

- 17 Agrawal, D. P., Dodia, R., Kothia, B. S., Razdan, H. and Sahni, A., *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 1989, 73, 267.
- 18 Yoshida, M. and Gautam, P., *Proc. Indian Natl. Sci. Acad.*, 1988, 54, 78.
- 19 Barry, J. C., Lindsay, E. H. and Jacobs, L. L., *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 1982, 37, 95.
- 20 Azzaroli, A. and Napoleone, G., *Riv. Ital. Palaeontol. Stratigr.*, 1982, 87, 739.
- 21 Kothia, B. S., *Eiszenaher Ggw.*, 1990, 40, 38.
- 22 West, R. M. and Munthe, J., *J. Nepal Geol. Soc.*, 1981, 1, 1.
- 23 Dongol, G. M. S., *J. Nepal Geol. Soc.*, 1985, 3, 43.
- 24 Mukerji, D. D., *Mem. Conn. Acad.*, 1936, 10, 323.
- 25 Prater, S. H., *Bom. Nat. Hist. Soc. Bombay*, 1971, 1.
- 26 Godwin-Austin, H. H., *Q. J. Geol. Soc. London*, 1864, 20, 383.
- 27 Kothia, B. S., *N. Jh. Geol. Palaeontol. Abh.*, 1992, 184, 339.
- 28 Black, C. C., *Palaeontology*, 1972, 15, 238.
- 29 Jacobs, L. L., *Mus. North Ariz. Press Bull. Ser.*, 1978, 52, 1.
- 30 Kothia, B. S., *Geol. Soc. India*, 1991, 38, 253.
- 31 Kothia, B. S. and Koenigswald, W. V., *Palaeontogr. Abt.*, 1992, A 22, 103.
- 32 Kothia, B. S. and Mathur, P. D., *Geobios*, (in press).
- 33 Shackleton, N. J. and Opdyke, N. D., *Nature*, 1977, 170, 216.
- 34 Repenning, C. A., in *Correlation of Quaternary Chronologies* (eds. Mahaney, W. C.), *Geobooks*, 1984, p. 105.
- 35 Boellstorff, J., *Science*, 1978, 202, 305.
- 36 Brunnacker, K., Loscher, M., Tillmanns, W. and Urban, B., *Quat. Res.*, 1982, 18, 152.
- 37 Reumer, J. W. F., *Rev. Palaeobiol.*, 1985, 4, 211.
- 38 Reumer, J. W. F., *Scr. Geol.*, 1984, 73, 1.
- 39 Kretzoi, M., *Geol. Hungarica Ser. Palaeont.*, 1956, 27, 1.
- 40 Sahni, A. and Khare, S. K., *Biol. Mem.*, 1977, 2, 187.
- 41 Patnaik, R., unpublished Ph.D. Thesis, Panjab Univ., Chandigarh, 1991.
- 42 Kothia, B. S., *Palaeontol., Soc. India*, 1989, 34, 19.

Quaternary basins of Ladakh and Lahaul-Spiti in northwestern Himalaya

T. N. Bagati and V. C. Thakur

Wadia Institute of Himalayan Geology, Dehradun 248 001, India

The Quaternary basins of Ladakh and Lahaul-Spiti regions are made up of sediments of lacustrine, fluvial and glacial origin. Quaternary tectonics has played a dominant role in the formation of these basins, differential uplift of the orogen having influenced the sedimentation of these basins, *vis-à-vis* climate and vegetation. The differential uplift during the past 35,000 years was substantially responsible for the climatic oscillations between cold-dry and hot-humid phases. These events varied from place to place due to tectonically caused elevational differences.

Introduction

THE Ladakh and Lahaul-Spiti region in northwestern Himalaya (Figure 1) is located between the Great Himalaya in the south and the high plateau of Central Asia in the north. In the cold arid to semiarid climatic zone there are a number of Quaternary basins of lacustrine, fluvial and glacial origin. The Quaternary tectonics has played a dominant role in the formation of these intermontane basins.

