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# Vegetation and climatic changes around Lamayuru, Trans-Himalaya during the last 35 kyr B.P.

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## ABSTRACT

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Palynological analysis of a 105 m deep palaeolake profile from Lamayuru, Ladakh, Trans-Himalayan region, provides a broad idea of temporal succession of vegetation *vis-à-vis* climatic changes during major part of the last glacial period. The present study suggests that the prevailing semi-arid climate of this region has been continuing at least from prior to 35 kyr B.P. characterized by the Chenopodiaceae-*Ephedra-Artemisia* steppe. Migration of *Betula* around 35 kyr B.P. into the steppe took place when climate was comparatively less arid than before and its further increase around 22 kyr B.P. in the *Ephedra-Artemisia*-Chenopodiaceae steppe suggests comparatively favourable climatic conditions. Subsequently the climate had turned to be cooler and drier with the expansion of steppe taxa.

**Key-words**—Trans-Himalaya, Palaeo-vegetation/climate, Palynology, Late-Pleistocene.

## अब से पिछले 35000 वर्ष पूर्व के दौरान हिमालय-पार लामायुरु के चारों ओर वनस्पति एवं जलवायु परिवर्तन

पी.एस. रण्होत्रा, ए. भट्टाचार्य एवं बी.एस. कोटलिया

## सारांश

हिमालय-पार क्षेत्र के लद्दाख के लामायुरु से प्राप्त 105 मीटर गहरी पुराझील परिच्छेदिका के परागाणविक विश्लेषण से अंतिम हिमनदीय अवधि के मुख्य भाग के दौरान जलवायु परिवर्तन की तुलना में वनस्पति के कालिक अनुक्रम के विस्तृत विचार प्राप्त होते हैं। वर्तमान अध्ययन से प्रस्तावित होता है कि चीनोपोडिएसी-*इफेड्रा-आर्टिमिसिया* स्टेप से गुणित इस क्षेत्र की मौजूदा अद्‌र्ध-शुष्क जलवायु कम-से-कम 35000 वर्षों पूर्व से बरकरार है। पहले की अपेक्षा जब जलवायु कम शुष्क थी तब लगभग 35000 वर्ष पूर्व *बेटूला* का स्थानान्तरण स्टेप में अभिगमन हो गया तथा इसका आगे *इफेड्रा-आर्टिमिसिया*-चीनोपोडिएसी स्टेप में लगभग 22000 वर्ष पूर्व बढ़ना अपेक्षतः अनुकूलन जलवायवी परिस्थितियाँ सुझाता है। इसके बाद स्टेप वर्गकों के विस्तार से जलवायु शीतल एवं शुष्क हो गई।

**संकेत-शब्द**—हिमालय-पार, पुरावनस्पति/जलवायु, परागाणुविज्ञान, अंतिम प्लीस्टोसीन।

## INTRODUCTION

THE Trans-Himalayan region seems to be a good archive for the analyses of pollen and other various proxy records because of its vast exposed Quaternary lacustrine and glaciofluvial sediments and the presence of a large number of brackish and fresh water lakes. Even then, there are only a few analyses related to palaeoenvironment based on pollen. The pioneer work in this aspect from this region was by Deevy (1937) from sediments of Pangong Lake at the elevation of 4,267 m. He reported a number of pollen grains of herbaceous taxa, on the basis of which he tentatively referred the lake deposits to be of second Interglacial (warm-humid) period. Subsequently, Bhattacharyya (1989) has provided a long record of climatic changes during the last glaciation based on pollen from Tsokar Lake (~5,000 m a.m.s.l), Ladakh, Trans-Himalayan region.

The present study is also an attempt to unravel the climatic changes during late Quaternary based on palynological investigations of the 105 m thick palaeolacustrine deposits exposed at Lamayuru (34° N latitude and 76° E longitude) at an altitude of 3,600 m a.m.s.l in the western Ladakh, Trans-Himalayan region, India (Fig. 1). Earlier this section has been analyzed based on palaeomagnetic, palaeontological and sedimentological records to understand the depositional environment and evolution. Lamayuru Palaeolake is believed to have been formed mainly by the neotectonic movements causing landslides, thus damming the river Lamayuru, a tributary of upper Indus River (Bagati *et al.*, 1996; Kotlia *et al.*, 1997b, 1998; Shukla *et al.*, 2002). Geology and geomorphology of the area is known from the studies carried out by earlier workers (Godwin-Austen, 1864; Lydekker, 1883; Oestreich, 1906; Norin, 1925; Trinkler, 1932; De Terra & Hutchinson, 1934, 1936; De Terra & Paterson, 1939) and some recent works (Thakur, 1981; Fort *et al.*, 1989; Bagati & Thakur, 1993).

