nine significant parameters (including derived parameters) responsible for avalanche activities on C–T axis region. The model accuracy is good for the occurrence case (67%) and better (84%) for the non-occurrence case. It may further be improved for both cases by incorporating terrain features as well as snow pack stability factors and can also be a task for the future.

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ACKNOWLEDGEMENTS. We thank Dr J. C. Kapil, Sri S. K. Dewali and Sri Piyush Joshi for helpful suggestions and discussion on this approach. We also thank to Dr R. N. Sarwade, Director SASE, Manali for interest and encouragement during this work. We also thank the technical assistants of the avalanche forecasting group for support.

Received 26 September 2005; revised accepted 6 July 2006

Late Holocene vegetation and climate change in the alpine belt of Himachal Pradesh

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Pollen analysis of 1 m deep sediment core from Naychhudwari Bog, Himachal Pradesh has revealed that around 1300 to 750 yrs BP, the alpine belt of this region experienced warm and moist climate. The glaciers receded and the tree-line ascended to higher elevations. Around 750 to 450 yrs BP, intermittent deterioration and amelioration of climate have been witnessed. From 450 yrs BP onwards, the glaciers advanced and consequently the tree-line descended under the impact of cold and dry climate in the region.

Keywords: Himachal Pradesh, Late Holocene, Naychhudwari Bog, pollen analysis, palaeoclimate.

So far a large amount of work has been carried out on the vegetation succession and contemporary climatic events during the Quaternary Period from the subtropical and temperate belts of the western[1–4] and northwestern Himalaya[5–7]. However, the alpine region with a large number of potential glacial lakes and bogs has not yet received much attention for the reconstruction of precise climatic changes and their impact on the vegetation scenarios exists in a chronological order, barring some sketchy information available from Garhwal Himalaya[8,9], Himachal Pradesh (HP)[10–12] and Ladakh[13]. In the present communication an attempt has been made to deduce the short-term climatic variability and contemporary vegetation shifts as well as tree-line and glacier movement in the alpine belt of HP during late Holocene. The work also aims at finding signals of global climatic events like Medieval Warm Period and Little Ice Age in this climatically sensitive region. A 1 m deep sediment core from Naychhudwari Bog in Kullu district has been used in the present study.

Naychhudwari Bog (77°43′ long., 32°30′ lat.) lies about 4 km east of Tundabhuj and 40 km northeast of Manikaran township in Kullu district, at an elevation of 4200 m asl on the hill slope to the right bank of Parvati river (Figure 1). The large perennial bog fed by a subterranean spring spreads over a gentle mountain slope. The surrounding mountains remain covered with perpetual ice for most part of the year, except during June–August. The rich presence of Quaternary sediments in the region is the outcome of intense glaciofluvial action. The mountain peaks attain maximum altitude of over 6000 m asl.

The vegetation in the vicinity of the bog is characterized by the presence of alpine steppe. The herbaceous vegeta-

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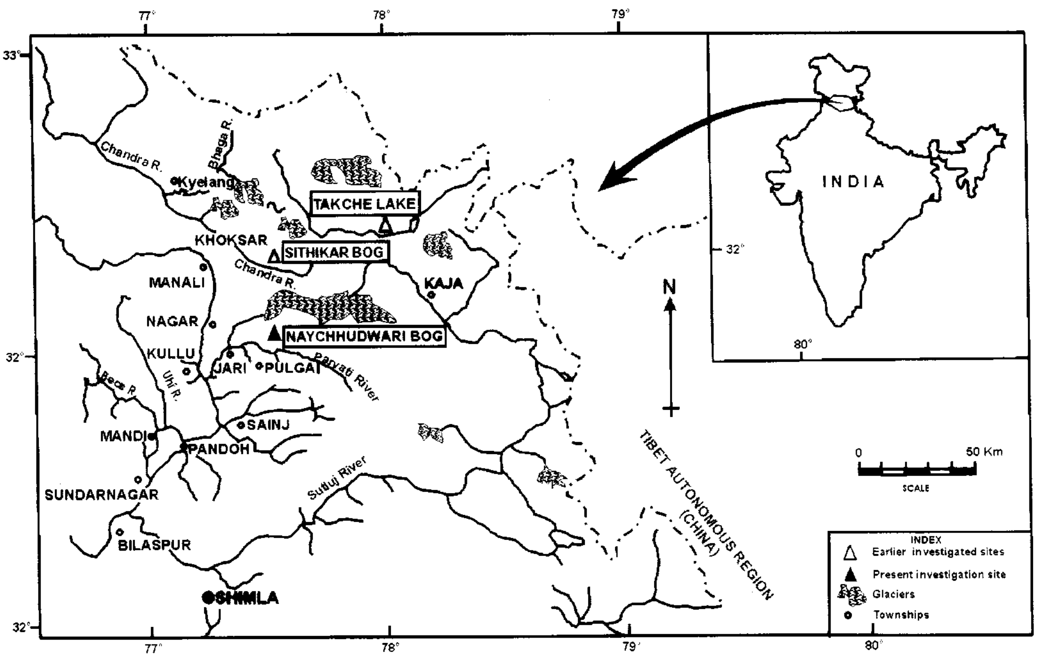