The nature of the Quaternary basins with special reference to the Late Pleistocene-Holocene remnant lacustrine deposits of Lamayuru (Ladakh), saline Tsokar lake (Ladakh), relict lake deposits between Kenlung and Yunam Tso (Lahaul) and ancient lacustrine deposits of Hanse-Kioto and Attargo-Lingti-

Dankar (Spiti) are discussed (Figure 1). Some aspects of lacustrine sediments of the region have recently been described by Bürgisser *et al.*¹, Fort *et al.*², Bhattacharyya³ and Bagati and Suresh⁴.

Tectonic evolution

Following the continent-continent collision between India and Asia, around 45–50 m.y., the first major phase of the uplift occurred around 20 m.y. This event initiated development of the Siwalik foreland basin in front of the rising Himalaya. The second major uplift took place around 4–5 m.y., giving rise to intramontane basins of Kashmir and Peshawar⁵. The Boulder Conglomerate of the Upper Siwalik, dated at 1.6 m.y. and indicative of rapid uplift of the provenance, demarcates the third major phase of uplift in the Himalaya.

In the Trans-Himalaya region the first major phase of uplift produced intramontane basins in the Indus Suture Zone of Ladakh which got filled up with Tertiary molasse. The younger Quaternary molasse are located at Karoo, Liyan and Kyul. At Karoo the molasse deposit resting over the southern margin of the Ladakh batholith is principally derived from Ladakh plutonic complex. The Liyan molasse contains clasts of volcanics and ophiolite of the underlying Nidar Formation. At Kyul, the molasse is totally derived from the Ladakh