## MATERIAL, METHODS AND RADIOCARBON DATES

The collection of sediments was done from a 105 m thick sedimentary sequence (Fig. 2a, b) exposed at Lamayuru. The sediments range from mud size to cobble and pebble, showing a coarsening upward in the sequence. The lower 15 m section of the profile (from bottom to 90 m depth) mainly consists of thick layers of finer sediments that range from mud, clay to silty-clay with two carbonate rich beds of few centimeters thickness. The middle 70 m of the sequence (90 to 20 m from bottom) consists mainly of coarse sand beds with thin layers and lenses of fine sand, silty clay and carbonate. Two to three narrow bands of mud and

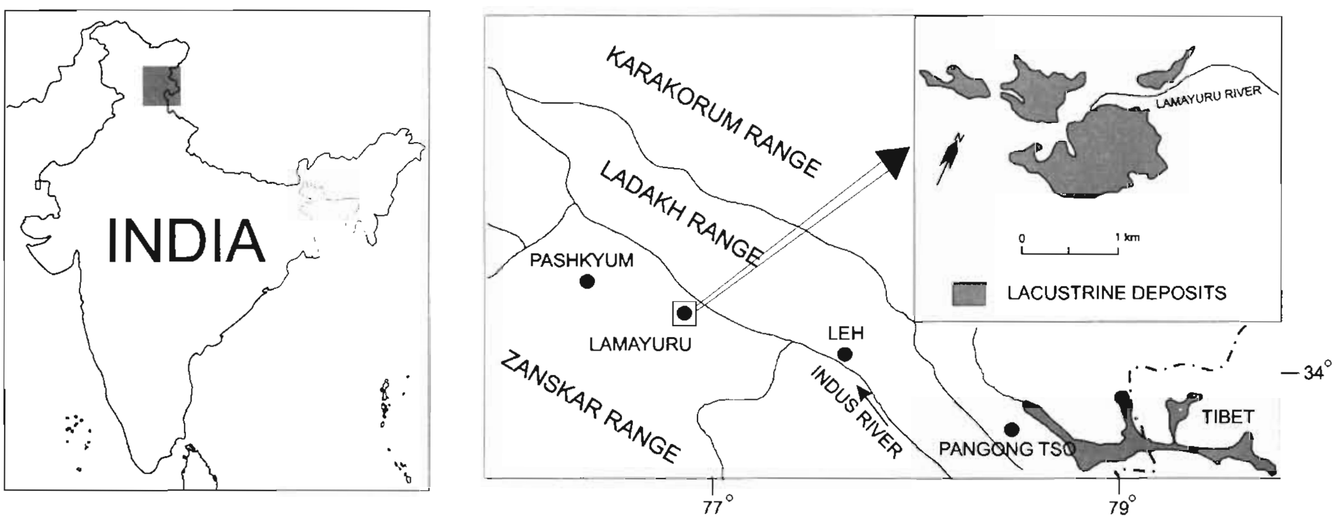


Fig. 1—Map showing the location of palaeolacustrine deposits at Lamayuru, Ladakh, Trans-Himalaya.

carbonate rich layers are also present within the sandy beds. The topmost part (20 m to near top surface) exposes breccia only. For the palynological analysis, samples were processed following common method of acetolysis (Faegri & Iverson, 1989) with slight modification. All the samples of the profile were analyzed except the upper 20 m coarser sediments which are unsuitable for the palynological analysis.

The number of pollen grains counted per slide vary at different depths. The fine-grained sediments from the base up to 90 m and 75-55 m contain sufficient pollen-spores to make pollen spectra. But at the other depths, sediments were found either barren or poor in pollen content. Overall the pollen counted per sample ranges from 120 to 400 grains, which is taken as "Total Pollen Count". This includes a good number of saccate grains also (especially *Pinus*), which might have been transported from long distance with the upthermic winds from nearby temperate or sub alpine forest. These saccate grains along with few other temperate elements are considered as 'Extra Local'. In the percentage calculation, the pollen number of extra local elements was excluded from the total pollen count to make "Pollen Sum" of each sample. To avoid the masking of local pollen elements, the percentage frequency of pollen taxa of each local element is determined in terms of Pollen Sum. To avoid over representation of the extra local pollen taxa, their percentages are calculated on the total pollen count. The pollen diagram is divided into two parts (Fig. 2a, b) to view the fluctuations of some rare taxa more clearly within the pollen spectrum. The Fig. 2a displays the pollen frequency of sub-alpine arboreal taxa, shrubby elements and extra-local elements. Fig. 2b shows the herbaceous, steppe, marshy-aquatic and unidentified taxa along with the total pollen count and pollen sum. Sporadic presence of the pollen is shown by '+' sign in the pollen diagrams.