Figure 1. Map showing the study area.

Table 1. Lithological details of the core

Depth (cm)	Lithology
0–30	Clayey sand with organic matter and rootlets
30–50	Coarse sandy clay with pebbles and rootlets
50–80	Sandy clay with little organic matter
80–100	Coarse sand with pebbles and little organic matter

tion turns to be profuse during the rainy season and is constituted of grasses, sedges, *Pedicularis punctata*, *Saxifraga moorcroftiana*, *Anemone obtusiloba*, *Saussurea obvallata*, *Gneum elatum*, *Potentilla atrosanguinea*, *Rheum webbianum*, *Impatiens thomsonii*, *Corydalis govaniana*, *Sedum ewersii*, *Meconopsis aculeata*, *Gnaphalium* sp., *Parnassia nubicola*, *Ranunculus hirtellus*, *Bistorta vaccinifolia*, *Primula denticulata* and *Iris hookeriana*. In moist and shady habitats *Rumex* sp., *Impatiens thomsonii*, *Polygonum* sp., etc. occur gregariously in pockets. Thickets of *Juniperus macropoda* together with stray *Ephedra* occur in patches on the dry gentle hill slopes. The other stunted shrubby associates comprise *Crataegus cranulata*, *Berberis chitria*, *Cotoneaster microphyllus*, *Rosa macrophylla*, *Gaultheria trichophylla*, etc. In the valley areas, particularly along the bank of the Parvati river, mixed forests composed of gnarled trees of *Betula utilis*, *Rhododendron anthopogon*, *R. lepidotum* and *Salix daphnoides* together with scattered dwarf trees of *Pinus wallichiana* and *Abies spectabilis* can be seen.

Material for the present study includes surface and core samples. Five surface samples (moss cushions) were picked up at an interval of 50 m from the vicinity of the bog to study modern pollen deposition pattern in the region. A 1 m deep sediment core was collected from the centre of the bog, using Hiller's peat auger. In all, 20 samples for pollen analysis and two radiocarbon dating samples were taken from this core.

The sediment composition of the core shows the presence of sand, clay and organic matter in varying proportions at different depths. Rootlets were also detected in the upper part of the core. The lithlogical details of the core are given in Table 1.

Two radiocarbon dates have been determined for this core at larger intervals. These are 1170 ± 110 yrs BP (BS-2162)) at 80–100 cm depth and 470 ± 90 yrs BP (BS-2201) at 40–50 cm depth.

The available two absolute radiocarbon ages have been used for the interpolation of more ages at different depths, based on sediment accumulation rates, which are approximately 1 cm/15.5 yrs for 45–100 cm depth and 1 cm/10 yrs for 0–45 cm depth. The three interpolated dates of 1300 yrs BP at 100 cm depth; 750 yrs BP at 62.5 cm depth and 450 yrs BP at 42.5 cm depth have enabled the precise temporal delineation of the major vegetation shifts and climatic events in the region.

Samples were treated with 10% aqueous KOH solution and 40% HF solution to deflocculate the pollen/spores from the sediments and to dissolve the silica content respectively. Thereafter, the standard technique of acetolysis[14] using acetolysing mixture (9 : 1 of acetic anhydride and concentrated sulphuric acid) was employed. The samples for microscopic examination were prepared in 50% glycerin solution.