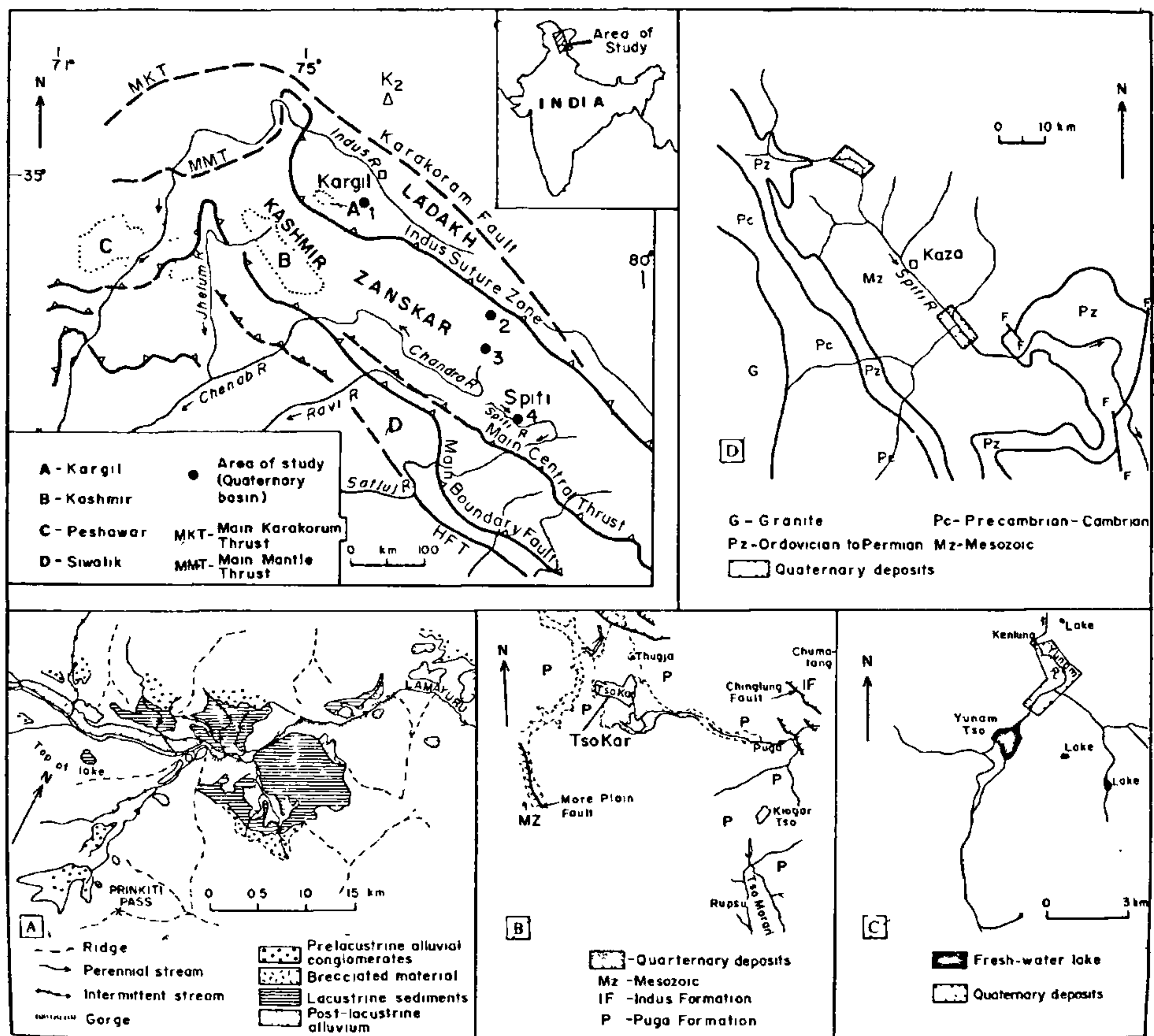


Figure 1. Index map showing the general tectonic trends of northwestern Himalaya and location of the Quaternary basins. Insets (A-D) refer to the basins discussed in the text.

batholith, although it overlies the ophiolite sequence. Similar molasse deposits of the intramontane basins were developed in Kailas and southeastern Tibet.

The post-collision uplift of the Ladakh Range and the Zaskar Range, coinciding with the major uplift of the Himalaya around 20 m.y., produced intramontane depressions of molasse sedimentation. Later (Pleistocene) these were tilted 30–40° southwards at Karoo and Kyul. It appears that younger Quaternary molasses of the intramontane basins have been largely eroded away along the Indus valley, leaving behind some isolated terraces such as in the Wakachu belt.

The Quaternary tectonics has continuously affected

the structural and sedimentational characteristics of these basins, mainly due to reactivation of the faults in the region. For example, movements along the Karakoram Fault⁶ (Figure 1) have at one time or the other influenced the accretionary processes of the Quaternary basins due to the accommodation of release or post-orogenic stresses in the constituent tectonic blocks. Likewise, the Holocene tectonics is responsible for later evolutionary changes in the Quaternary basins of the entire Ladakh and Lahaul-Spiti region. The Tso Moriri Fault, cutting across the Tso Moriri fan, is considered to be still active⁷. So are the Tsokar, More Plain, Chandra, Sarchu, Spiti and Lingti faults.

Geomorphic features

The Ladakh and Lahaul-Spiti region shows Tibetan-type plateau geomorphology. The Quaternary basins are located (Figure 1) within the Karakoram, Ladakh and Zaskar ranges. These basins were formed by tectonic processes.

The remnant of the 200-m-thick lacustrine fill at Lamayuru located at an altitude of 3200 m is the result of formation of a massive debris dam across the Lamayuru River (Figure 1a). The debris slide (Figure 2) was caused probably by a tectonic activity².

The Tsokar lake, 125 km southeast of Leh (Figure 1b), is at an altitude of about 4572 m, lying between the Zaskar and Ladakh ranges. The lake was formed when the palaeo-Tsokar River got blocked as a result of movements of a fault⁷ or when a graben was formed⁸.

The Kenlung lake is located at an altitude of about 4700 m covering approximately 1 km² (Figure 1c). The lake basin was formed as a result of movement on the Chandra Fault, probably in the Holocene and attendant landslide that formed a dam across the Yunam River.

The lacustrine deposits at Hanse-Kioto and Attargo-Lingti-Dankar at the altitudes of, respectively, 3900 m and 3400 m in the Spiti River (Figure 1d) represent major landslides due to tectonic activity along the Spiti Fault⁹.