Three radiocarbon dates are available in the lower part of this profile (Fig. 2a, b) from the published records by Fort *et al.* (1989), Kotlia *et al.* (1997b, 1998). Two dates, 35 kyr B.P. of sediments close to the top of bottom-most mud horizon and the other one 25 kyr B.P. comparable with the deposit at the depth of 100 m were taken from Fort *et al.* (1989). The only date 22 kyr B.P. at the depth of 99.7 m of this profile was made at the Radiocarbon Laboratory of Birbal Sahni Institute of Palaeobotany, Lucknow by Kotlia *et al.* (1998). Rate of sedimentation for this exposed section could not be calculated because of heterogeneous nature of sediments and insufficient number of C-14 dates due to non-availability of suitable materials in that section.

## VEGETATION AND CLIMATE

No detailed account on the present vegetation in and around Lamayuru is available though a good account in this aspect from Ladakh as a whole has been published earlier (Stewart, 1916, 1917). The plants around Lamayuru are mostly herbs and a few stunted shrubs of smaller size. In general, vegetation is poor like other parts of Ladakh. The natural forests are non-existent in this region. A good number of trees viz., *Populus balsamifera*, *Salix alba*, *Populus pyramidales*, and *Juglans regia* grow along the banks of streams, which are all introduced. The moist ground around streams are covered with the taxa mainly of Polygonaceae, Poaceae, Cyperaceae, Chenopodiaceae and in the marshy zone where salinity is higher, species of Chenopodiaceae are very common with other taxa of restricted occurrence.

The detailed climate data of the sampling site is not available. Data from other sites of the Trans-Himalayan region provide a broad idea of the climate of this region. The temperature records for last several decades for Drass (3,066 m a.m.s.l), Kargil (2,682 m a.m.s.l) and Leh (3,514 m a.m.s.l) in Ladakh show that the maximum temperature ranges from 23.1°C to 29.7°C in July and minimum temperature ranges from –22°C to –10°C during February.

## DESCRIPTION OF POLLEN DIAGRAM

The pollen grains recovered from the sediments have been found to be dominated by some particular taxa through out the diagram. The taxa *Pinus*, *Betula*, *Juniperus* and *Ephedra* are most common among the arboreals. Similarly, the non-arboreal taxa viz., Chenopodiaceae, *Artemisia*, Poaceae, Asteraceae (Tubuliflorae and Liguliflorae) and others are recorded