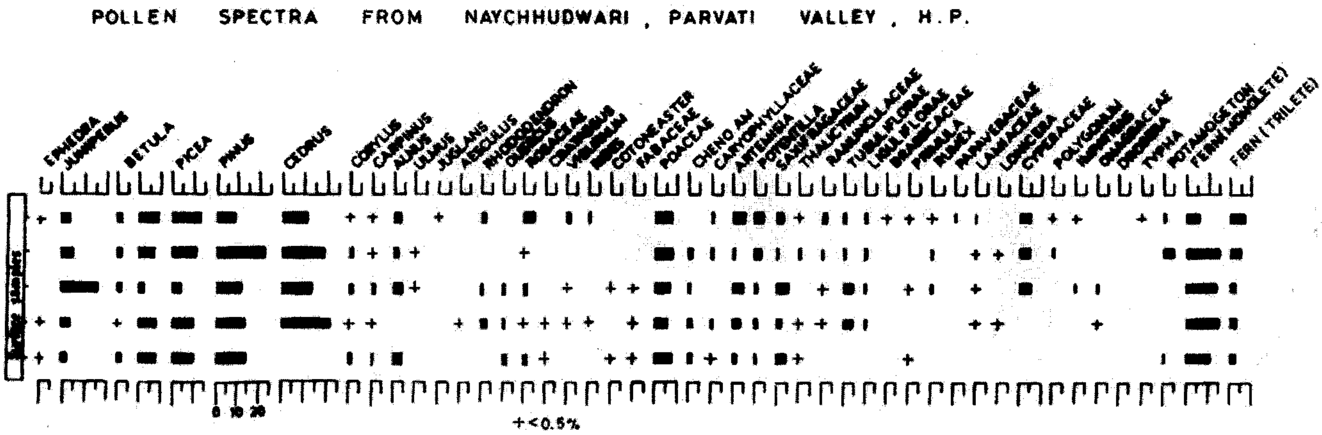

Figure 2. Pollen spectra from Naychhudwari, Parvati Valley, HP.

All the surface and core samples analysed were found rich in pollen/spore content. The pollen sums range from 331 to 611 for surface samples and 469 to 851 for core samples. The pollen sums exclude the pollen of aquatic plants and spores of ferns owing to their local origin. In the case of core samples, the Cyperaceae pollen were also not taken into account due to their over-representation in all the samples. The percentage frequencies of the retrieved pollen taxa have been calculated from these pollen sums. The plant taxa have been categorized as trees, shrubs, herbs (terrestrial and aquatics) and ferns, and are put in the same sequence in the pollen spectra and pollen diagram.

Five surface samples were analysed from the vicinity of Naychhudwari Bog in order to understand the depositional behaviour of pollen of various regional, extra-regional and local plants in the surface sediments compared to the factual occurrence of the pollen producing taxa in the natural vegetation (Figure 2). This has helped in the proper appraisal of the pollen diagram constructed from the region in terms of past vegetation and climate. In general, the pollen composition reveals much higher frequencies of arboreals in contrast to non-arboreals. Regional elements such as *Juniperus* (3–16%) and *Betula* (0.5–2.28%) are consistently represented, whereas *Rhododendron* (2.7%) and *Quercus* (1.16–2.74%), despite their sporadic occurrence, are recorded in moderate values. *Ephedra* (0.5%) is present meagrely. The shrubby element, Rosaceae (0.24–4.81%) is recovered in high frequencies in contrast to *Viburnum* (0.61–2%), *Ribes* (0.5–1.5%), *Cotoneaster*, *Crataegus* and Fabaceae (under 1% each), which are met with occasionally.

Among the non-arboreals, grasses (6.72–8.65%) followed by *Artemisia* (1.2–5.5%), *Potentilla* (0.9–3.58%) and Saxifragaceae (0.72–6.04%) are the major components of the steppe vegetation. Besides, Tubuliflorae (0.96–4.8%), Cheno/Am (0.6–2.16%), Liguliflorae, Caryophyllaceae (1% each) and Ranunculaceae (0.44–1.62%) are encountered in moderate to low frequencies. Brassicaceae, *Primula*, *Rumex*, Papaveraceae and Lamiaceae (under 1% each) are characterized by their stray pollen.

The marshy element, Cyperaceae (3.08–5.04%) has uniformly good frequencies in all the samples. Others such as *Polygonum*, *Impatiens* and Onagraceae are recorded in low frequencies. Fern spores (monolete 5.86–14.82% and trilete 2.8–6.6%) are encountered frequently in high values. The encounter of stray pollen of *Typha* could be attributed either to the presence of *Typha* plants in the vicinity of the study site or transportation of its pollen by upthermic winds from the adjoining temperate belt.

