Quaternary deposits in Ladakh and Karakoram Himalaya: A treasure trove of the palaeoclimate records

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Preliminary observations on the Quaternary deposits of Ladakh and Karakoram Himalaya and their palaeoclimatic significance are highlighted in this article. Based on the geomorphology and sedimentary field evidences, a tentative scenario of landscape evolution and climate is proposed. Our observations suggest that the Quaternary landscape was evolved due to the interaction of climate and seismicity. The earliest event was dominated by regional glacial activity that was followed by humid fluvio-lacustrine environments. This phase was succeeded by a renewed phase of glacial activity, though restricted to higher altitudes due to moisture-starved condition. Following this the region experienced marginal improvement in aridity that continued till Present. The landform diversity and Quaternary deposits provide an opportunity to undertake a multidisciplinary approach for reconstructing the history of Quaternary climate and seismicity in the region.

THE Ladakh and Karakoram in the trans-Himalaya that lies on the southwestern part of the Tibetan Plateau, has been an area of attraction for earth scientists mainly for two reasons. First, it holds the key to resolve problems related to the dynamic relationship between Indian and Eurasian plates; and secondly, to unravel the causative factors controlling the mechanism of global climate change[1]. From the palaeoclimatic point of view, the uplift of Himalaya and Tibet exerts profound influence on regional and global climate in several ways. The Tibetan Plateau for example, splits the surface westerly winds into northern and southern branches and prevents the southward flow of cold continental air towards the Indian subcontinent. The heating of the plateau provides required thermal gradient during summer that drives the South Asian summer monsoon[2]. On longer timescale, the uplift of the Himalaya and Tibetan Plateau is argued to have affected the regional as well as global climate due to draw-down of carbon dioxide by silicate weathering[3,4]. The debate is on whether the upliftment and climate change are coupled processes, or one leads to the other[5].

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Recent evidences suggest that the Himalaya and Tibetan Plateau were poorly glaciated during Quaternary[6–8]. This would imply that the region had a limited influence, such as pace maker for global climate change in triggering the major climatic events. There exist fairly good amount of data on the Quaternary climate change and tectonics of the Tibetan Plateau[8–11]. The Ladakh and eastern Karakoram area, however, is less explored[12–18] to draw inferences on palaeoclimate of the region. Based on the detailed field observations[19] along the north–south transect (Figure 1), an attempt is made to reconstruct the landscape evolution and Quaternary climate of the region.

Climate

The territory of Ladakh and Karakoram is situated in the rain shadow zone of the Indian summer monsoon. The South-

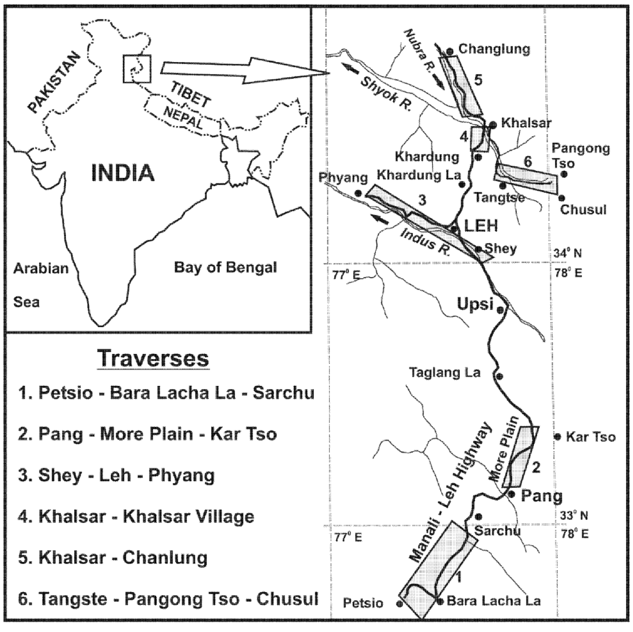

Figure 1. The study area showing details of traverses and important localities referred in the text.

east Trade Winds from the Indian Ocean and the Bay of Bengal sweep northwestwards across the entire subcontinent as far as the high Himalayan barrier. The Karakoram has entirely arid to semi-arid landscape. Westerly-derived disturbances are the dominant source of precipitation during winter, which falls as snow (October–April), and the remaining one-third is contributed by summer monsoon invasion from south[20–22]. On a regional scale, north and northeast winds bring dry weather from the barren desert of Takla Makan, the Aksai Chin and western Tibet.

Present status

Glacial processes have been the most important geomorphic activities operating in the region above ca. 3000 m altitude. Evidences of the past glacial advances are well preserved in major and minor valleys, indicating the former extents of valley glaciers. Besides this, the presence of wide U-shaped valleys is a clear manifestation of glacial erosion in the region. Glacial streams have laid-down well-developed flood plains followed by terrace sequences. The fluvial processes are operative in areas around 3000 m altitude, a zone of enhanced moisture in the otherwise arid environment. Seasonal variability in temperature controls fluvial discharge and sediment supply. During summer the rivers are turbid and flash floods are quite common in the region. This is evident from the presence of assorted sediments along the course of major rivers. In addition, rivers in the region cause significant denudation and estimates suggest that the rate in the upper Indus and Hunza valley varied between 1 and 5–6 mm/yr, respectively[22]. Sediments thus generated by the denudation are deposited under different geoenvironmental settings such as glacial, glacio-fluvial, lacustrine, alluvial fan (debris flow), aeolian, and mass movements[21].

