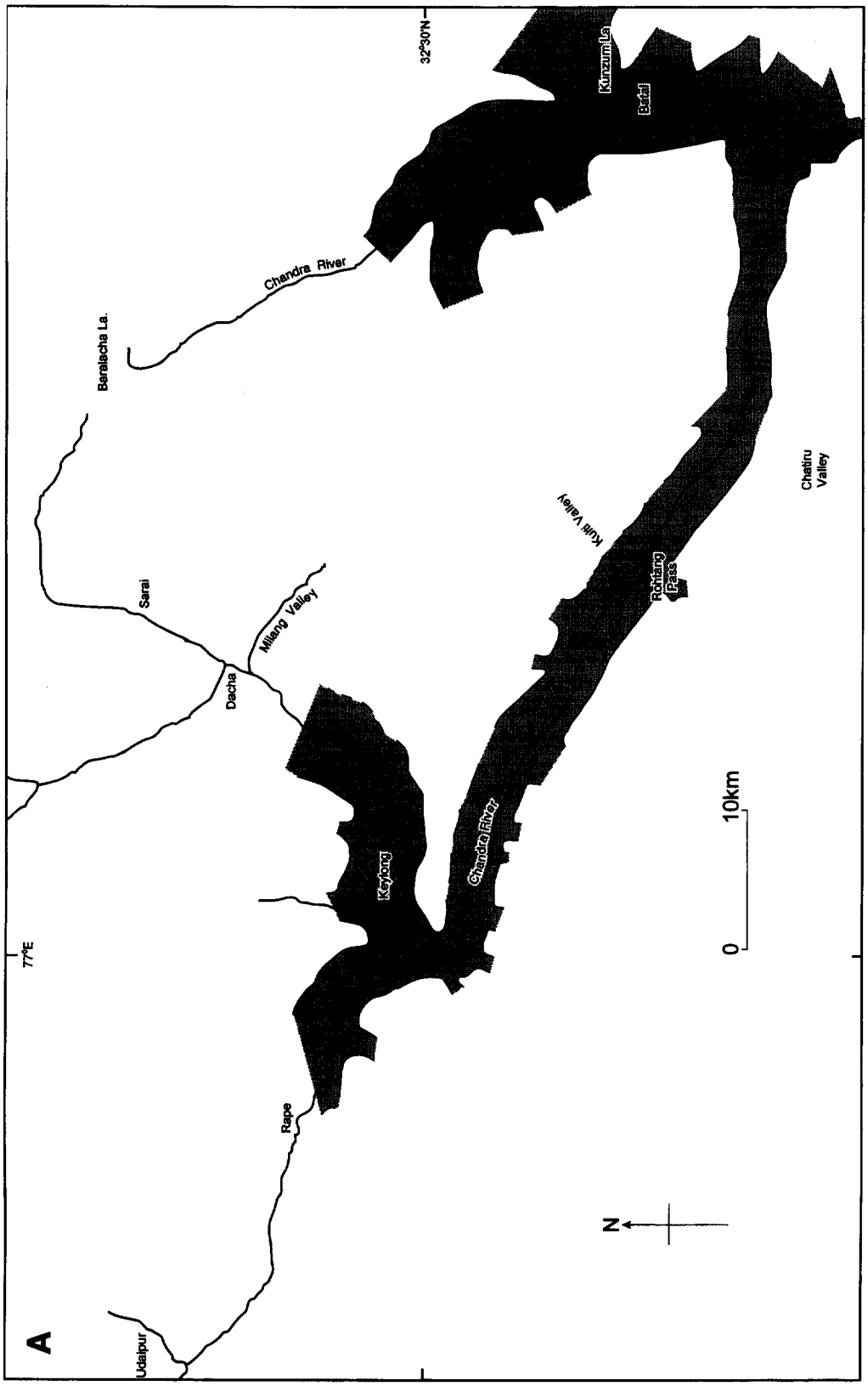

FIG. 10. Reconstruction of the former extents of ice during (A) the Chandra Stage; (B) the Batal Stage; and (C) the Kulti Stage in the Lahul Himalaya (after Owen *et al.*, *in press*).