The temperate conifers, *Pinus* (9.12–22.8%), *Cedrus* (11.7–21.5%), *Picea* (3.9–12.7%) and *Abies* (2.11–8.8%) are consistently recorded in much high frequency. On the other hand, the temperate broadleaved elements, viz. *Alnus* (3.5–2.9%), *Corylus* (0.45–1.68%) and *Carpinus* (0.24–1%) are represented in low to moderate values. However, *Ulmus*, *Juglans* and *Aesculus* are recorded scantily.

The pollen sequence derived through the investigation of the sediment core from Naychhudwari Bog, has been divided into three distinct pollen zones by taking into account the fluctuating frequencies of the major regional arboreals and non-arboreals. The pollen zones have been prefixed with the initials 'NB' after the name of the investigated site and are numbered as NB-I, NB-II and NB-III from bottom to top of the pollen diagram (Figure 3).

NB-I (100–62.5 cm) with solitary radiocarbon age of 1170 ± 110 yrs BP and encompassing the time span of 1300 to 750 yrs BP, depicts the high frequencies of grasses (8.7–15.6%), *Impatiens* (7.84–13.9%) and *Artemisia* (2.64–6%). Other steppe elements, viz. Cheno/Am (0.37–3%), Asteraceae (Tubuliflorae 0.53–2.7% and Liguliflorae 0.9–3.3%), Papaveraceae (0.6–3.7%), Caryophyllaceae (0.9–2.79%) and Saxifragaceae (0.7–2.4%) are also recorded consistently in moderate values. *Potentilla* (0.37–2%), Brasssicaceae (0.3–1.32%), *Thalictrum* (1%), etc. are lowly represented.

The regional arboreals such as *Betula* (3.5–5%), *Salix* (0.46–2.86%) and *Quercus* (3.18–4.6%) are better represented in contrast to *Juniperus* (2.3–1.6%) and *Ephedra* (< 1%). The shrubby element *Lonicera* (0.57–1.58%), despite its reduced frequencies is consistently recorded,

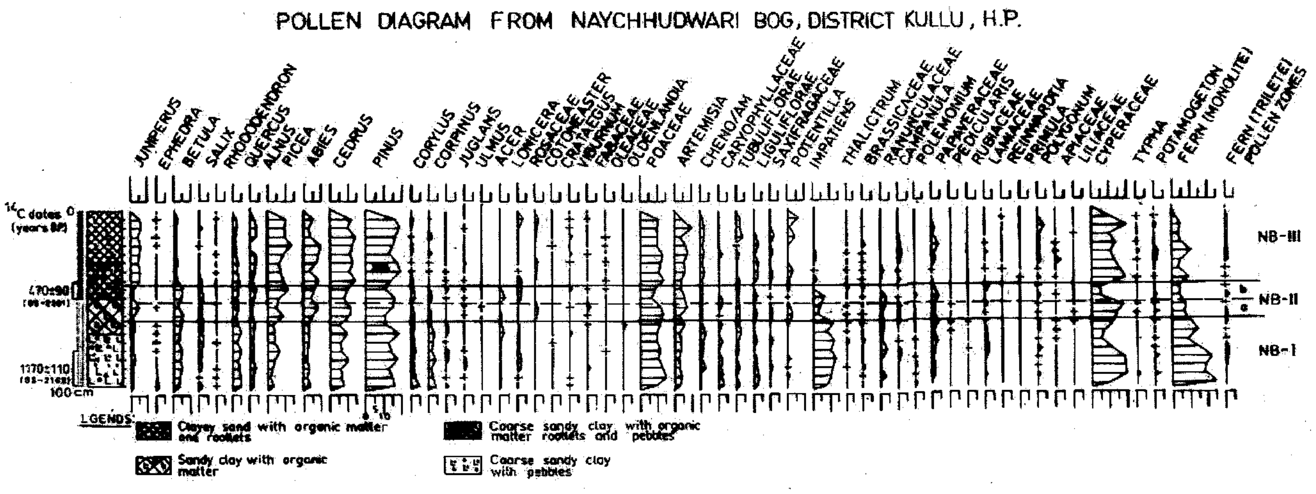

Figure 3. Pollen diagram from Naychhudwari Bog, District Kullu, HP.

whereas *Crataegus*, *Viburnum*, Oleaceae amd *Oldenlandia* are extremely low and sporadic.

