Climatic changes during the last 1800 yrs BP from Paradise Lake, Sela Pass, Arunachal Pradesh, Northeast Himalaya

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An exploratory pollen and carbon isotopic study carried out from a 1 m deep sediment profile at the Paradise Lake (4176 m amsl) near Sela Pass has revealed vegetation vis-à-vis climatic changes during Late Holocene. Around 1800 yrs BP (around AD 240), conifer-broad-leaved forest used to grow in the vicinity of the study site under warm and moist climate, similar to the prevailing present-day conditions which turned out to be comparatively more warmer 1100 yrs BP (around AD 985) corresponding to the Medieval Warm Period. The glaciers seem to have receded and tree line might have been closer to the site. Around 550 yrs BP (around AD 1400) decrease in *Tsuga*, *Juniperus* and *Quercus* suggests a trend towards comparatively cooler and less moist climate corresponding to the Little Ice Age. This is followed by an amelioration of climate more or less equivalent to the present day. Carbon isotopic analyses in sediments at different intervals reveal fluctuation of C-3 taxa dominantly throughout under variable moist climatic regime.

Keywords: Climate changes, Late Holocene, palaeoclimate, palynology, Paradise Lake.

THE Himalaya is an exceptional repository of the past climatic records, which provides a unique environment to study the interaction of glaciation and climate without much interference of habitation, industry and pollution. Because of its wide latitudinal (21°57′–37°5′N) and orographical factors due to altitudinal variations (~300–8000 m), there is a great diversity in climate. In general, a trend towards increasing aridity from its northeast to northwest gradient is noticed. Since this area has a key role in controlling the regional and extra-regional atmospheric circulation system[1,2], there is an urgent need to develop a long climatic record through analyses of various proxy data from diversified geographical locations. Among the various proxies, pollen grains from continental sediments offer a broad perspective of the palaeoclimate and significantly help in understanding the long-term climate changes. Pollen grains/spores preserved in the sediment layers provide details about the environmental condition at the time of their incorporation and hence their alterations both qualitatively and quantitatively in sediments at different depths, are unique indices for the analysis of temporal variation of climate.

A good number of climatic reconstructions based on palynology are available from the higher elevation sites of the Himalaya, but these are mostly from its western part[3–13]. In this regard, data from the Eastern Himalaya are scanty and are recorded only from its temperate belt[14,15]. No palynological information regarding climate is available from the alpine belt of this region.

This communication is an exploratory attempt at a shallow sediment profile from Paradise Lake, an alpine lake in northeastern Himalaya (Figure 1 *a*), using pollen and carbon isotopic study to understand climate change during the recent past and potentiality of this site to take up a detailed palaeoclimatic study.

The Paradise Lake (Figure 1 *b*) extending between 27°30.324′N lat. and 92°06.269′E long., is located at an altitude of 4176 m amsl, near Sela Pass. It is 92 km southeast of the Tawang main town, Tawang District, Arunachal Pradesh. This site is just above the tree line and represents an alpine meadow. Birch and *salix* form the tree line and grow just above the sub-alpine forest represented by small patches of open fir (*Abies densa*) forest at an elevation of about 3500 m amsl.

A shallow pit of 1 m depth was dug along the dry bed of the lake shore. Lithologically, the top 30 cm of the profile comprises mostly of gravel followed by a clay band of 35 cm thickness, below which is a black sandy clay zone. Except from the top 30 cm, i.e. from the coarse sediment bed as it was not suitable for pollen analysis, the samples were collected at an interval of 10 cm from the rest of the profile. Detailed lithology of the sediment profile is shown in Figure 2. Two samples have been dated at the Radiocarbon Laboratory, Birbal Sahni Institute of Palaeobotany (BSIP), Lucknow. These dates are modern and 1780 ± 130 yrs BP, i.e. AD 300, at a depth of 31–35 cm and 100 cm respectively. The radiocarbon date is calibrated to calendar years using radiocarbon calibration program[16]. The approximate rate of sedimentation for this profile has been calculated on the basis of these two consecutive radiocarbon dates at two depths (Figure 2). The 65 cm thick sediment between these two dates comprising sandy clay seems to have been deposited at the rate of 4 cm/100 yrs. There is not much change in lithology between these two depths, which is suggestive of a more or less closed system of deposition in which there had been no variations in the characteristics of the depositional basin. The other dates in the profile have been interpolated based on this sedimentation rate to demarcate if there were any major changes in the pollen sequences.