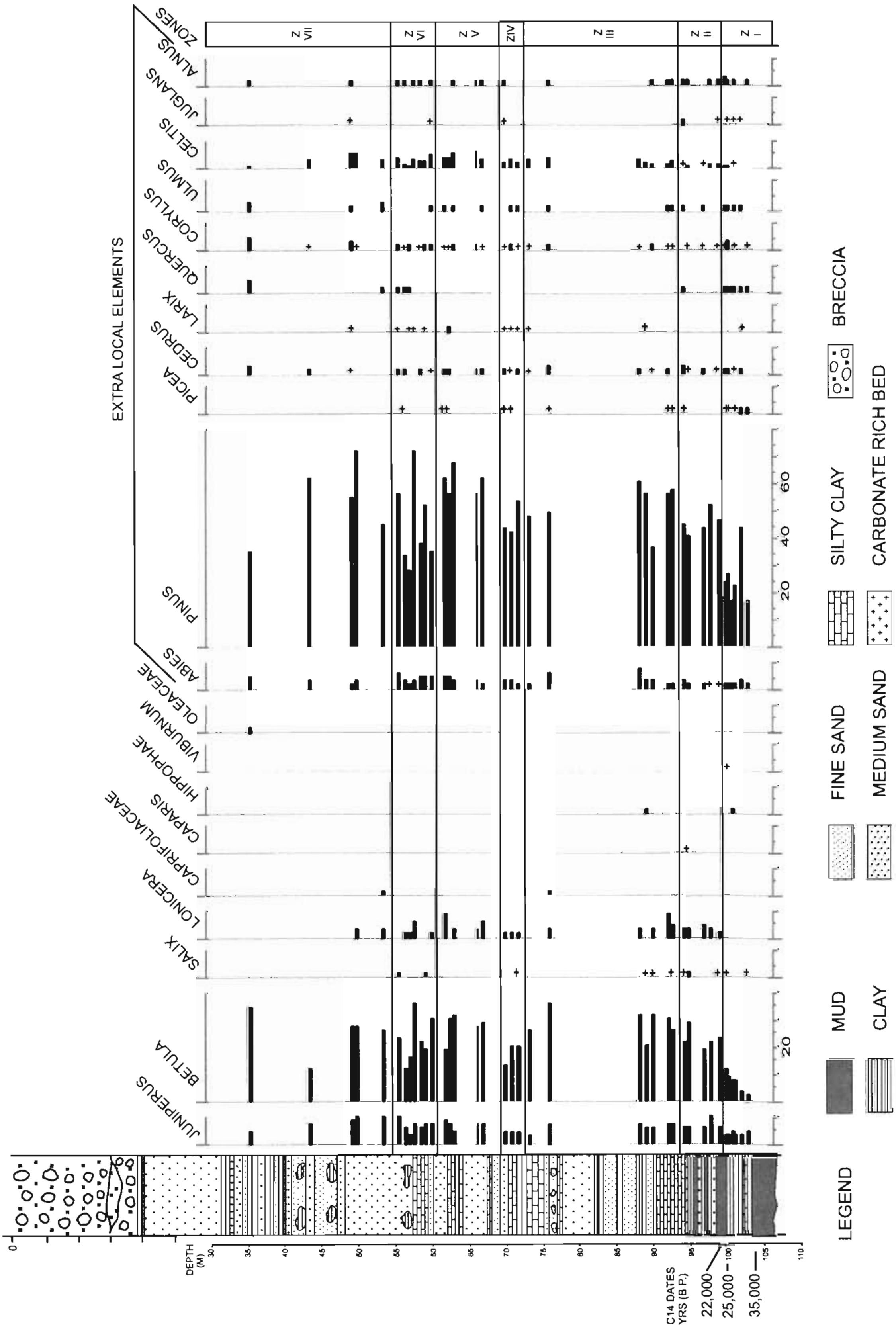


Fig. 2(a)—Lithology and pollen diagram of profile from Lamayuru, Ladakh, J & K.

through out. The other taxa are either sporadic or represented by low values. As a whole the pollen count of the arboreal ones is more than that of non-arboreal taxa. For convenience of interpretation, the pollen diagram (Fig. 2a, b) has been divided into seven pollen zones based on the fluctuations of some important extra-local and local elements.

**Z I - Chenopodiaceae – *Pinus* – *Ephedra* – *Betula* – Poaceae – *Juniperus*.**

Section from the base to depth of 99.5m, covering the time period 35 kyr B.P. to around 24 kyr B.P., is characterized by the dominance of Chenopodiaceae (29-51%). This is followed by *Pinus* (16-26%) reaching up to 43% in one sample. Other conifers like *Abies*, *Picea* and *Cedrus* are sporadic to under 6%. *Larix* is sporadic. *Ephedra* (5-21%) represents higher values at the base. Amongst the other arboreal taxa, *Betula* is represented by 1% at the base and gradually increases to 12% at the top of this zone. *Juniperus* and *Salix* are sporadic and around 3% respectively. Amongst the other shrubby taxa viz. *Lonicera*, *Viburnum*, *Caparis*, *Hippophae*, Caprifoliaceae, Oleaceae, only few are reported sporadically. The temperate broad–leaved taxa altogether are represented by around 6% of the total pollen count, in which *Alnus* is around 2% whereas *Celtis*, *Corylus*, *Carpinus*, *Quercus* and *Juglans* are generally less than 1% each. Amongst non-arboreal taxa, Poaceae ranges 4-10% followed by *Artemisia* (3-6%) and Asteraceae (2-13%). Other herbaceous elements viz., Brassicaceae, Ranunculaceae, Saxifragaceae, Polygonaceae, *Oxyria*, Primulaceae, Lamiaceae, Apiaceae, Caryophyllaceae, Urticaceae, etc. altogether are around 11-18%. Fern spores (monolete and trilete) are 1-3% and aquatic element (*Potamogeton*) is sporadic.