Stratigraphy and sedimentation

Lamayuru lake

The sedimentation in Lamayuru lake basin commenced around 35,000 years B. P. and continued uninterruptedly until 1000 years B.P.². Three stages of sedimentation within 200-m-thick stratigraphic succession have been

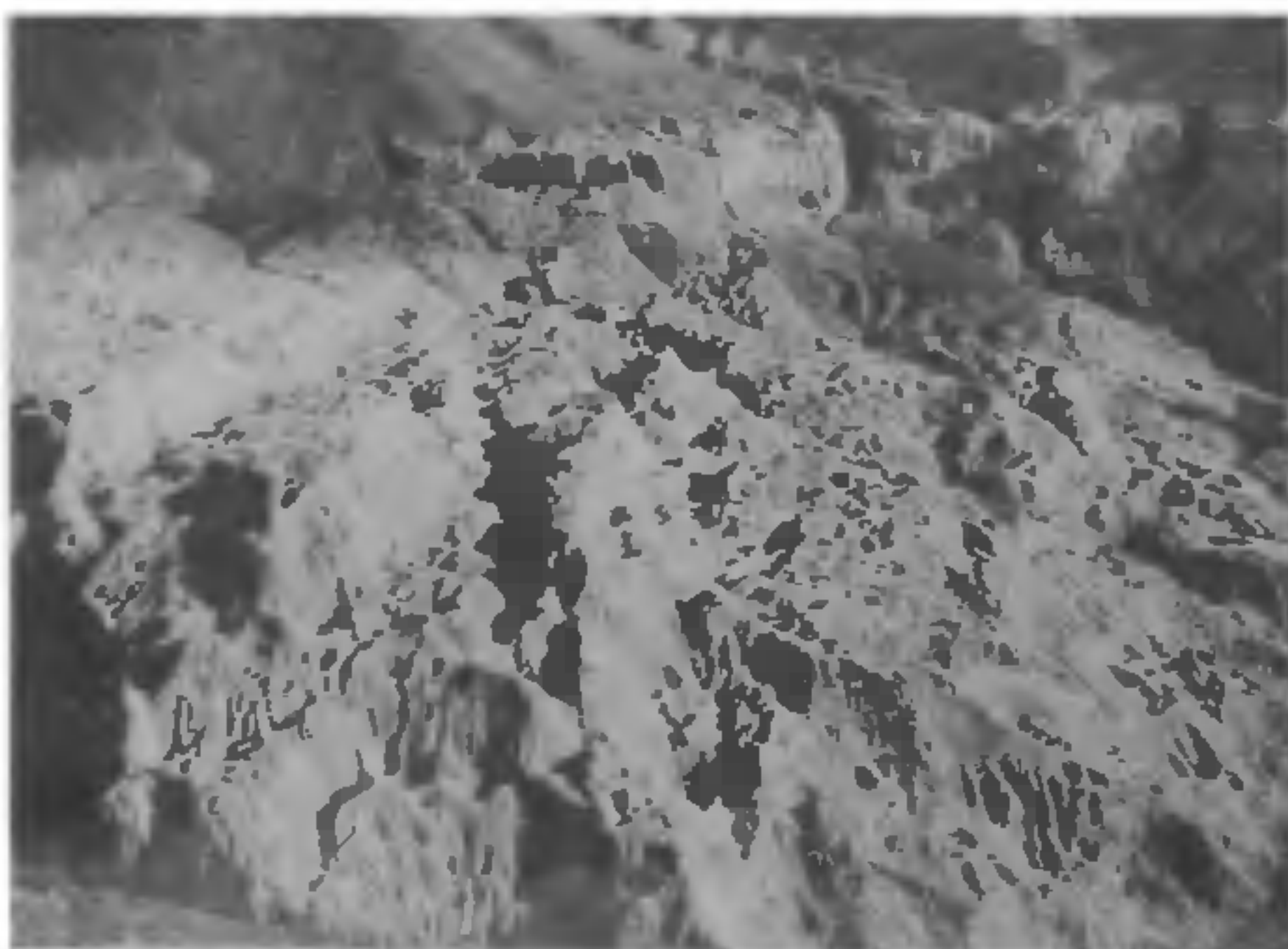


Figure 2. Dissected lacustrine sediments of the Lamayuru lake.