The marshy vegetation is marked by much high values of Cyperaceae (6–27%). *Polygonum* sp. (0.18–1.14%), Apiaceae, *Polygonum plebeium*, *Solanum* and *Heliotropium* are met with scantily. *Typha* and *Potamogeton* represent the aquatic vegetation, with much low frequency. Fern spores (monolete 8.2–26% and trilete 1.1–2%) are quite frequent throughout.

Temperate conifers such as *Pinus* (1.37–28.6%), *Cedrus* (9.5–15%), *Picea* (7.1–13.7%) and *Abies* (3.1–10%) are encountered in high values, whereas the broadleaved taxa, viz. *Corylus* (0.58–1.36%), *Carpinus* and *Juglans* (1% each) are rare.

NB-II (62.5–42.5 cm) dated to 470 ± 90 yrs BP in the upper half and covering a time span of 750 to 450 yrs BP, also reveals the dominance of grasses (7–13.5%), though in fluctuating low values. Likewise, *Impatiens* (2.7–7.78%) also decline sharply together with Cheno/Am (0.5–1%) and Caryophyllaceae (0.29–2%). *Artemisia* (2.4–7.2%) and *Potentilla* (0.12–3.5%) exhibit a rising trend. Papaveraceae (1.31–2.7%), Ranunculaceae (0.73–2.8%), Saxifragaceae (0.48–2.4%), Asteraceae (Tubuliflorae 1–1.9% and Liguliflorae 0.96–4.4%) remain more or less static as before. Brassicaceae, *Campanula* (0.12–1.6% each) and *Pedicularis* (<0.5%) are present sporadically.

The marshy element, Cyperaceae (3.8–18.6%) after a decline in the middle, gains increased values. The aquatic elements such as *Typha* and *Potamogeton* decline further. Fern spores (monolete 3.2–7.96% and trilete 0.2–4%) dwindle sharply in this zone.

Among the arboreals, *Betula* (3.1–6.5%) and *Quercus* (1.7–4.3%) after a decrease in the beginning show a slight rise in the upper half. *Salix* (1.5–3.04%) remains same as before. *Juniperus* (1.6–2%) exhibits higher values in the lower half, but decline thereafter. *Ephedra* vanishes in the upper part of this zone.

The shrubby elements, *Lonicera* (0.2–2%), Rosaceae (0.7–2.5%) and *Viburnum* (0.27–1%) are sporadically recovered.

The temperate conifers, *Pinus* (11–17%), *Cedrus* (8.3–12.3%), *Abies* (2.5–6.7%) and *Picea* (3.7–11.8%) have increased values. The broadleaved temperate taxa, viz. *Corylus* (0.68–2.7%), *Carpinus* (0.75–2%) and *Juglans* (1%) have reduced values in this pollen zone, whereas *Alnus* (0.87–3.8%) remains unchanged.

NB-III (42.5–0 cm) with a time interval from 450 yrs BP to the present, is characterized by somewhat improved frequencies of Poaceae (9.9–13.6%) followed by *Artemisia* (3.5–10%) and *Potentilla* (0.7–6%). Tubuliflorae (0.9–4.4%), Liguliflorae (0.44–2.5%), Cheno/Am (0.8–2.23%), Papaveraceae (0.47–3.81%) and Saxifragaceae (0.8–3.12%) also have increased values. *Impatiens* (0.14–1.7%) declines severely and diminishes thereafter in the upper part of this zone.

Cyperaceae (11.4–17%) is marked by a considerable enhancement along with its associates such as *Polygonum* (0.23–2.9%) and Apiaceae (0.61–3.68%). *Typha* (0.48–3.68%) and *Potamogeton* (0.23–1.7%) are again recorded sporadically.

Juniperus (5–8%) shows a steep rise, attaining the maximum value of 8%. Similarly, *Ephedra* despite its low frequencies is better represented. The broadleaved taxa, *Quercus* (3–1%), *Betula* (2–1%) and *Salix* (1%) are recorded in reduced values than before.