**Z II - *Pinus* – *Ephedra* – *Betula* – Poaceae – Chenopodiaceae - *Juniperus*.**

This zone from depth 99.5 to 93.6 m incorporates the strata dated 22 kyr B.P. There is a sudden decline in Chenopodiaceae (3-10%) and simultaneous increase in *Pinus* (40 to 52%) and *Betula* (18-29%) as compared to the previous zone I. The other broad-leaved taxa consisting of *Ulmus*, *Juglans*, *Corylus*, *Carpinus* and *Quercus* are sporadic to around 3% each. *Juniperus* is 5-10%. *Salix* is sporadic to 2%. Amongst other shrubby taxa *Lonicera* is 3-5%. *Ephedra* shows a sharp increase from the previous zone and value ranges from 18-31%. There is an increase in Poaceae also with minimum and maximum values 5% and 13% respectively. There is decline of Asteraceae (2-7%) as compared to zone I, whereas *Artemisia* remains unchanged (2-6%). Other herbs do not show much change (9-18%). Fern spores and *Potamogeton* are under 3% each and Cyperaceae is sporadic.

**Z III - *Pinus* – *Betula* - *Ephedra* – Poaceae – *Juniperus* – Chenopodiaceae.**

This zone represents depth from 93.6 to 72.5 m. Some of the samples of this zone are almost barren except few pollen grains of *Pinus* and *Betula*. Rest of the samples has shown good representation of pollen grains in which *Betula* (20-40%) shows small increase. Temperate broad-leaved elements are 2-6%. *Salix* remained sporadic to 2%. Other shrubby elements are 2-8%. *Pinus* has increased further and generally remained 40-60%. Other conifers (2-9%) show some increase than previous zone of which *Abies* shows good increase from 1% at the base to 7% at the top of this zone followed by *Cedrus* and *Picea*. *Juniperus* is 3-7% with slight increase. *Ephedra* shows some decline in values (4-29%) than the previous zone. *Larix* that has not been recorded in previous zone is represented in two samples, though sporadic. Amongst non-arboreals Poaceae is the dominating element with 8-14% followed by Chenopodiaceae, which declines further than zone Z II. It does not exceed 8%, and does not occur at some depths. *Artemisia* (2-9%) and Asteraceae (sporadic to 4%) show same trend. The other herbs together are 4-16%. Ferns 2-7% show some increase.

**Z IV - *Pinus* – *Ephedra* – *Betula* – Chenopodiaceae - Poaceae – *Juniperus*.**

From depth 72.5 to 69 m *Pinus* though shows a decline but still exhibits good values (42-53%). *Abies*