distinguished. Recent field work (by TNB) revealed a 2.46 m thick succession of charcoal-bearing bed in the lower part of the Lamayuru lake (Figure 3a). The lake deposit comprises (i) fine-to-medium grained grey sandstone characterized by charcoal and mud pellets along bedding planes, (ii) alternating layers of sandstone and grey mudstone containing sporadic occurrence of charcoal, (iii) silty mudstone with abundant charcoal and leaf impressions (Figure 4), and (iv) light grey mudstone-siltstone showing parallel laminations, with charcoal pieces aligned parallel to the bedding in siltstone. The charcoal at various levels and leaf impressions in a few horizons (Figure 4) indicate as many episodes of fire in the forests close to depositional sites¹⁰ presumably during the mid-post glacial warm periods¹¹. This fact carries further implication that during early stages of sedimentation the climate was warm when forests grew luxuriously in the Lamayuru region. This deduction is at variance with that of Fort *et al.*² who suggest semiarid conditions.

Tsokar lake

The sedimentation and stratigraphic record of this lake basin is provided by Bhattacharyya³. Coarse sand and gravel form the base (23–23.75 m), or the sand and gravel with intercalated clay layers occur between 6 and 12 m levels, with limestone fragments occurring in the clays above 6 m level. The alternation of fluvial and lacustrine sediments indicates periodic changes in the provenance and also in hydrological regime in the basin catchment. Biogenic activity between 19.75 and 21.85 m levels (Figure 5) indicates warmer times. Fresh and brackish-water conditions prevailed in the period 30,000–9000 years B.P.³.

Kenlung lake

Lying between Kenlung and Yunam Tso (not to be confused with the present-day Yunam Tso lake¹²) this small lake consists of the sediments which vary in thickness from 2 to 10 m. The sediments are dominated by silty mudstone and mudstone with subordinate sandstone.

Hanse-Kioto lake

At the base there are chaotic blocks of limestone (some measuring few metres in size) 'floating' in the muddy matrix of conglomerate (Figure 6). The lake deposit consists of stratified matrix-supported conglomerate occurring at various levels and varying in thickness from 3 to 5 m. Sand lenses showing planar and trough cross stratification up to 20 cm thick are present at one

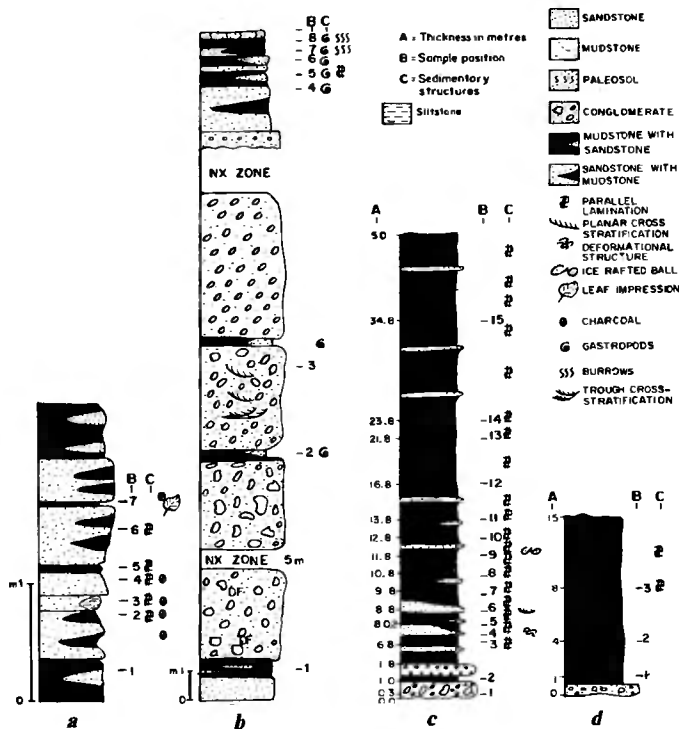


Figure 3. Lithostratigraphy and facies distribution of remnant lacustrine fills of the (a) Lamayuru, (b) Hanse, (c) Lingti and (d) Attargo.