The early explorers provided some impressive descriptions of the glacial landforms, sedimentary deposits and geomorphic features in Karakoram Mountains[23–28]. Influenced by the glacial sequences in European Alps, Dainelli[29] proposed a fourfold glacial advancement in Ladakh and Karakoram region. Considering the geomorphological and climatic situation, however, this classification probably has little or no relevance to the glacial history of the Ladakh and Karakoram Himalaya[30]. The occurrences of 'bottom moraines' within the terrace succession led Norin[31] to interprete that the ice of the last Pleistocene glacial maximum (Shigar glacial sub-epoch) filled the whole of the Indus drainage system, and descended to altitudes between ca. 1675 and 1830 m on the Kashmir side. He further believed that most of the valleys in Baltistan were originally filled with several hundreds of metres of drift from Shigar glacial sub-epoch. Large boulders on the Potwar Plateau named as 'Punjab erratics', were transported during the ice age that extended down the Indus Valley during maximum advance[31]. However, it is now believed that the glaciation was not so extensive to reach as far down the Punjab, and in fact these erratics were carried down the Indus Valley by catastrophic floods[32–34]. Paffer *et al.*[35] and Schneides[36] emphasized a relict 'pre-Pleistocene relief' above 4000 m, with a shoulder below 3000 m. Derbyshire *et al.*[37] confirmed the occurrence of similar Pleistocene surfaces (Patundas surface) between 4100 and 4200 m altitudes in Pasu area of the Hunza Valley. In addition an older surface above 5200 m was also identified and assigned Pliocene age[37].

Derbyshire *et al.*[37] provided the first absolute ages on the glacial sediments using thermoluminescence and radiocarbon dating methods. Threefold glacial sequence seems to be indicated throughout the area studied. Besides this, some attempts have also been made to explore the lacustrine records in the region in order to reconstruct the past climatic history[13–18]. However, so far no concentrated effort has been made to study the full potential of the region for palaeoclimatic and palaeoseismic reconstruction. Here observations made along the N–S and E–W transects provide a first-order framework of the successive climatic events that may help evolving the methodology to generate high-resolution climate and tectonic history of the Ladakh and Karakoram Himalaya.

Transects

Detailed field observations (Figure 1) were made along the Manali–Leh National Highway from Petsio in south of Bara Lacha La to Leh, from Khardung village to Changlung in Nubra Valley, from Khalsar to Partapur along the river Shyok, and from Chang La to Pangong Tso and Chusul in the Eastern Karakoram.

Petsio – Bara Lacha La – Sarchu

A deep valley carved by the Bhaga River between Petsio and Bara Lacha La (La = pass) exhibits scenic valley slopes covered with scree deposits. The scree apron provides a gentle coat to the slopes. At places, deep vertical furrow-like features are prominent. Furrows are deep scars with sharp crests, often terminating abruptly halfway down the slope with crescentic lobs. Multiple furrows, which mimic the mini- cirque with lateral and terminal moraines, are also observed (Figure 2 *a*). In addition, rib-like features known as 'stripes' are also found on the slopes. Stripes are elongated bodies with convex surfaces composed of finer material, whereas the intervening depressions are filled with coarse pebbles (Figure 2 *b*). The Bara Lacha pass (5000 m) acts as a water-divide between the southwest-flowing Bhaga river and the northeast-flowing Yunam that meets east–west draining Lingti Chu at Tingting Khur and flows northward as Tsarp Chu.

Extensive glacial landforms are well preserved around the Bara Lacha pass. These include glacial valley-fill deposits,