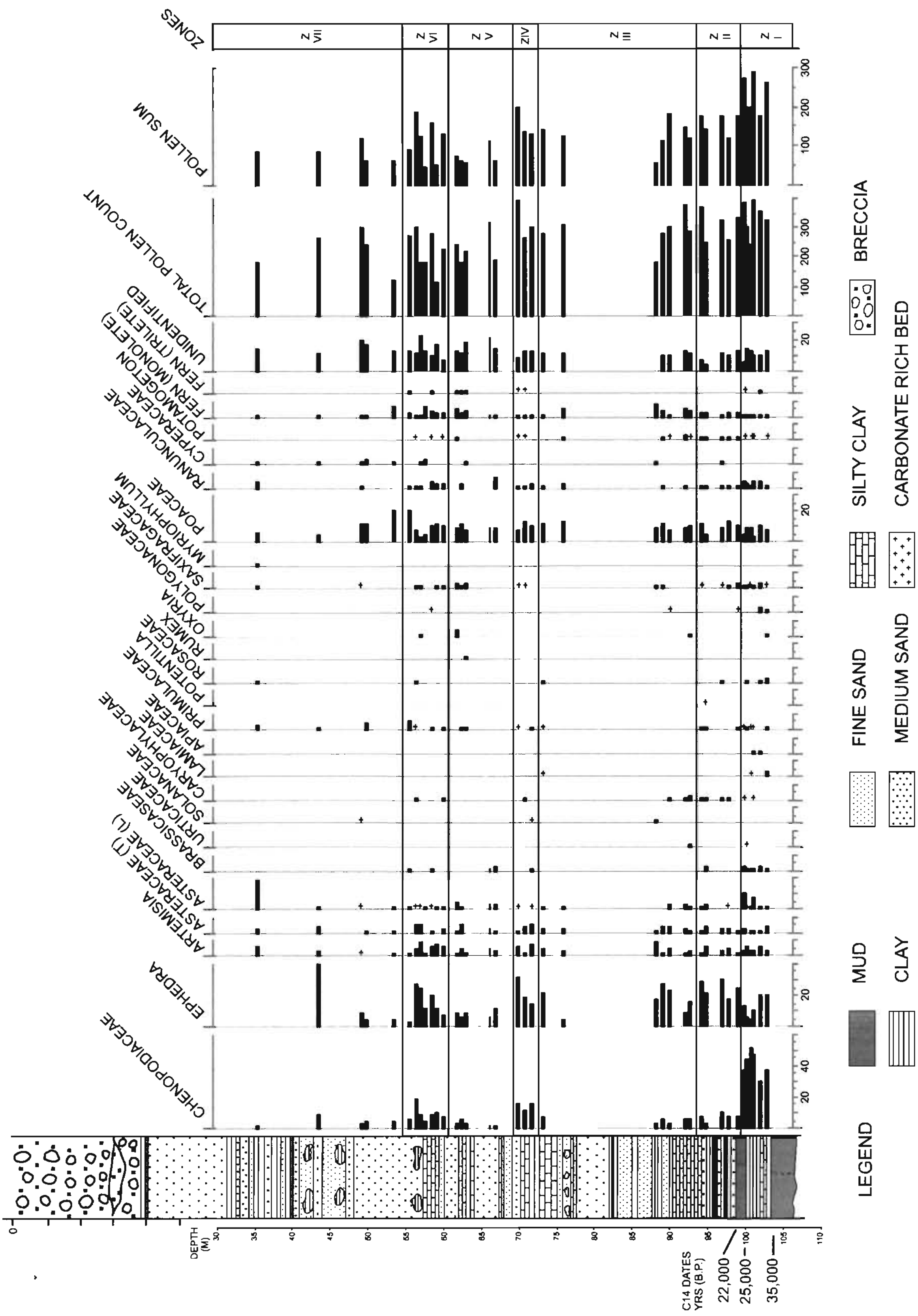


Fig. 2(b)—Lithology and pollen diagram of profile from Lamayuru, Ladakh, J & K.

(3%) also declines in this zone. *Cedrus* (2%) and *Picea* remain sporadic. Over all other conifers are 3-5%. *Betula* (14-21%) and *Juniperus* (3-4%) also decline. Temperate broad-leaved elements are 3-5%. *Celtis* is around 4%, *Corylus* (2%), *Alnus, Ulmus, Juglans* and *Salix* are sporadic to 1%. Other shrubby taxa are also around 1%. *Larix* is sporadic. *Ephedra* (14-33%) shows some increase. Chenopodiaceae also shows increase and value ranges between 12-17%. Poaceae (8-15%) also shows some increase. *Artemisia* and Asteraceae (2-8% each) are not showing much change. Other herbaceous taxa together are 10-15% representing increase than the previous zone. Fern spores in this zone are nearly 2%, which is less than previous zone.

**Z V - *Pinus* – *Betula* – Poaceae – *Ephedra* - *Juniperus* – Chenopodiaceae.**

This zone is from depth 69 to 61.5 m. Almost all arboreal taxa show increase in this zone. *Pinus* is 56-68%. Other conifers are 3-8%, of which *Abies* is 2% at the base and 5% at the top of this zone. Similarly *Cedrus* is also 1-2% to sporadic. *Picea* is occasional. Both, *Betula* (21-35%) and *Juniperus* (4-9%) show increase in this zone. Temperate broad-leaved taxa are 3-8%, of which *Celtis* (2-5%) shows some increase whereas *Corylus, Carpinus, Alnus* and *Ulmus* remain around 1%. *Salix* is absent but other shrubby taxa (2-9%) have higher values than zone IV. *Lonicera* (2-8%) reappeared in this zone with good representation but *Larix* is absent. Both, *Ephedra* (6-12%) and Chenopodiaceae (1-8%) have lower values than the earlier zone. Poaceae (8-12%) also declines slightly. *Artemisia* and Asteraceae show almost same trend. Pollen of rest of the elements like Brassicaceae, Ranunculaceae, Saxifragaceae, Primulaceae, *Rumex*, Caryophyllaceae, etc. are grouped under other herbaceous taxa which range between 15-28% indicating higher values than the previous zone. Fern spores are 2-7% and *Potemogeton* is sporadic to 1%.