The temperate elements such as *Pinus* (13.7–28%) followed by *Cedrus* (9.5–15%), *Picea* (7.1–13.7%) and *Abies* (3.12–9.9%) are encountered with further increased values, though fluctuatingly. The broadleaved taxa, viz. *Corylus*, *Juglans* and *Carpinus* become more sporadic, except for *Alnus* (0.9–3.7%) which has improved frequencies.

Pollen analytical investigation of 1 m deep sediment core from Naychhudwari Bog located in the alpine belt of Kullu district (HP) has provided some interesting inferences concerning the vegetation shifts and climatic variability in the region since the last 1300 years. The pollen proxy records envisage that between 1300 and 750 yrs BP, the alpine steppe comprising mainly grasses, sedges, Chenopodiaceae/Amaranthaceae, *Artemisia* and Caryophyllaceae with patchy occurrence of thermophillous, broadleaved taxa, viz. *Betula*, *Quercus* and *Salix* grew in the region under warm and moist climatic condition. This is also substantiated by the abundance of moisture-loving elements such as *Impatiens* and ferns. The dry elements such as *Juniperus* and *Ephedra* might have occurred sparsely in the rocky habitats on the mountain slopes. The preponderance of pollen of conifers, viz. *Pinus*, *Picea*, *Abies* and *Cedrus* together with broadleaved elements, *Alnus*, *Corylus*, *Carpinus* and *Juglans* implies their transportation by upthermic winds from the adjoining temperate belt, where all these taxa occurred abundantly.

During 750 to 450 yrs BP, the alpine steppe continued to flourish in the region with the dominance of grasses together with *Artemisia*, Chenopodiaceae/Amaranthaceae, etc. However, the short-term decline in most of the thermophillous, broadleaved taxa, namely *Quercus*, *Salix* and *Betula* and a corresponding increase of the dry elements, *Juniperus* and *Ephedra* have been witnessed. This is followed by a reverse trend of all these arboreals during the latter part of this brief time-span. Thus, the fluctuating behaviour of the arboreal vegetation in the alpine steppe is suggestive of intermittent deterioration and amelioration of climate, thereby indicating shifts of tree-line to the lower and higher elevations respectively. This is also well manifested by the declining and increasing frequencies of temperate conifers and broadleaved taxa respectively.

From 450 yrs BP onwards, there was again the onset of cold and dry climatic regime in the region as indicated by the expansion of dry arboreal elements such as *Juniperus* and *Ephedra* into the alpine steppe and a contemporary reduction in the broadleaved taxa, *Quercus*, *Salix* and *Betula* on the other hand. Such a change in the vegetation pattern occurred on account of prevailing harsh climatic conditions in the region. This is also well corroborated by a sharp decline and subsequent disappearance of the moisture-loving herbaceous element, *Impatiens* and ferns during this phase. The tree-line shifted to lower elevations in contrast to its earlier limit, in response to the alteration in the climatic condition from warm-moist to cold-dry.

Thus, the present investigation on a small sediment core from Naychhudwari Bog has generated significant information regarding the palaeoclimatic changes encompassing a short span of late Holocene. Mainly, two broader climatic episodes of warm-moist and cold-dry have been witnessed in the pollen sequence for larger intervals. However, intermittent brief spells of deterioration and amelioration in the climate have also been noticed between these major events. Around 1300 to 750 yrs BP, i.e. AD 650 to 1200, the glaciers retreated owing to the prevalence of warm and moist climatic condition. The tree-line or temperate belt ascended to higher elevations. In the global perspective, this climatic episode is equivalent to the Medieval Warm Period[15], which has been witnessed in most parts of the world around AD 740 to 1150. However, the subtle deterioration followed by amelioration of climate has been noticed during a brief spell between 750 and 450 yrs BP, i.e. AD 1200 to 1500, depicting thereby the pulsatory advancement and retreat of the glaciers. Subsequently, from 450 yrs BP, i.e. AD 1500 onwards, the climate changed to cold and dry. Because of the severity of climate, the mountain glaciers as well as tree-line descended downward to the earlier temperate belt. This cooling of the climate falls within the time-limit of Little Ice Age event[16], which has been recorded at global scale between AD 1550 and 1850.

Earlier investigated sediment cores from Sithikar Bog and Takche Lake, located in the alpine belt of Spiti region have unfolded the palaeoclimatic and palaeovegetation shifts since 2300 and 2000 yrs BP respectively. Both the pollen sequences have generated similar climatic trends, though for varying temporal ranges. Contrary to these, the present study covering only a time-span of 1300 yrs BP portrays the two later phases of climatic sequence of Spiti region with some minor oscillations between them. The Spiti region differs from the Parvati Valley in term of its topographic features and relatively harsh climatic condition.