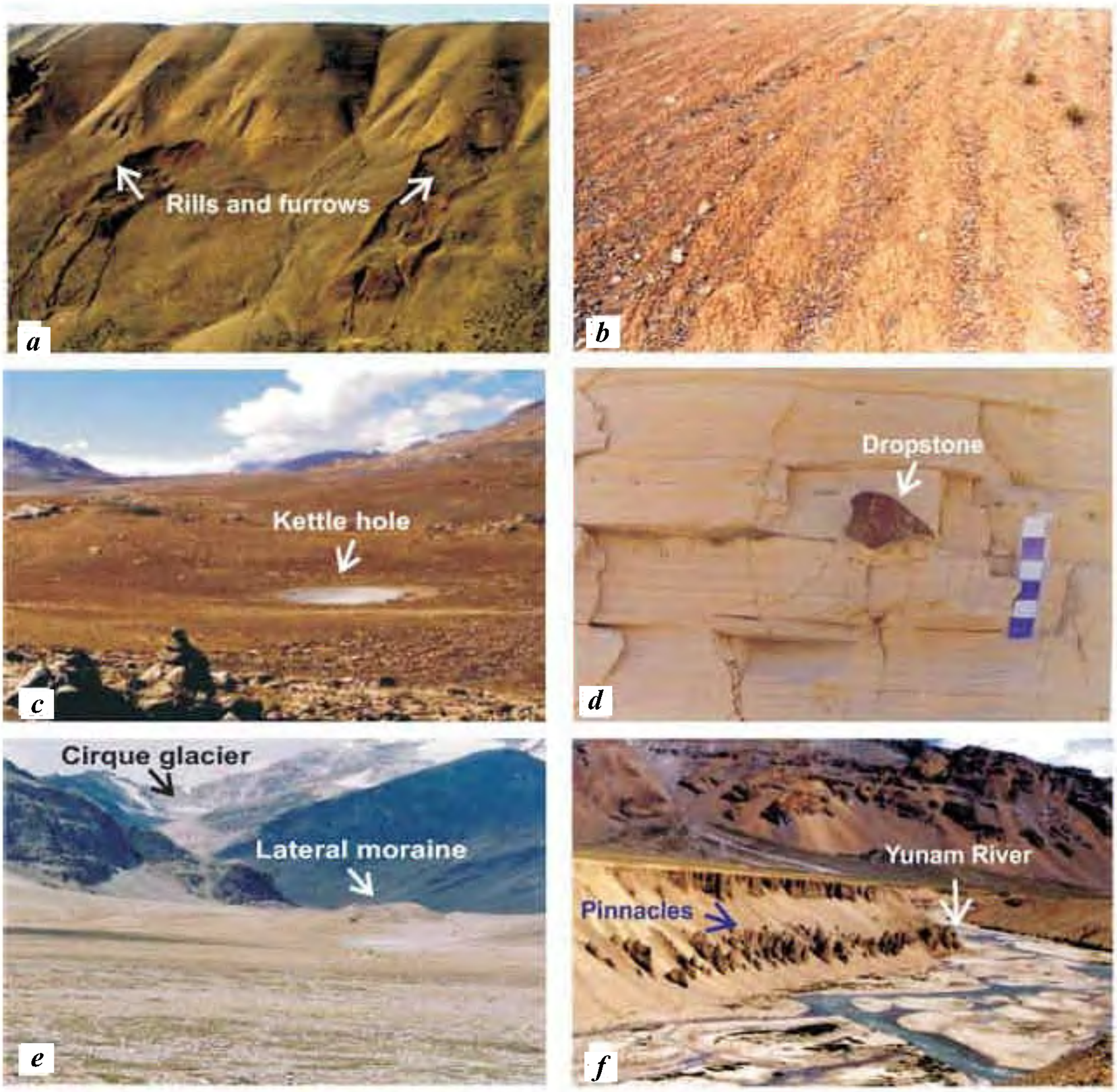

Figure 2. Traverse between Petsio and Sarchu Plain. ***a***, Slided mass and multiple furrows appearing like mini cirques. ***b***, Stone stripes. Crioturbeted features on a sliding ground (cf. Figure 4 *c*). Convex surface is composed of finer material compared with relatively coarser material along the depression. ***c***, Kettle hole feature formed by melting of dead ice of retreating glacier observed at Bara Lacha Pass. ***d***, Lacustrine sediments exposed near Bharatpur, north of Bara Lacha Pass exhibiting a varve sequence containing dropstones (scale = 6 cm). ***e***, Cirque glacier north of Bara Lacha Pass showing old lateral moraine. ***f***, Meandering channel of north-flowing Yunam river in Sarchu Plain. Note the scenic view of a gravel bed projected as pinnacles.

kettle holes (Figure 2 *c*), lateral, ground, and terminal moraines, drumlins and varve deposits (Figure 2 *d*, *e*). Impressive trails of moraines situated ca. 100 m above the valley floor are well preserved along the course of river Yunam that drains into the Sarchu Plain, north of Bara Lacha pass. These are huge elongated mounds of boulders of irregular shape and size, having deep brown (chocolate) lustrous surface (desert varnish). Between the two flanking moraine ridges, the wide valley is filled with glacio-fluvial deposits. It is likely that the wide basin supported a lake till recent past, as it is still called Yunam Tso (lake). The drained-out lake has exposed about 8-m thick sequence of varve sediments. Trails of drumlins followed by hummocky structures are well preserved in the proximal area of the Sarchu Plain. The drumlins may be genetically related to the lateral moraines in the upper reaches.

The wide Sarchu basin is filled with thick fluvial sediments that are incised by the river Yunam, giving rise to flat-topped elevated terraces occurring ~100 m above the river bed. The present river is a braid-meandering type with dominance of point bars and distributary channels, implying that the incised sediments were deposited under improved hydrological regime (Figure 2 *f*). Presence of glaciogenic sediments above the fluvial deposits that constitute the Sarchu Plain suggests that the glacial process post-dates the formation of the Sarchu Plain.

Landscape evolution in this segment reveals that the river Yunam once supported a valley glacier that scoured a wide U-shaped valley (Figure 3). Following this, sediment-laden melt water fluxes dominated by gravel led to gradual aggradation of the basin, giving rise to Sarchu Plain. At places, the Sarchu gravel bed is folded, suggesting the post-depositional deformation[38].

The aggradational phase subsequently ceased with the advent of a small-scale glacial event confined to the northern base of the Bara Lacha pass. The subsequent incision by smaller streams led to the development of gravel pinnacles that stand out impressively (Figure 2 *f*). These features continue into the More Plain, which is the most spectacular geomorphic feature of the Ladakh area.

Pang – More Plain – Kar Tso (Tso = lake)

A gently undulating, northward-sloping surface with a central depression occupied by a dry Rokchung Nala called the More Plain is spread over around 200 km^2 area (Figure 4 *a*). The Nala takes a U-turn where it is called Ponge Yak Nala that peters out in the sands of Kar Tso (Figure 4 *b*). Except for the presence of high-altitude grasses, the plain is otherwise dry. A number of seasonal streams descend from either flank of the plain and meet the depression at right angles. The geomorphological evolution of More Plain is similar to the Sarchu Plain. The exposed sections (>150 m) show an alternating sequence of gravel and sand beds, indicating rhythmic fluctuation in fluvial aggradation.