**Z VI - *Pinus* – *Ephedra* – *Betula* – Chenopodiaceae - Poaceae – *Juniperus*.**

In this zone from depth 61.5 to 56 m *Juniperus* (3-9%) does not show much change. *Betula* (11-37%) exhibits some decline in values. Temperate broad-leaved elements are 2-11%. *Alnus* is 1-2% and *Celtis* is 1-6%. *Quercus, Corylus, Ulmus* and *Juglans* remain sporadic. Though the dominance of conifers continued but *Pinus* (30-72%) shows much decline in most of the samples. Other conifers are 1-7%, of which *Abies* (1-6%) exhibits almost same trend followed by *Cedrus* (sporadic to 1%). *Picea* is recorded in only two samples sporadically. Pollen of *Larix* (1%) is present throughout the zone. Amongst non-arboreals, both *Ephedra* (9-27%) and Chenopodiaceae (5-20%) show increasing trend. Poaceae (4-12%), *Artemisia* (2-10%) and elements of Asteraceae (2-7%) also show some increase. Other herbaceous taxa register 11-25% with slight decrease than the previous zone. Cyperaceae (2%) is present in the upper half of the zone. Fern spores (sporadic to 7%) are better represented in the lower half and afterwards became sporadic.

**Z VII– *Pinus* - *Betula* – Poaceae – *Juniperus* – *Ephedra* – Chenopodiaceae.**

In this zone, from depth 56 to 30 m, a number of samples are palynologically barren and only few are productive. Among the arboreal pollen *Pinus* is well represented at this zone with values ranging from 35-72%, followed by other conifers (2-7%). *Juniperus* is 3-11%, while *Betula* (12-35%) shows higher values than the previous zone. Temperate broad-leaved taxa together are 3-11%. Shrubby elements are around 2%. Poaceae (22-5%) has shown higher values but the values of *Ephedra* (5-10%), Chenopodiaceae (4-6%) and *Artemisia* (1-6%) are lower. The other elements of Asteraceae together are 1-7% and increase to 20% at the top of this zone. Other herbaceous elements together (12-25%) exhibit no change than the previous zone. Cyperaceae (1-4%) and fern spores (1-7%) do not show much change in frequency.

## RECONSTRUCTION OF VEGETATION AND CLIMATE

The most salient features in the pollen diagram are fluctuation of few local trees or shrubs viz., *Betula*, *Juniperus, Hippophae, Salix, Celtis* versus steppe elements, i.e. *Ephedra* and Chenopodiaceae and others suggesting that the area was occupied throughout by the steppe vegetation. Poaceae and Cyperaceae have been found low throughout the diagram. Ferns and aquatics, which are indicators of moist conditions, are also found to be low in the whole profile, supporting in general the existence of arid to semi-arid condition in the area during major time span of the last glacial period. Pollen of *Larix,* which is not growing presently at the area, has been recorded scarcely at certain depths. However its presence suggests that either Larch used to grow in that area or along with Birch it might be the constituents of upper tree line of sub-alpine belt closer to the site. The vegetational reconstruction based on seven pollen zones discussed earlier reveals that there are predominantly fluctuations of steppe taxa along with some tree elements of both local and extra local origin. The existence of steppe vegetation mostly represented by *Ephedra, Artemisia* and members of Chenopodiaceae throughout the diagram reveals prevalence of semi-arid climate at this region at least since last 35 kyr B.P. However, there are also some intervals when expansions of *Betula,* and other local tree taxa took place within the steppe when climate seems to be comparatively less arid than the present condition. Besides, a good amount of conifer pollen grains in the pollen diagram might be of extra local origin as it is recorded in the modern sediments of this region (Bhattacharyya, 1989). These extra local taxa were transported by the upthermic wind from the distant lower sub alpine/temperate forests. Their fluctuations also seem to be related with the changes of tree line and wind direction. Overall vegetational scenario in the present study could be summarized as: in the beginning around 35 kyr B.P at the pollen zone Z-I the area was characterized by Chenopodiaceae-*Ephedra-Artemisia* steppe under the semi-arid cold climate. Subsequently the migration of *Betula* at the pollen zone Z-II took place when climate was comparatively warmer and less arid than before and its further increase around 22 kyr B.P. in the *Ephedra-Artemisia*-Chenopodiaceae steppe suggests comparatively more favourable climatic condition. During pollen zone Z-III this amelioration of climate is continued where Birch might have grown at the vicinity of the site. High value of Pine suggests that tree line was much closer to the site of investigation. Subsequently during pollen zone Z-IV climate had turned to be cooler and drier with the expansion of steppe taxa. During Z-V increase of arboreal taxa and simultaneously decline of *Ephedra*, Chenopodiaceae again suggest amelioration of climate, i.e. climate was comparatively less dry than the previous zone. During Z-VI climate might have changed towards more aridity, which is evidenced by the increase of steppe elements. During Z-VII climatic amelioration was noted again with decline of both *Ephedra* and Chenopodiaceae. The climate reverted to warm-moist when the area again was colonized by stands of Birch within the steppe.