For palynological analysis, sediments were macerated using the standard procedure of acetolysis[17]. Minimum 300 pollen grains per sample were counted, which was taken as the 'total pollen count'. Pollen percentage dia-

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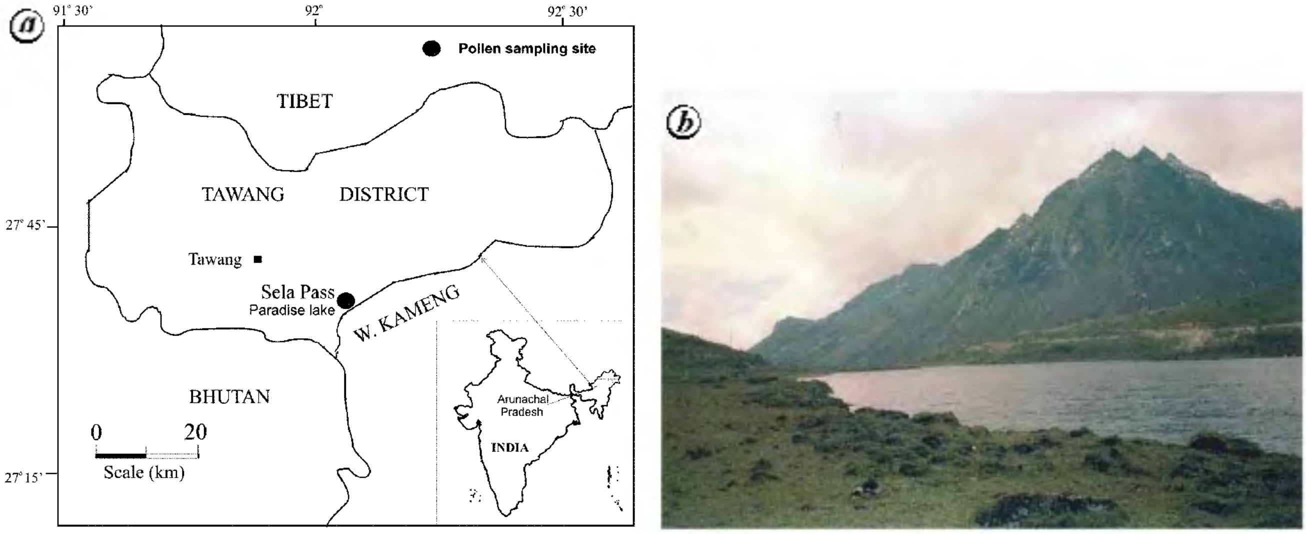

Figure 1. *a*, Location of pollen sampling site in Paradise Lake, near Sela Pass, Tawang, Arunachal Pradesh. *b*, View of Paradise Lake.