Towards the northern margin, sand dunes ingress upon the More Plain. Largely barchan dune or coalescing barchan show well-developed inter-dunal depressions. The southern margin, however, is devoid of sand dunes; instead the surface is covered with closely set 'stone polygons' (Figure 4 *c*) having convex, fine-grained relief lined by pebbles or coarse material. Such features[39] generally develop where the mean annual ground temperature lies between 30 and 40 °C. These features were formed due to the thawing of surface material around the polygon that eventually fills the fissures appearing like 'stone stripes' on a sloping ground (Figure 2 *b*). Butzer[40] has vividly summarized the phenomenon of cryoturbation resulting in the formation of 'stone polygons' and 'stripes'.

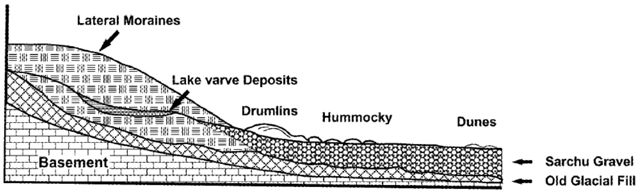

Figure 3. Event stratigraphy of sediment succession along the upper course of Yunam river, north of Bara Lacha Pass.

The above observations reveal that glacial conditions not only carved wide valleys, but also generated enormous debris in the upper reaches. During the subsequent warm and humid conditions, thick fluvial gravels aggraded the basin. Considering the regional extent of the fluvial sedimentation, a sustained hydrological regime can be invoked. The younger fluvial sediments in More Plain show distinct fining-up sequence, indicating weakening of the hydrological regime probably associated with the beginning of aridity in the region. The supporting evidence also comes from the presence of glaciogenic sediments following the fluvial phase, and presence of cirque glaciers in the region (Figure 4 *d*), implying that glaciers never descended down to the More Plain since their retreat probably after the penultimate glaciation predating the Last Glacial Maximum (LGM).

Record of the dwindling hydrological regime succeeding the fluvial aggradation stage is also evident from the receding shore margins of Kar Tso and other lakes in the region. Glacier-fed rivers draining through the More Plain are the feeders to the brackish water Kar Tso that is located on its eastern margin. The periphery of the lake is an extensive sandy waste with raised shorelines, suggesting shrinkage in lake level since its formation (Figure 4 *b*). Four raised shorelines (strands) separated by smooth corrugated features indicate that lowering of the lake level was gradual. We attribute it to the reduction in fluvial input from the catchment, or the capture of the main feeder Sumkhel Lungpa by the Toze River. Phillip and Mazari[41] attribute the shrinking of lake margins solely to tectonics, but do not rule out the climate factor.

Shey – Leh – Phyang

Three geomorphic features, viz. low-angled coalesced colluvial fans, palaeolake deposits, and dune fields stand out on the topography between Upshi and Leh. Extensively incised palaeolake deposits could be seen along the stretch of the Leh airport road and beyond up to Phyang. These are light buff-coloured cliffs forming tableland topography similar to the Upper Karewa deposits of Kashmir Valley. The profiles measure nearly 50 m in thickness, consisting of thinly laminated yellow to dark clay laminae punctuated by sand horizons. It appears that these sediments were deposited in a tectonically induced landslide-dammed Indus river. One of the evidences suggesting tectonic activity was the presence of displaced boulders on either flank of the river. These boulders are similar to those found in the vicinity of the palaeolake. Similar observation was made by Phartiyal *et al.*[18]; however, the interpretation needs further confirmation.

Well-preserved obstacle dunes located between Shey and Sabu on Upshi–Leh highway (Figure 5 *a*), abut against