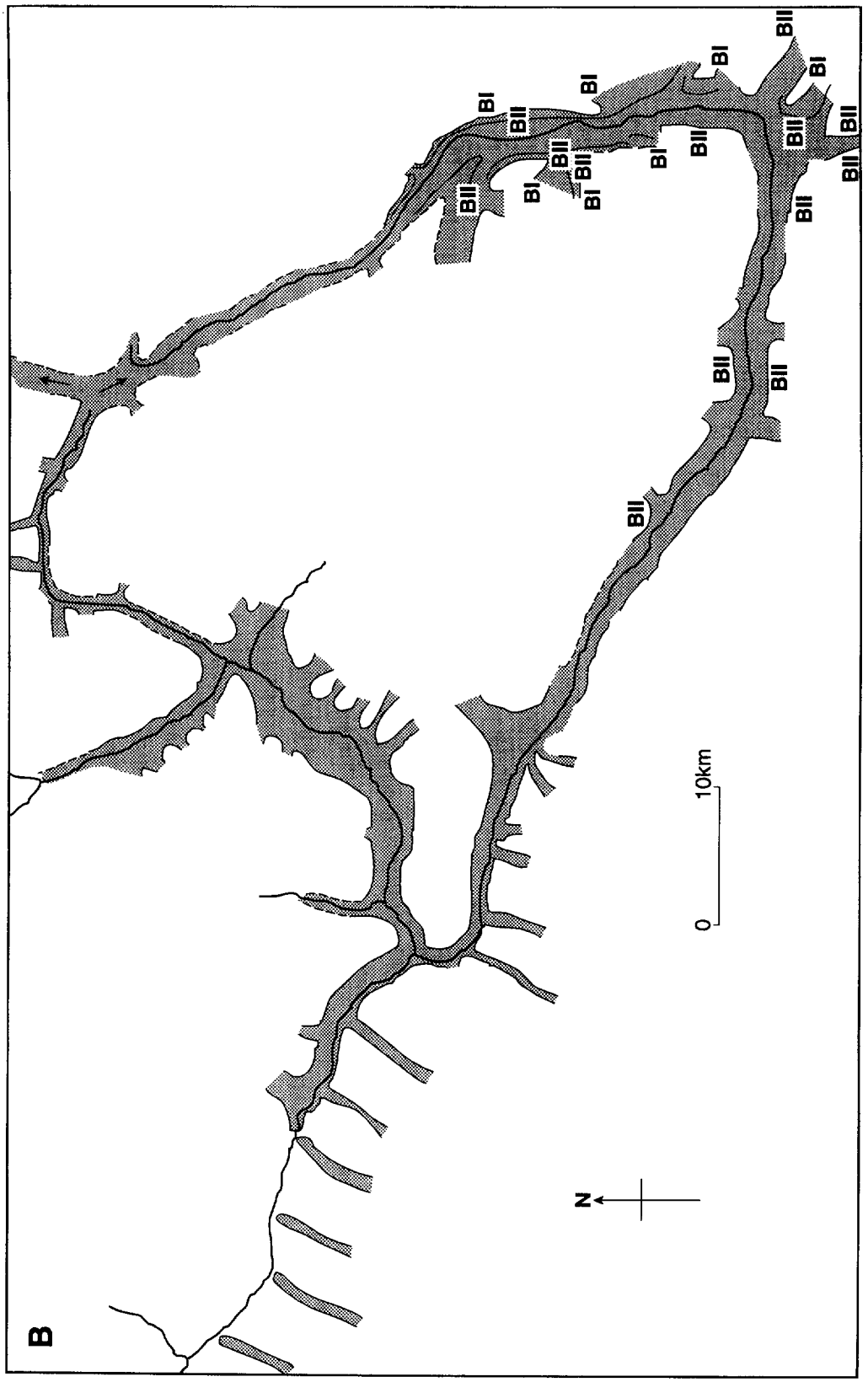

FIG. 10. B.