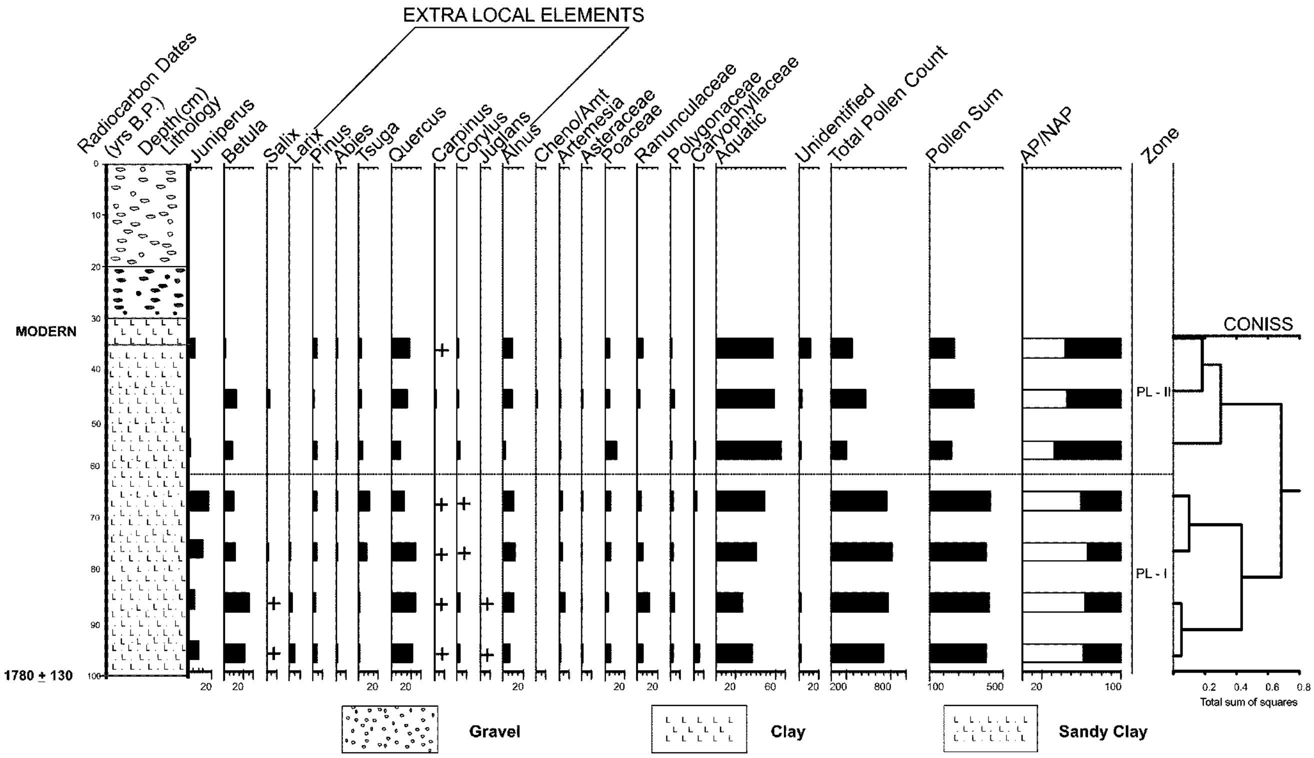

Figure 2. Pollen diagram of the profile from Paradise Lake.

grams were constructed[18] using the TILIA and TG View 2.0.2. Several tree-pollen taxa not growing at the site of investigation, viz. *Abies*, *Alnus*, *Carpinus*, *Corylus*, *Juglans*, *Larix*, *Picea*, *Pinus*, *Quercus*, *Rhododendron* and *Tsuga* are considered here as extra local elements and were not included in the 'pollen sum'. These taxa grow at comparatively lower elevations at the upper level of sub-alpine fir forest, approximately 500 m away from the study site. Their pollen grains are carried to the site by upthermic winds and get deposited there. The percentage of these taxa was calculated with respect to the total pollen count. For local taxa which grow at the site or close to it, percentage was calculated in relation to the pollen sum. To make the pollen diagram more synthetic some of the pollen taxa, which were represented by very low quantities throughout the profile analysed, viz. Aceraceae, Apiaceae, Lamiaceae, Primulaceae, *Rhododendron*, Rosaceae, Saxifragaceae and *Viburnum* are not shown in the pollen diagram, but have been included in the pollen sum. The pollen taxa lower than 1% are shown by '+' sign in the pollen diagram (Figure 2).