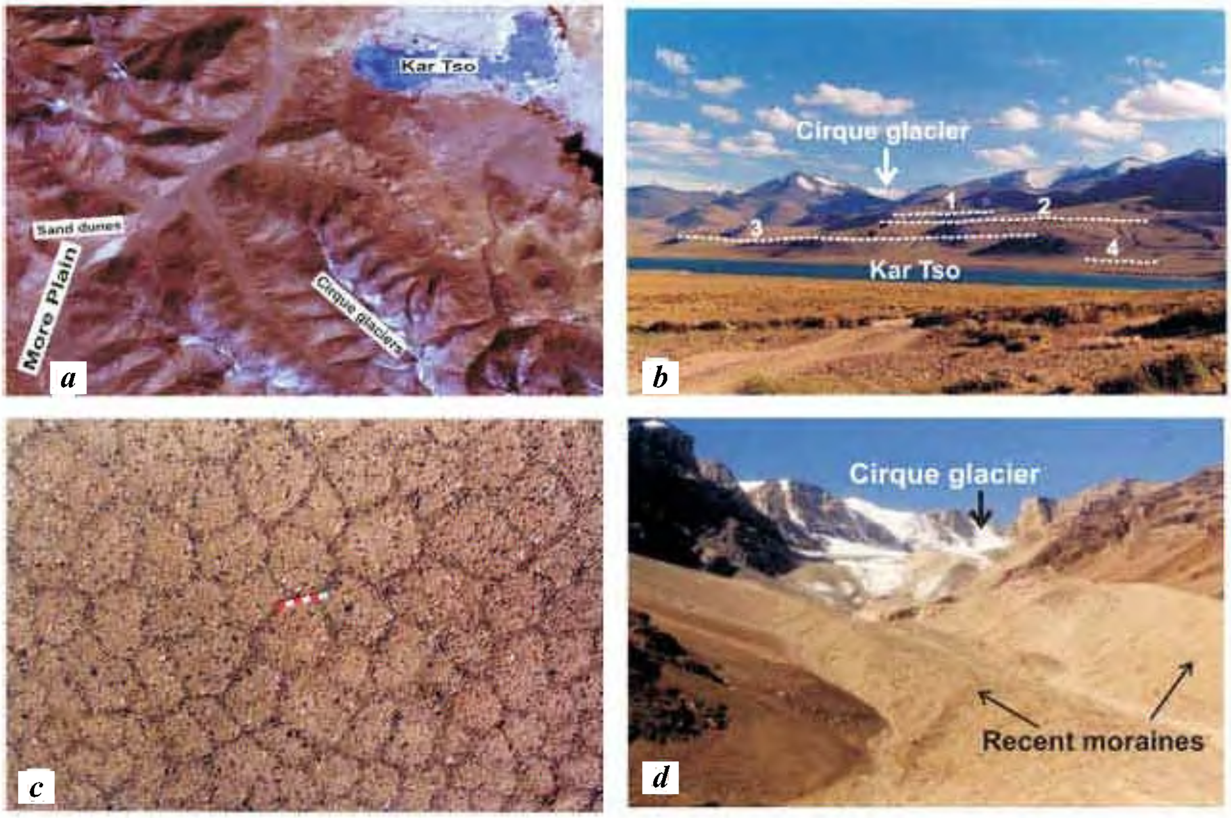

Figure 4. Traverse along the More Plain and Kar Tso. ***a***, False colour composite of More Plain and Kar Tso. ***b***, View of Kar Tso showing shrunken water body, flight of strandlines preserved along the western slope, and cirque glaciers confined to higher reaches. ***c***, Stone polygons. Cryogenic features on the horizontal ground (cf. Figure 2 *b*) of More Plain (scale = 6 cm). ***d***, Hanging cirque glacier with foreground showing well-developed recent lateral moraines.

Figure 5. Traverse between Shey and Leh in Indus Valley. ***a***, Obstacle dune developed near Shey en route to Leh. ***b,*** Deflation hollows, a typical rock-weathering feature of cold arid climate.

hills on the right flank of the Indus river. At places, they appear to climb over the hills. Unlike the previous traverses, the surrounding hills in the basin are devoid of scree. The fresh section of a stabilized dune near Sabu showed five distinct bounding surfaces that were identified based on the degree of induration and presence of mud drapes. These surfaces indicate temporary hiatus in dune accretion. Evidences suggesting intense wind activity are further substantiated by the presence of ventifacts, wind-sculptured exposed rocks (cf. inselberg), polishing/varnishing rock surfaces and occurrence of deflation hollows (Figure 5 *b*).

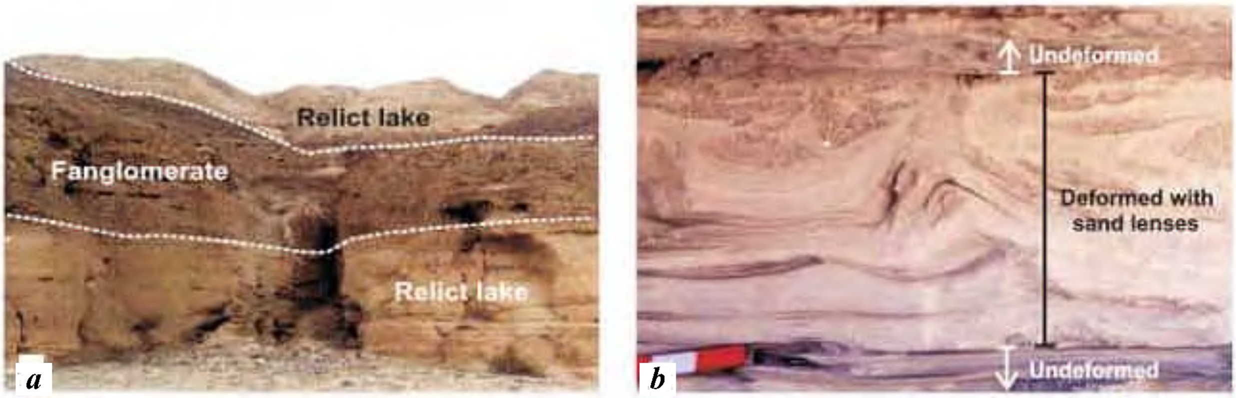

Figure 6. Traverse near village Khalsar. ***a***, Closer view of palaeolake sediments exposed near Khalsar. ***b***, Syn-sedimentary deformational features (seismites) preserved in Khalsar palaeolake sediments.

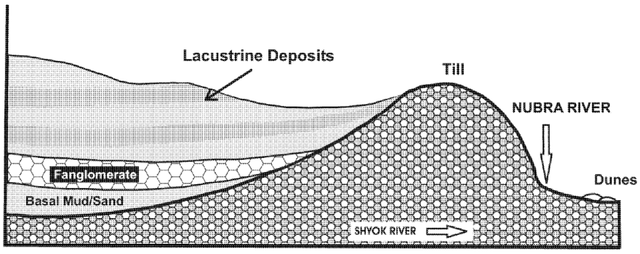

Figure 7. Event stratigraphic succession around Khalsar.