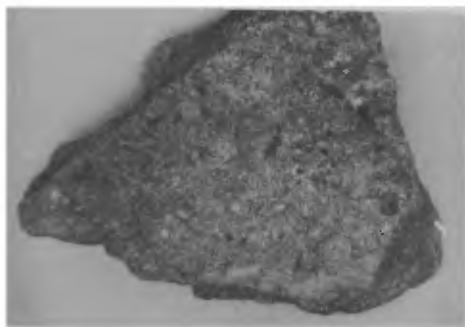


Figure 4. Charcoal and twig casts in the silty-mudstone facies in the basal part of the Lamayuru lake.

level. The conglomerates are followed upwards by grey, fine-to-medium-grained sandstone, varying in thickness from 15 to 50 cm. Higher up occurs interbedded sandstone-mudstone sequence, its thickness varying from 0.2 to 1.5 m, and characterized by trace fossils and gastropods in the upper part. The uppermost mudstone represents shallow-water lacustrine facies mantled by paleosol.

Attargo-Lingti-Dankar lake

This lake was formed due to reactivation of Spiti Fault during the Holocene (?) and is younger than the Kioto lake (Figure 3). The lake sediments⁴ are about 50 m thickness at Lingti (Figure 7) exhibiting fluvio-lacustrine facies in the lower part (0-7 m level).