The pollen sequence in the diagram has been divided into two pollen zones, PL-I and PL-II, prefix PL represents Paradise Lake. These zones were determined by stratigraphically constrained cluster analysis using CONISS[19], available in the computer program[18] TG View 2.0.2. Zone PL-I (100–60 cm) covering a time-span of 1780–684 yrs BP (AD 245–1295), is characterized by overall dominance of arboreal taxa (63–66%) over non-arboreal taxa (37–34%). The extra local conifers are characterized by dominance of *Tsuga* (8–10%), followed by *Pinus* (4–5%), *Larix* (3–4%) and *Abies* (2–3%). Amongst the local, sub-alpine taxa, *Juniperus* (8–18%) and *Betula* (11–25%) show higher representation than *Salix* (1–2%). The broadleaved elements also mark their appearance, amongst which *Quercus* (13–24%) and *Alnus* (7–12%) dominate over *Corylus* (2–3%), *Carpinus* (1–2%) and *Juglans* (1–2%). The non-arboreal taxa are represented by Ranunculaceae (7–11%) followed by Poaceae (6–7%), *Artemisia* (5–6%), Caryophyllaceae (3–6%) and Polygonaceae (2–3%). The aquatic and marshy taxa including *Potamogeton*, Cyperaceae and fern (monolete, trilete) show an increase from 35% to 50% from the base to the upper part of zone at a depth of 65 cm.

Zone PL-II (60 cm – surface) covering a time-span of 684 yrs BP (AD 1295) to Recent is characterized by a major change in vegetational pattern, where the non-arboreals (55–75%) dominate over the arboreals (45–25%). There is an overall decrease in the percentage of conifers, broadleaved taxa and local sub-alpine arboreal taxa. Amongst the extra local conifers, *Tsuga* shows remarkable decline compared to zone PL-I and *Larix* does not mark its appearance in this zone. The sub-alpine taxa also show a decline in *Juniperus* (2–5%) and *Betula* (5–13%). Broadleaved taxa are represented by *Quercus* (9–25%) followed by *Alnus* (2–9%), *Corylus* (2–3%) and *Carpinus* (1–2%). Non-arboreal taxa are characterized by decrease in Poaceae from 15% to 5%. Ranunculaceae (2–4%) and Caryophyllaceae (1–2%) also show a decline compared to zone PL-1, whereas there is an increase in overall marshy and aquatic taxa represented by Cyperaceae, Ranunculaceae, Saxifragaceae, ferns and *Potamogeton*. Chenopodiaceae and *Artemisia* are the other non-arboreal taxa that mark their presence, but their percentages are very low (2–3%).

The pollen diagram reveals that there were at least two broad phases of vegetation vis-à-vis climatic changes in the region. During the time-span of PL-I, i.e. around AD 245–1295, higher representation of arboreal taxa in comparison to non-arboreal taxa suggests that the tree line was either much closer or alpine forest represented by birch–juniper grew in the vicinity of the site. Sub-alpine conifer forest represented by larch–fir–pine overtopped by broadleaved conifer upper temperate forest represented by *Pinus*, *Tsuga*, *Quercus*, *Juglans* and *Alnus* were located not far from the lake site. Diversified alpine taxa belonging to Poaceae, Cyperaceae, Ranunculaceae, *Artemisia*, Chenopodiaceae, Asteraceae and ferns grew in the alpine belt near the lake.

Zone PL-II covers the time-span from 684 yrs BP (AD 1295) to Recent. At the beginning the tree line descended to lower elevations. There was an abrupt decrease in local arboreal taxa. *Salix* did not mark its presence in the lower part of the zone around 550 yrs BP (AD 1400). During this time period, the percentage of extra local conifers and broadleaved taxa also diminished and there was an overall drop in the total pollen count, advocating that the conditions might have become less moist compared to PL-I. The increased percentage of marshy or moisture-loving taxa, i.e. Cyperaceae and ferns reveals that the lake became shallower due to comparatively drier climatic conditions, leading to more area exposed to the growth of these plants. Moreover, the lake might have turned from oligotropic to eutropic, thereby supporting a good number of aquatic taxa. It is a general observation that most of the pro-glacial alpine lakes of the Himalaya with higher lake levels do not support good aquatic flora. However, in the upper part of the zone around 400 yrs BP, there was again a tree line shift towards higher elevation, supported by the increase of both broadleaved and local arboreal taxa. This may be attributed to the reversal of climate towards more humid conditions.