A good amount of pollen grains of *Pinus, Picea, Abies* and *Alnus* recorded in the pollen diagram are of extra local origin. These pollen grains were transported from their long distance source and got deposited at the site along with the local sparse steppe vegetation. Among these extra local elements *Pinus* though represented in most pollen zones displays comparatively lower values in zones Z-I, Z-II and Z-IV, i.e. in the lower and middle part of the diagram when the climate was comparatively drier. The higher values of *Pinus* at other zones indicate that the climate experienced less aridity and tree line was closer.

## CORRELATION WITH OTHER SITES

The climatic changes derived from the palynological analyses from Lamayuru have been found to have good correspondence with the climatic inferences drawn from the other Himalayan sites. During the last glacial period several episodes of amelioration seem to be "Interstadial" reported during 34, 32, 30.7, 29, 21.7 and 18 kyr in the Kumaun, Lesser Himalayan (Kotlia *et al.*, 1997a, 2000) and also from Ladakh, Trans-Himalayan region (Bhattacharyya, 1989). Amelioration of climate during 22 kyr B.P and its subsequent one in the present study seem to be comparable to 21.7 and

18 kyr of the other sites, though paucity of absolute dates restricts the detailed temporal comparisons for other periods. Earlier eight fossiliferous horizons were recognized at depths 30 cm, 1.5 m, 6.4 m, 17 m, 24.8 m, 27.8 m, 31.7 m and 37 m from the base and it has been suggested that deposition took place under shallow fresh water environment (Kotlia *et al.*, 1997b). This is also supported by the palynological data except bottom of the profile suggests brackish condition when good number of Chenopodiaceae plants used to grow in the vicinity of the lake margin of these horizons. 17 and 24.8 m depths from the base fall in palynologically unproductive zone.

The Interstadial around 35 kyr B.P in Lamayuru has also been recorded from other Trans-Himalayan site, Tsokar Lake, Ladakh (Bhattacharyya, 1989). Interstadial during 37-32 kyr B.P in Lake Manas, Zunggar, northern Xinjiang, western China (Rhodes *et al.*, 1996), also seem to be contemporaneous event. Interestingly almost similar climatic trend has also been noticed in the Mediterranean region. Such closer association between Himalayan and Mediterranean region has been reported earlier from the palynological study of Tsokar Lake (Bhattacharyya, 1989).

The contemporaneous palaeoclimatic records from the peninsular India indicate relatively dry conditions during the last glacial period. The carbon isotope study from Nilgiri Hills (Rajagopalan *et al.*, 1997) in the southern India reveals the moist conditions around 40 to 28 kyr B.P. followed by increase of aridity and more arid conditions around 16 kyr B.P. The other multyproxy studies from southern India (Sukumar *et al.*, 1993; Bera *et al.*, 1996; Sukhija *et al.*, 1998), western and central India (Andrews *et al.*, 1998; Singh *et al.*, 1974, 1990; Srivastava *et al.*, 2003), Arabian sea (Duplessy, 1982; Van Campo *et al.*, 1982; Van Campo, 1986) and Bay of Bengal (Chauhan & Suneethi, 2001) also suggest arid conditions between 25 to 15 kyr B.P.

## CONCLUSION

Palynological analysis made from 105 m thick profile from Lamayuru palaeolake, provides a broad idea of temporal succession of vegetation vis-a-vis climatic changes during the major time span of the last glacial period since the base of the profile has been assigned to be around 35 kyr B.P. Present study suggests that the prevailing semi-arid climate of this region characterized by the continuation of *Ephedra*-Chenopodiaceae-*Artemisia* steppe at least from around 40 kyr B.P. Migration of *Betula* after 35 kyr B.P took place when climate was comparatively less arid than before and its further increase around 22 kyr B.P in the *Ephedra-Artemisia*-Chenopodiaceae steppe suggests comparatively favourable climatic conditions. Subsequently climate had turned to be cooler and drier with the expansion of steppe taxa. However because of non-availability of dates in the upper part of the profile these events remain undated.

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