Khalsar – Khalsar village

Khalsar is a small hamlet in the Shyok river basin across the Khardung La. Small glaciers are found on its northern slope facing the Shyok Valley. The Shyok river emerges from the eastern side of the Karakoram and flows north–south before it takes a westerly course to join the Nubra river. The Quaternary sediments exposed along its left bank could be traced up to 10 km from east of the village Sati to its confluence with river Nubra. In this area, the Quaternary stratigraphic succession begins with indurated lateral moraine (Till) that can be traced ~5 km downstream up to Khalsar. These deposits have erroneously been labelled as 'slide mass'[18] suggesting landslide debris, whereas undisturbed till fabric (typical glacial boulder clay deposit) with fairly well-preserved morphology suggests otherwise. In addition, occurrence of drumlins and glacially striatated valley walls suggests that the river Shyok was dammed by coalescing of Nubra and Shyok moraines that may have been breached by the activation of the Karakoram strike-slip fault at a later stage. At the proximal end, nearly 20-m thick alternate beds of sand and mud superimposed by about 40-m thick clast-supported fanglomerate overlie the Shyok moraine. Towards the top, the semi-consolidated sand body interbedded with massive mud horizons overlies it (Figure 6 *a*). At places, the lacustrine deposits exhibit convolute bedding showing narrow anticlines with typical upward increasing amplitudes and relatively broader synclines. Such structures can be ascribed both as water-escape and load cast. There is no density difference between the underlying and overlying sediments, as these are mainly silt and sands and hence can be suggested to be formed by seismically induced liquefaction[42]. Their proximity to the active Karakoram Fault[21], further strengthens this interpretation (Figure 6 *b*).

Lateral moraines developed around Khalsar (Figure 7), document the extension of valley glaciation during the cold stadial/glacial condition. Following recession of the valley glacier, the lacustrine environment was established in the basin that led to the deposition of sand and mud sequences. A thick sequence of fanglomerate associated with high relief and dry climate in the middle of the exposed lake profile indicates temporary disruption in lacustrine environment.

Khalsar – Changlung

Nubra river emerges from the Siachen Glacier and flows north–south to meet the Shyok at a right angle before it takes a westerly trend (Figure 8 *a*). Between Sumur and Deskit, the lateral moraines laid down along the river Nubra are perched on steep slopes. The glacial striations developed on the rock faces along the left bank of river Nubra near Tirit (Figure 8 *b*) at ~3231 m altitude, indicate the extent of past glaciers in the basin. Striations are oriented parallel to the flow direction of the river. The lateral moraines are weathered and have undergone extensive gullying, leading to the formation of fans (Figure 8 *c*). They also appear at the junction of Nubra and Shyok rivers near Deskit. In addition, there are well-preserved drumlins near the confluence. These are typical ice-contact tills formed by glacial melt waters. Field observations thus suggest that the Siachen Glacier once descended to the point where the two rivers meet today. The magnitude of glaciation can be assessed from the location of moraines that scooped a deep and wide