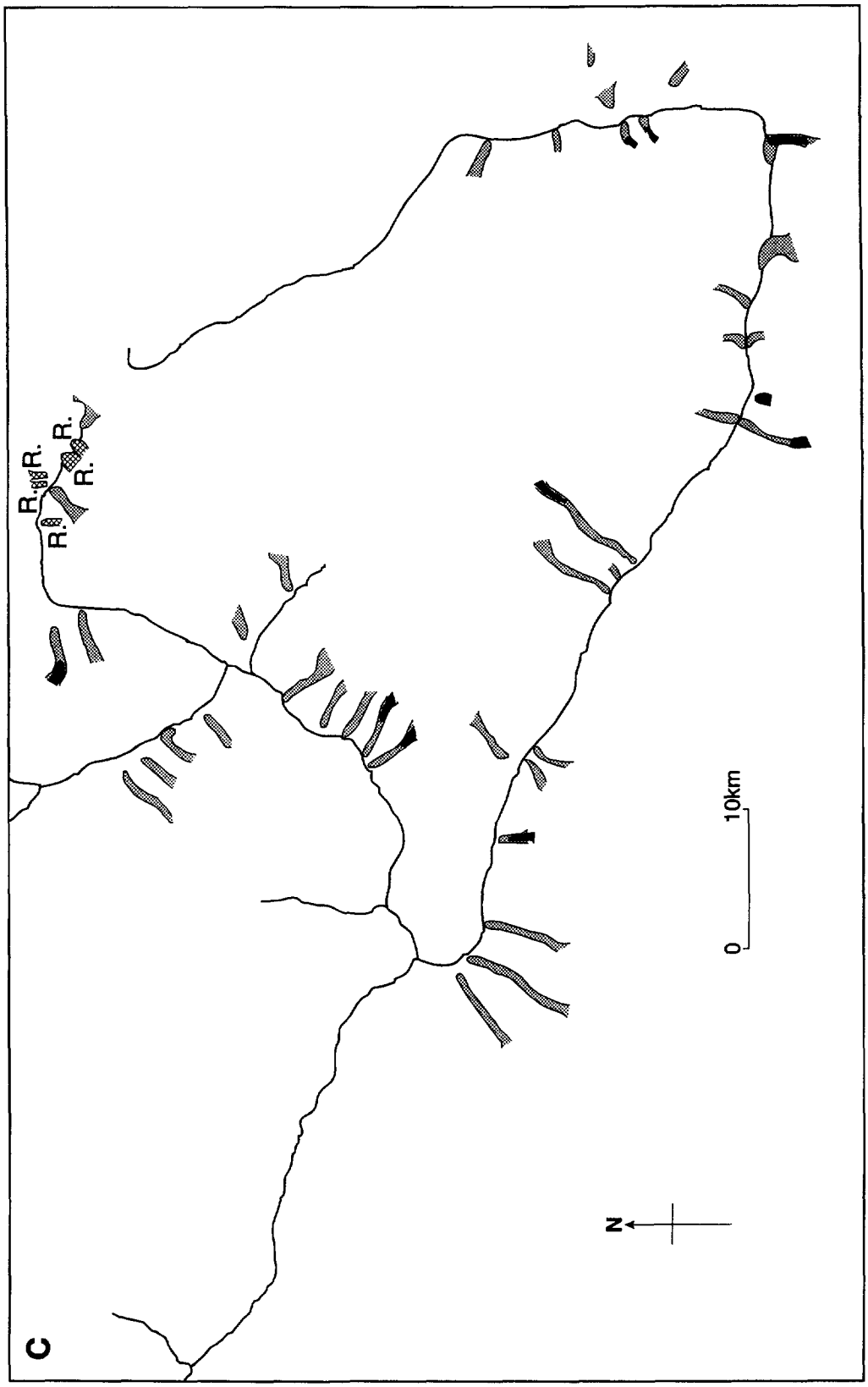

FIG. 10. C.