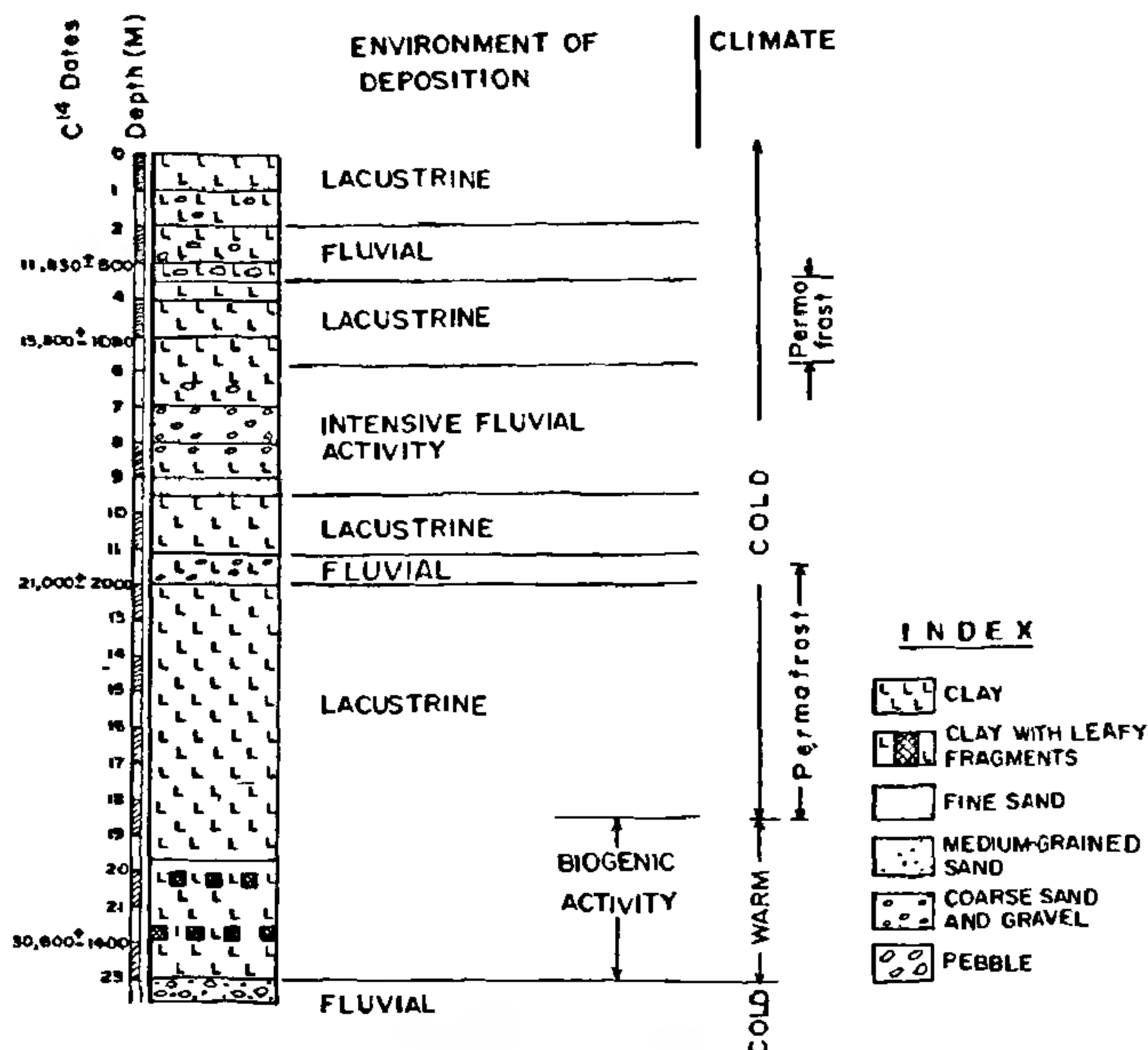


Figure 5. Lithostratigraphy, environment of deposition and climatic changes recorded in the Tsokar lake, Ladakh (compiled from Bhattacharyya, 1989).



Figure 6. The gorge near Kioto showing basal part of the landslide material (dark) overlain by lake sediments (light). Vertical displacement of the deposits is clearly seen.



Figure 7. Lacustrine sediments exposed near Lingti showing maximum thickness in the upstream direction.

Discussion

The uplift of the Himalaya in the Quaternary around 1.6 m.y. was responsible for the deposition of the Upper Siwalik conglomerate in the south and the younger molasse deposits in the north at Karoo, Liyan and

Kyul. While the lake sediments at Lamayuru and Tsokar in Ladakh, Kenlung in Lahaul and Kioto-Hanse and Attargo-Lingti-Dankar in Spiti were deposited during the Late Pleistocene-Holocene. Besides the closed-basin sedimentation, alluvial accretion also occurred in the form of terraces in major river

valleys in the region. The Quaternary tectonism manifest in differential movements created depositional basins which were largely uncoeval. It is during this time that the Himalaya registered maximum upheaval of the order of 3–4 km (ref. 13).

The Ladakh and Lahaul-Spiti region exhibits various events of hot-humid and dry-cold climate in the last 35,000 years. The climatic changes were accompanied with advance and retreat of forest and steppe-type vegetal covers, as recorded by the Tsokar sediments between 30,000 and 9000 years B.P. The plant impressions and charcoal fragments in the basal part of Lamayuru indicate warm temperate climate up to around 30,000 years B.P., whereafter semiarid climate prevailed until about 1000 years B.P.⁷. The presence of rock varnish in Ladakh suggests hot and dry climate in the Holocene (?).

The forest- and/or steppe-type vegetation with mild climate must have been favourable for the migration of humans up to the Indus valley in Ladakh. The charcoal pieces from a fire place on the Indus terrace has been dated 6710 ± 130 years B.P.¹⁴. The Qinghai-Xizang region in the Tibet plateau likewise shows periodic occurrence of warm-moist and cold-dry climate during the past 10,000 years¹⁵. Lake cores of the brackish water Qinghai lake have indicated warm-humid and arid-cold periods during the last 13,000 years, the climatic fluctuation being mainly the result of Quaternary tectonic uplifts of the Tibetan plateau and Himalayan mountains¹⁶. It seems that in the Late Quaternary (particularly in the last recorded 35,000 years), atmospheric circulation changed dramatically

due to strong but differential uplifts creating varying topographic highs and lows and the environment alternated sharply and frequently between cold-dry and hot-humid, so that forest- and steppe-type vegetation moved backward and forward.