Carbon isotopic analyses revealed that $\delta^{13}C$ in sediments at different intervals of the 1 m section of lacustrine deposit ranged from –23.9‰ to –25‰. Generally, $\delta^{13}C$ in trees, shrubs and herbs growing in moist environment (C-3 plants) ranges from –24‰ to –34‰, whereas plants distributed in deserts and salt marshes growing in drier environment (C-4 plants)[20] range from –6‰ to –19‰. Earlier studies have established that the lower values of $\delta^{13}C$ indicate moist climate, whereas higher $\delta^{13}C$ values specify drier and colder climate in the monsoon-dominated region[21,22]. Thus $\delta^{13}C$ (–24‰ to –25‰) recorded in the present study clearly indicates the dominance of C-3 plants at least since 1800 yrs BP, and their fluctuations might be due to change in the moist-regime.

In general, around AD 245 conifer-broadleaved forest was close to the site when the climate was comparatively warmer and moist than that prevailing in the present condition. Around 1100 yrs BP, i.e. AD 985, increase of *Tsuga*, *Abies*, *Picea* and varying amounts of *Pinus*, *Abies* and *Juniperus* and other broadleaved taxa suggested that the area was closer to sub-alpine forest corresponding to the East Himalayan dry temperate conifer forest[23] and the climate was comparatively warmer. This might be the impact of the Medieval Warm Period (MWP). Similar warm climatic condition has also been noted from the lower temperate belt of the Eastern Himalaya[15]. The amelioration of climate was followed by a decline in the forest cover at the bottom of PL-II, when climate might have been cooler and less moist than the previous zone. This phase seems to be the impact of the Little Ice Age (LIA) that is believed to cover a time-span from the 15th to 19th century[24,25]. On the contrary, pollen data from the temperate belt of this region do not show any impact of LIA, as is evident by an amelioration of climate at Khechipiri Lake since 1600 yrs BP to recent time[15]. Recent studies[26,27] suggest that cooling during LIA was a discrete phenomenon intermittent with small phases of warming and cooling episodes respectively. But overall decline of vegetation and increase in steppe elements in the alpine region of the Himalaya might be due to the impact of major time-span of low temperature in relation to long-term average during LIA. Generally plants growing in the alpine region are found more sensitive to slightest changes in climate. The impact of longer duration of cooler phases than warm periods during LIA is also reflected in the long-term tree growth both from Eastern[26] and Western Himalaya[27]. Though pollen data suggest that there is an impact of LIA in the alpine region, absence of its effect in the lower belt trees of the Eastern Himalaya[15] suggests that it is not a significant event in the eastern Himalayas as it has been in Tibetan Plateau and elsewhere. This is also supported by $\delta^{13}C$ values (–23.9‰ to –25‰) at different intervals in the sediments of Paradise Lake analysed here. This range of carbon isotopic values suggests that the region has been in general under cool, moist climate at least since the last 1800 yrs BP (AD 245) and did not show much change in climate during that time-span to support C-4 taxa, which are indicators of glacial drier environment. It is apparent that glaciers might not have descended to much lower altitude in this region at least up to 4000 m amsl close to Paradise Lake during neo-glacial advances. This is evident in the palynological investigation from this region, which does not show much variation of the alpine taxa, viz. *Artemisia*, Chenopodiaceae, *Ephedra*, etc. which are indicative of drier climate.