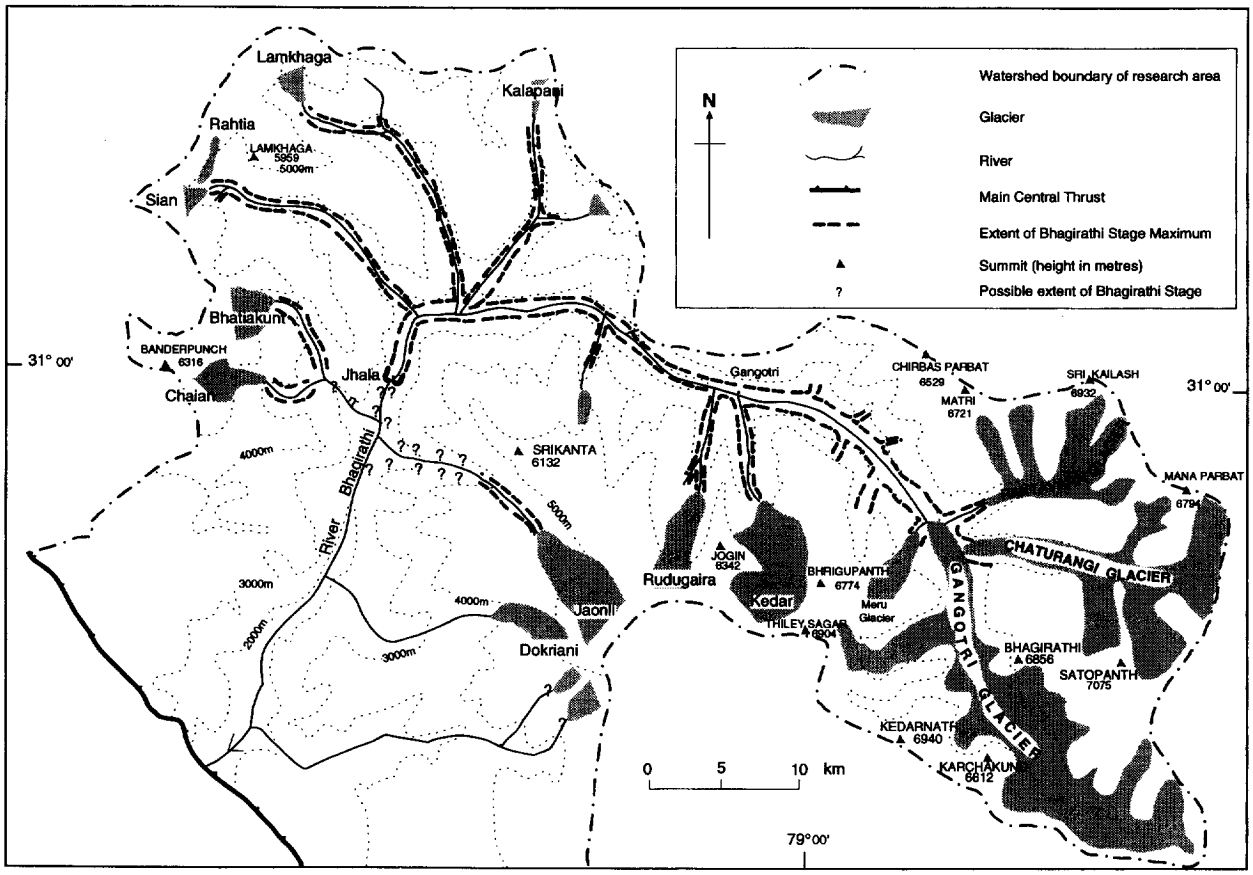

FIG. 11. Reconstruction of the former extent of ice during of the Bhagirathi Glacial Stage in NW Garhwal (after Sharma and Owen, 1996).