1. Bürgisser, H. M., Ganseer, A. and Pika, J., *Ecolgae. Geol. Helv.*, 1982, **75**, 51–63.
2. Fort, M., Burbank, D. W. and Freytet, P., *Quat. Res.*, 1989, **31**, 332–350.
3. Bhattacharyya, A., *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 1989, **73**, 25–38.
4. Bagati, T. N. and Suresh, N., *J. Him. Geol.*, 1991, **2**, 125–132.
5. Burbank, D. W., *Earth Planet. Sci. Lett.*, 1983, **64**, 77–92.
- 6a. Fort, M., in *Contributions to Himalayan Geology* (ed. Gupta V. J.), Hindustan Publishing Company, Delhi, 1983, vol. 2, pp. 39–58.
- 6b. Molnar, P. and Tapponier, P., *J. Geophys. Res.*, 1978, **83**, 5361–5375.
7. Bhargava, D. N., *Tectonophysics*, 1990, **174**, 315–320.
8. Rastogi, S. P., *Misc. Publ. Geol. Surv. India*, 1979, **41**, 259–277.
9. Mazari, R. K. and Bagati, T. N., *J. Him. Geol.*, 1991, **2**, 111–117.
10. Tolonen, K., in *The Role of Fire in Northern Circumpolar Ecosystems* (eds. Wein, R. W. and Maclean, D. A.), John Wiley, Chichester, 1989, pp. 21–44.
11. Waddington, J. C. B., *Geol. Soc. Am.*, Special paper 123, 1969, pp. 263–283.
12. Kanwar, S. S., *Bull. Indian Geol. Assoc.*, 1980, **13**, 1–6.
13. Ganseer, A., *Ecolgae. Geol. Helv.*, 1991, **84**, 33–59.
14. Sharma, K. K., Rajagopalan, G. and Choubey, V. M., *Curr. Sci.*, 1989, **58**, 306–308.
15. Wang Fu-Bao and Fan, C. Y., *Quat. Res.*, 1987, **28**, 50–60.
16. Kelts, K. et al., *Ecolgae. Geol. Helv.*, 1989, **82**, 167–182.

ACKNOWLEDGEMENTS. One of the authors (TNB) wishes to thank Dr R. K. Mazari and Dr Rohtash Kumar for fruitful discussion in the field and during the preparation of this paper. He also thanks Anil Kaul for helping in the field at Lamayuru.

Quaternary deposits along the Indus Suture Zone and evolution of Himalayan rivers

M. E. Brookfield

Land Resource Science, Guelph University, Guelph, Ontario N1G 2W1, Canada

Quaternary deposits, found only in isolated basins behind the main great Himalayan crest-line and along the courses of the main rivers, are preserved only in isolated structural depressions scoured by valley glaciers because of rapid Quaternary uplift and attendant erosion. The Early Quaternary deposits rest unconformably on basement and are preserved only in the Chilas and Skardu areas of Baltistan, where they consist of a basal till overlain by fining upwards valley fill sequences. Palaeomagnetic reversal correlation suggests an earliest Pleistocene age. The Middle Pleistocene deposits seem to be absent. The early Pleistocene (or pre-Quaternary) is overlain at Leh and elsewhere, by a complex of tills and

terraces associated with possibly the last three main glacial phases of the Late Pleistocene. The Quaternary events cannot ordinarily be disentangled from earlier Pleistocene events. Correlation is very difficult due to the isolation of most exposures and the lack of dateable sections.

Introduction

THE Indus Suture Zone extends northwest from southeastern Tibet to Ladakh (Figure 1). Apart from studies of modern glaciers¹, little has been done on the