The pollen sequences derived from Sithikar Bog[12] and Takche Lake[11] demonstrate that cold and dry climate prevailed at these sites during 2300–1500 yrs BP and 2000–1000 yrs BP respectively. The temporal difference of 300

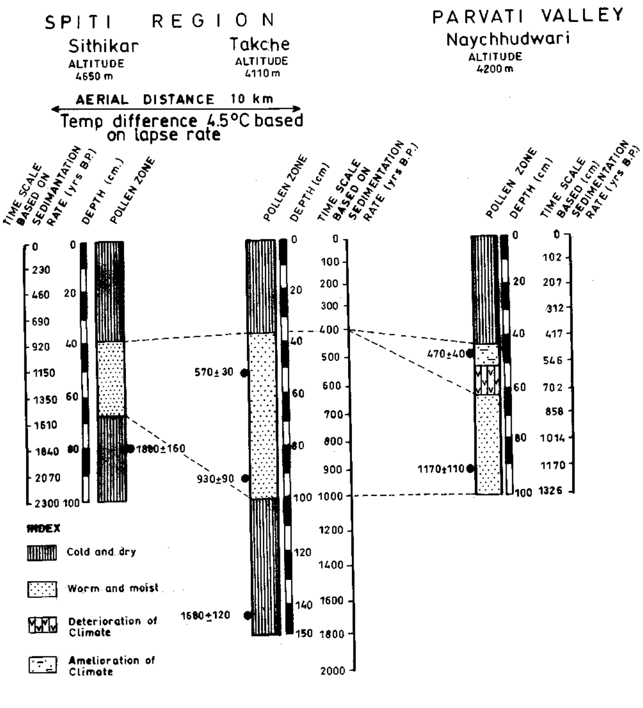

Figure 4. Correlation of pollen profiles from Spiti region and Parvati Valley, HP.

to 500 years for the prevalence of equivalent climate at these sites could have occurred with respect to the altitudinal control of climatic variance (Figure 4) and sensitivity of the Sithikar area, which is located at a comparatively higher elevation. This phase could not be deciphered in the Naychhudwari sequence owing to non-availability of older sediments. Subsequent phase of warm and moist climate commenced around 1500 yrs BP at Sithikar and continued till 900 yrs BP, whereas it occurred between 1000 and 400 yr BP at Takche. On the other hand, at Naychhudwari this phase has been witnessed between 1325 and 741 yrs BP, i.e. 200 years later than Sithikar and 300 years earlier than the Takche region. The discrepancies of time lapses for the prevailing similar climatic condition could be further attributed to their variable altitudinal locations as well as topographical settings. Interestingly, the intermittent deterioration and amelioration of climate have only been noticed during the time interval of 750 to 450 yrs BP at Naychhudwari area. They might have occurred in response to local variability of climatic factors. The ultimate cold and dry spell is inferred since 900 yrs BP at Sithikar and it commenced quite earlier compared to the two other alpine sites, i.e. Takche in Spiti Valley and Naychhudwari in Parvati Valley, where this has been recorded since 450 and 400 yrs BP onwards respectively. The early response of this phase at the Sithikar site of upper Spiti region could be inferred to the more sensitivity of this region to climate change owing to its 450 m higher altitudinal location than the other sites. Thus, the above account clearly shows that no precise common upper and lower time limit of the prevailing equivalent climatic phase can be drawn for different sectors of the Himalaya in term of their lateral and vertical extents.

The various climatic zones represented in the sediment cores from the alpine belt of HP may not match exactly in terms of time intervals and some minor fluctuations, because of geological settings and altitudinal variability and non-availability of more absolute dates. However, correlation of the major global events such as Medieval Warm Period and Little Ice Age seems to be well documented in Spiti region and Parvati Valley, based on pollen proxy records.

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ACKNOWLEDGEMENTS. I am grateful to Dr N. C. Mehrotra, Director, Birbal Sahni Institute of Palaeobotany, Lucknow for constant encouragement and to my senior colleague, Dr R. R. Yadav for valuable suggestions. Thanks are due to Indra Goel for chemical processing of the samples.

Received 20 February 2006; revised accepted 18 July 2006