glaciers in the tributaries of the Indus re-entered the Skardu Basin at a relatively late stage considered, on the basis of the varnish on till erratics, to be terminal Pleistocene or even early Holocene (Owen, 1988a, b). In the Lahul Himalaya, the late Pleistocene *Kulti* oscillation left moraines just a few kilometres outside the present ice fronts. However, there is no evidence here of a mid-Holocene advance, only the sharp, fresh moraines of the *Sonapani I* and *II* advances of the late Holocene. In the NW Garwhal Himalaya, the maximum late Pleistocene ice advance (over 40 km beyond the present ice front) occurred around 63 ka BP (TL) and so was not coincident with the Last Glacial Maximum of the northern hemisphere. There is evidence of a mid-Holocene (<5 ka BP) TL age for the *Shivling Glacial Advance*, and fresh moraines mark one or more local advances 200–300 years old.

Given the recurring evidence of a substantial advance of valley glaciers in this region at some stage prior to the beginning of the Holocene (the *Ghulkin I* and its assumed correlatives: see Table 1), there is an urgent need to determine the possible chronological relationship of this event to the *Younger Dryas Stade* of NW Europe or to earlier periods of glacier growth, notably that around 18–15 ka BP reported from several widely-separated regions including South America and northern Tibet (cf. Clapperton, 1995).

Finally, Glacier retreat has accelerated in the past few decades in several parts of this region including the NW Garwhal Himalaya, Lahul and in parts of the Hunza Karakoram where, for example, the terminus of the Pasu Glacier wasted back over 600 m between 1980 and 1989.

It is important to recognise that the study of the Quaternary glacial history of the western end of the Himalayas and adjacent regions is still in its infancy. This is not simply because of the well-known difficulties of access and the constraints on precise work imposed by the scale of these great mountains, for poor adherence to strict stratigraphic procedures in many Himalayan Quaternary studies has also been a significant factor. We emphasise that there is a need to establish distinct glacial stages based on features which are unequivocally of glacial origin. Glacial stages should be clearly separated spatially, stratigraphically, and sedimentologically, and differences in age between groups of landforms and sedimentary suites based on absolute dating or, at least, relative weathering criteria. Potential errors in absolute dating ought to be fully recognised and the methods and procedures adequately described. In the case of relative weathering techniques, the effects of microclimate, altitude and aspect on weathering have to be fully considered when comparing different sites. When assigning names to glacial stages, reference should be made to type sites. The practice of naming stages 'Neoglacial', 'Late Pleistocene', 'Last Glacial Maximum', for example, is best avoided in favour of a locally-based terminology.

Only when reliable absolute dating frameworks have been established, can such stages be equated with full glacials, stades, climatic optima or glacial maxima. Such a rigorous approach is vital if locally discordant glacial fluctuation histories, such as appear to be emerging in parts of the Garwhal Himalaya, are to be authenticated and their regional and global significance evaluated.

Many studies of the Quaternary glaciations of the Himalayas have inferred the further complication of a significant tectonic influence on glaciation. Ideally, therefore, any study which attempts to relate tectonism to climate change should establish an independent measure of surface uplift. It has to be admitted, however, that it is almost impossible to establish absolute uplift rates. Climate change cannot be attributed to tectonics unless it can be shown that the climate change is not a consequence of regional and/or global changes induced by forcing external to the region. The absolute dating of glacial stages is essential. Moreover, it must also be shown that changes in glaciation are not the consequence of topographic constraints produced as a result of progressive erosion of the landscape.

In reconstructing palaeoenvironments, particular attention ought to be given to obvious pitfalls intrinsic in calculating former ELAs such as variations in aspect, snow drift and blowing, avalanche supply, aspect, topography, and possible tectonic displacements of former ELAs. It is essential to ensure adequate sampling throughout a region so as to take into account microclimatic variability. Clearly, an understanding of the variability in contemporary glacial sedimentary environments is essential in any reconstruction of former ice dynamics as proxies for climate.

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