Pollen analyses supplemented with carbon isotopic study from a shallow sediment profile in Paradise Lake, Arunachal Pradesh, Eastern Himalaya provide vegetational changes and their relationship to climate during the past 1800 yrs BP (AD 245). The study revealed that this area experienced warm and moist climatic conditions around AD 245 with a trend towards comparatively more warm and moist climate, which is cumulated around AD 985. Subsequently, the climate turned towards comparatively cooler and less moist condition before it reverted again to warm–moist condition. This exploratory study has significance as it exhibits the signature of two important climatic epochs of the recent past at this region, viz. MWP during AD 985 and LIA around AD 1400, though the impact of latter is not major in the Eastern Himalaya, as it is elsewhere. It has also been testified that this alpine lake site is suitable for detailed palaeoclimatic analysis using pollen and other proxy data from the Eastern Himalaya.

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Ancient technology of jetties and anchoring points along the west coast of India

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The Indian coast, with a long history of maritime activities, has been dotted with several ancient ports. The evidence for this exists in port-related structures on the shore and in relics lying in the sea adjacent. Marine archaeological explorations have revealed the existence of jetties at Dwarka, Rupen Bandar and Porbandar, and offshore anchoring points at Bet Dwarka, Miyani, Visawada and Somnath on the Gujarat coast. The preferred anchoring points fall in a water depth of 5–7 m. This communication also discusses the effect of tide when using jetties and loading points along various parts of the west coast India.

Keywords: Anchoring points, ancient jetties, ports shipping, stone anchors.

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MESOPOTAMIAN texts vividly described the existence of docks in the 3rd millennium BC. For example, king Sargon the Great boasted that boats of Dilmun, Magan and Meluhha anchored at the docks of Agade, which was his capital[1]. An ancient Sanskrit text, the *Arthasastra*[2] of Kautilya, finds the description of a Superintendent of Shipping (Navadhyaksha), who was in charge of the ocean-going ships and strictly enforced the rules framed for the management of ports. He was empowered to kill pirates and punish those who did not follow the rules. The owner of the ship had to pay taxes before leaving the port. Further, the anonymous author[3] of *The Periplus of the Erythrean Sea* dating back to the 1st CE, has mentioned a chain of ports along the Indian coast. Ancient texts, including Indian (such as Tamil Sangam literature, Persian literature) and foreign sources (Ptolemy's *Geography* and Arian's *Indica*) have also made ample references to the existence of harbours and ports along the Indian coast during the historical and the medieval periods. Further, 'Pattana' is a Sanskrit term for the word port, that has been used in various ancient texts, appearing as two types, namely 'Samudrapattana', i.e. port on the coast of a sea and 'Jalapattana', i.e. port on the bank of a navigable river[4].

de Kerchove[5] defines a port as 'a place for the loading and unloading of vessels recognized and supervised for maritime purposes by the public authorities'. Further, he expands on the differences between a port and harbour thus:

> 'A port may possess a harbour, but a harbor is not necessarily a port. Any natural creek or inlet on the seashore with adequate depth of water and sufficient shelter for ships fulfills the essential conditions of a harbor. To make it a port, in the accepted sense of the word, there must be in addition accommodation and facilities for landing passengers and goods and some amount of overseas trade.'

One of the facilities for landing or loading passengers and goods is the jetty and it is described by de Kerchove as 'an engineering structure projecting into the water, of the nature of a pier, dike, embankment, constructed of timber, earth, stone or a combination thereof'[5]. Here we use the term jetty in a generic sense and where the construction is known, it will appear described as timber jetty, stone jetty and so on.

In an archaeological context, structures associated with ports and jetties have been discovered along the Mediterranean coast, including Carthage and Thapsus on the Tunisian coast[6], Caesarea on the Israeli coast[7], etc. The excavation at Ur on the bank of the river Euphrates had revealed a massive brick structure, identified as a harbour[8], the oldest remnant of any port structure in the world. Similarly, archaeological studies of the oldest known civilization of the Indian subcontinent, namely the Indus Civilization,