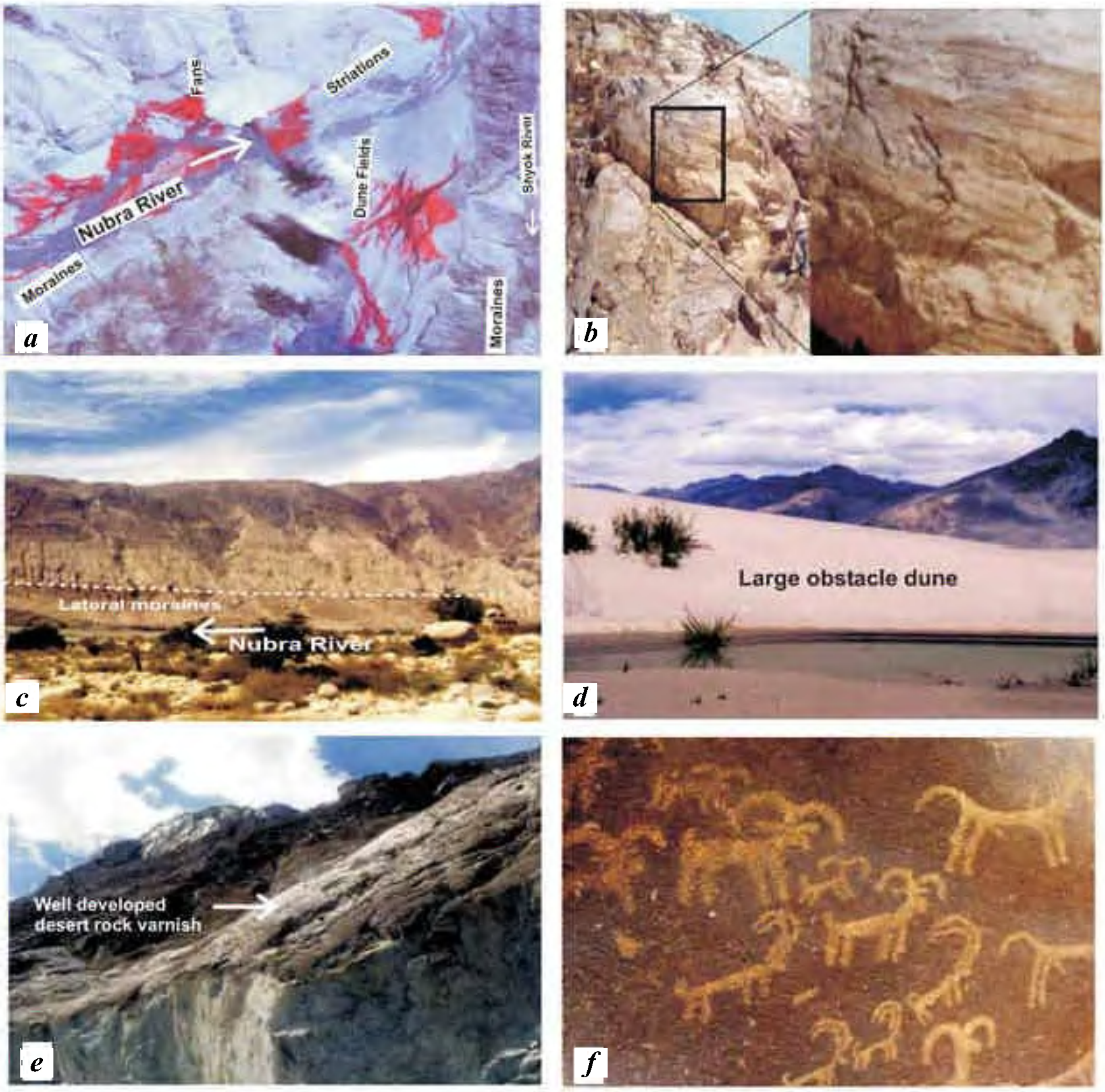

Figure 8. Traverse along Nubra river between Khalsar and Changlung. ***a***, FCC of Nubra and Shyok confluence showing well-exposed moraines and dune fields. ***b***, Glacial striations observed on an exposed granite surface near Tirit in Nubra Valley. The striations run parallel to flow direction. ***c***, Lateral moraines exposed along the right bank of river Nubra near Panamik. ***d***, Large obstacle dunes observed along the left bank of river Shyok near Hunder. ***e***, Varnished rock surface with oily lustre on the exposed granite surface observed en route to Panamik in Nubra Valley. ***f***, Neolithic rock engravings depicting a herd of ibex, near Changlung (Nubra Valley). Chocolate brown varnished surface engraved by pecking technique was used by the Neolithic people of the Kashmir Valley.

basin. Today, the snout of the Siachen Glacier is located at ~4800 m altitude, nearly 30 km upstream of the glacially striated rocks near Tirit. Except for the large dune fields near Hunder (Figure 8 *d*), no Quaternary deposit is observed downstream of the river Shyok.

The wide braided river Nubra carries little water to match its size. Both Shyok and Nubra rivers share similar geo-hydrological features, except that the Nubra has a span almost threefold larger than that of Shyok. The wide bed of river Nubra is occupied by medium to low size dunes separated by the interdunal depressions, which are filled either with water, or have an indurate crust. The occurrence of sandstorms due to cold gravity winds sweeping down the Siachen Glacier particularly during summer afternoons is a daily feature in the Nubra basin.

Another spectacular geomorphic feature of the Karakoram region is the desert rock varnish (Figure 8 *e*). This type of varnish, has not been observed so far in the Himalaya. The varnish is deep chocolate-brown, irrespective of rock types on which it has formed. It has an oily lustre that imparts a shine to the rocks. Probably the Neolithic (ca. 5000 yrs ago) hunters and food gatherers used these varnished

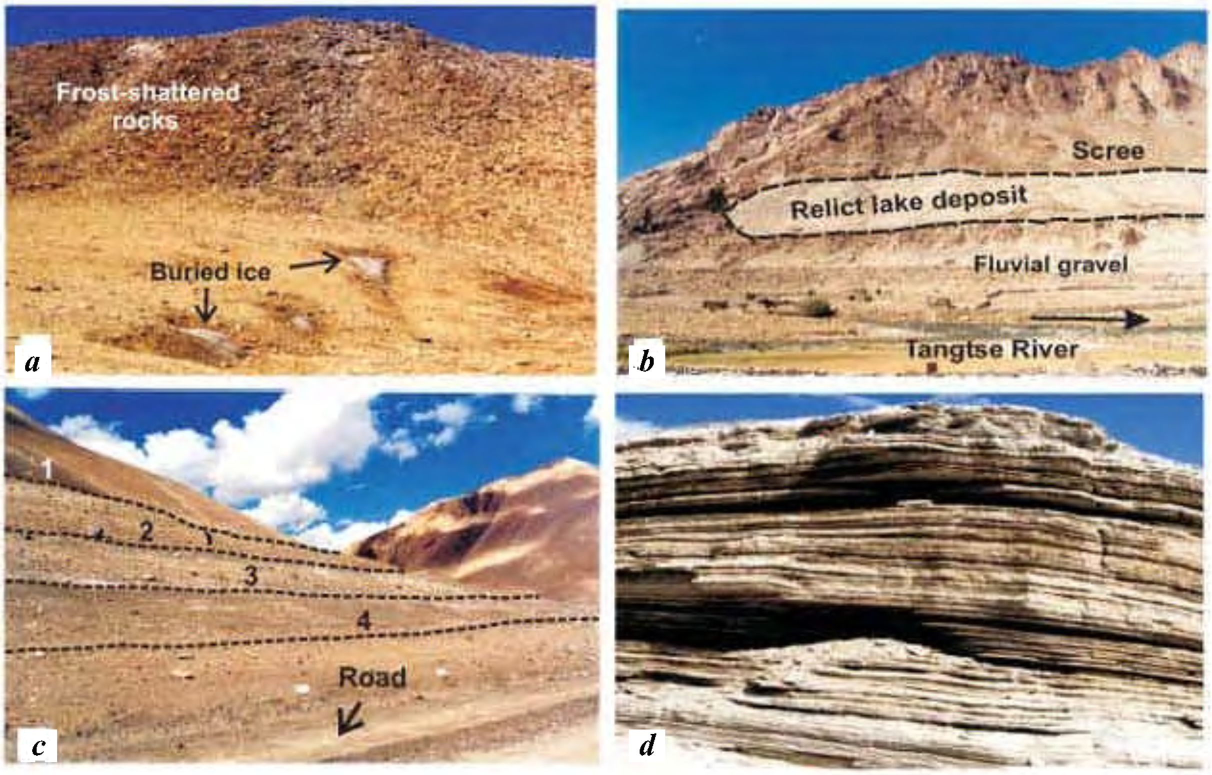

Figure 9. Traverse from Chang La to Pangong Tso. ***a***, Frost-shattered conical rubble and frozen ground showing exposed patches of buried ice at Chang La. ***b***, Thick sequence of lacustrine sediments exposed near village Tangtse. ***c***, Palaeostrands of the Pangong Tso depicting receding lake margin. ***d***, Lacustrine sedimentary sequence exposed on the NW margin of Pangong Tso.

surfaces for engravings (Figure 8 *f*). Techno-typologically, these engravings are identical to those unearthed at Burzahom – a neolithic site in the Kashmir valley[43]. Therefore, the occurrence of rock varnish may have climatic implications.

Tangtse – Pangong Tso and Tangtse – Chusul

The area is the eastern most tip of the Indian territory of Karakoram, where strike–slip Karakoram Fault splays in two branches: the north branch leading to the Pangong Tso and the southern branch towards Chusul. The area is reached after crossing the Chang La (5258 m altitude) via Durbuk.

The Chang La Pass is strewn with frost-shattered debris, whereas the Chang-La peak has been reduced to a conical heap of rubble (Figure 9 *a*). The ground beneath is in permafrost condition – a feature ubiquitous to the region, though there are no active valley glaciers. The Tangtse river has an almost straight course between Tangtse village in the east and its confluence with the tributary of river Shyok in the west. Presence of incised 50 m thick laminated mud and sand succession in the basin (Figure 9 *b*) indicates that river Tangtse was once blocked by the landslide debris at its confluence with the river Shyok. The landslide scar that gave rise to the lake, could be seen on the mountain flanking the river basin. However, in the upper reaches en route to Pangong Tso, the Tangtse river has retained the glacial debris. A good exposure apparently of the terminal and outwash moraines, could be observed immediately after crossing the ridge above Tangtse village. Above this village, a 20 to 30 m thick lacustrine succession dissected at places by rivers traversing the basin could be seen. These sediments are dominated by silty-clay; however, at places fine sand horizons were also observed. Field evidences suggest that the terminal moraines of the retreating valley glacier were responsible for the creation of lacustrine condition above Tangtse village.

The valley between Tangtse and Chusul is the widest in the Karakoram region. The wide, U-shaped valley extends up to 40 km in length to Pangong Tso. The entire stretch of the valley is monotonously marshy and vegetated with grasses typical of marshes and moors. At places, sluggish streams fed by melt waters from the cirque glacier break the monotony of the marsh. Another feature typical to this marsh is the salt-encrusted ground, particularly along the roots of grasses. Towards the Pangong Tso, small pools of water or ponds replace the marshy land. The Pangong Tso is a brackish water lake. Similar to Kar Tso of the More Plain, this lake has also shrunk in recent times. Flights of well-defined strand lines (Figure 9 *c*) in the incised surface of ~5 m thick mud and fine laminated sand could be observed (Figure 9 *d*).

Summary and conclusion

The observations made during the comprehensive field survey clearly demonstrate that the Ladakh and Karakoram area was extensively glaciated during the Quaternary period. This is amply demonstrated by the presence of wide, U-shaped glaciated valleys and extensively glaciogenic sediments along the upper course of major rivers. Well-developed lateral moraines preserved at many places (viz. Bara Lacha La and Shyok and Nubra valleys), clearly indicate that this region experienced at least two glacial advances during the Quaternary period. In Himalaya as well as western Tibet, the LGM event was less extensive due to weak monsoon[7,8]. The carving of U-shaped valleys with development of extensive moraines still well preserved above ~4000 m altitude, therefore, appears to be a pre-LGM episode of cool and moist climate that probably corresponds to increased accumulation during the Marine Isotope Stage-4 (MIS 4). Around this period, the increase in moisture condition is also observed in the northern part of the Indian Ocean[44]. In continental records, the maximum extent of glacier advance in adjoining Hunza Valley also pre-dates the LGM event[45]. In Garhwal Himalaya, this event was dated[46] to 63 ka BP.

With the retreat of major valley glaciers, lacustrine and fluvial environments dominated the region that appear to have coexisted depending upon the geomorphological situations. The lacustrine environment was restricted and prevailed in areas where the terminal moraines or landslide debris could block the rivers and created lakes. Comparatively, however, the fluvial regime was dominant during the period that followed the MIS-4. This accords well with the recent observation made by Phartiyal *et al.*[18] that lacustrine environment in the region probably post-dates 50 ka. The similar observation was also made in Higher Central Himalaya as well as western India[47,48] suggesting the prevalence of lacustrine environment and enhanced fluvial activity during MIS-3.

The terminal phase of lacustrine successions in the region was dominated by varve and rhythemite sedimentation. Similarly, the transformation from meandering to braid-meandering regime suggests dwindling in hydrological regime. This was also a period that probably coincided with the retreat in snowline leading to the development of hanging glaciers (cirques). Further, the development of frozen grounds with buried ice-wedges, stone polygons on flat grounds, and stripes and furrow-like formations on sloping surfaces, together indicate the overall reduction in moisture. These evidences collectively suggest that the region experienced significantly cool and arid conditions. This event, therefore, should post-date the humid MIS-3, and probably corresponds to the drier MIS-2 period. The lake-level fluctuations, salt-incrusted marshy landscape and sand dune development, probably represent the youngest (i.e. Holocene) climatic event. However, because of the sparse data and lack of absolute dates for various sedimentary and geomorphic archives, the above inferences are provisional and need to be verified by systematic and detailed field observations supported by multi-proxy climate records of the region.

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