Vegetation and climate in upper Spiti region, Himachal Pradesh during late Holocene

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Pollen analysis of Sitikher bog near Kunzum Pass (Himachal Pradesh) indicates that between 2300 and 1500 yr BP, cold and dry climate prevailed in the upper Spiti region and glaciers advanced towards the lower elevations. Between 1500 and 900 yr BP the climate changed to warm and moist, which resulted in the retreat of glaciers and shift of tree line towards the higher elevations. From 900 yr BP onwards the mountain glaciers/tree line descended with the return of cold climate which continues until the present time.

CONSIDERABLE work has been done on the Quaternary vegetation and climatic fluctuations in the subtropical and temperate belts of the western Himalaya[1–5]. However, the alpine region which has a great potential to understand the short-term climatic alterations has not received adequate attention thus far except some sketchy information on Ladakh[6], Himachal Pradesh[7,8] and Garhwal[9]. In this paper, an attempt has been made to decipher the climatic oscillations and corresponding vegetation shifts in the upper Spiti region during the late Holocene by carrying out the pollen analytical investigations of core sediments from Sitikher bog near Kunzum Pass.

Sitikher bog (77°43′long., 32°30′lat.) lies about 23 km west of Losar village at an altitude of 4500 msl in close proximity of the Kunzum Pass (Figure 1). The bog is quite big in expanse and spreads over a gentle mountain slope on the right bank of the Takche nala. This bog is fed by a perennial stream which flows on its right side. The presence of plenty of disturbed sediments in certain areas is considered to be generated as a consequence of intense frost action in the region. Extensive morainic deposits can be seen along the banks of streams and rivulets as well as in the valley areas. The surrounding mountain range remains covered with a thick ice blanket during a major part of the year, except during the months of June to August. The mountain peaks rise up to an altitude of over 6500 msl.

In general, the vegetation in and around the Sitikher bog is very scanty owing to the prevailing severe cold and dry climate. However, it is chiefly constituted of graminods together with herbaceous elements such as *Potentilla multifida*, *Pedicularis* sp., *Polygonum filicaule*, *P. cognatum*, *P. viviparum*, *P. amplexicaule*, *Geranium nepalense*, *Ranunculus cymbalaria*, *Anemone rupicole*, *Sedum shodiola*, *Berginia* sp., *Onosma echoides*, *Oxygraphis polypetala*, *Nepata floccosa*, *Gentiana humilis*, *Rheum spiciformae*, *R. webbiana*, *Impatiens* sp., *Thalictrum chelidonii*, etc. In moist and shady habitats the pure crops of *Potentilla multifida*, *Polygonum* sp. and *Aster* sp. can be seen.

The distribution of scrubby elements, *Ephedra gerardiana*, *Juniperus* sp. and *Arnebia hispida* is scattered mainly on certain dry rocky slopes, whereas gnarled trees of *Salix daphnoides* are present along water courses.

A 1-m deep sediment core was taken from Sitikher bog using Hiller's peat auger. It is difficult to collect a deeper core owing to the highly frozen nature of the sedimentary horizon. From this 1-m core, 20 samples were selected at an interval of 5 cm for pollen analytical investigation and two samples were collected for radiocarbon dating. The lithology of the core is mentioned in Table 1.

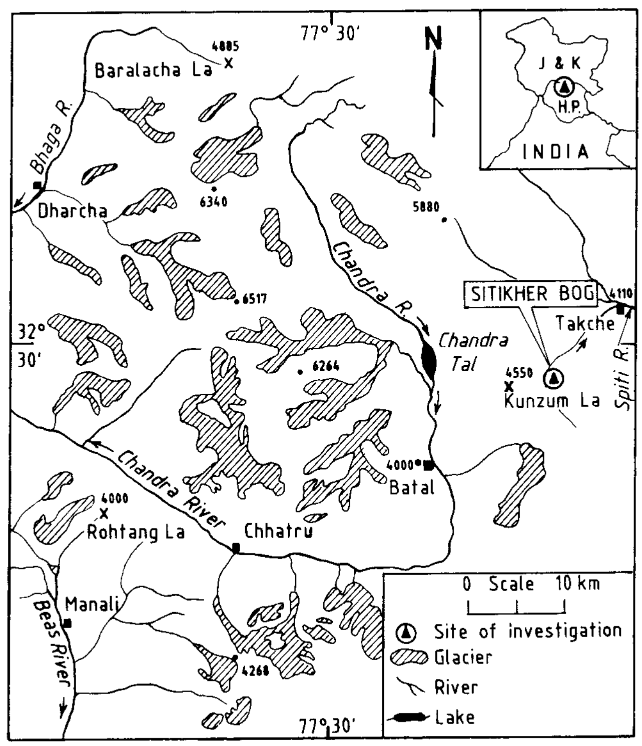

Figure 1. Map showing the site of investigation.

Table 1. Lithology of the core from Sitikher bog

Depth (cm)	Lithology
0–25	Greyish-black silty mud with gravels and rootlets
25–33	Greyish-black clay with gravels and rootlets
33–42	Greyish silty clay with occasional rootlets
42–70	Blackish silty clay with occasional gravels
70–100	Blackish silty clay with rootlets

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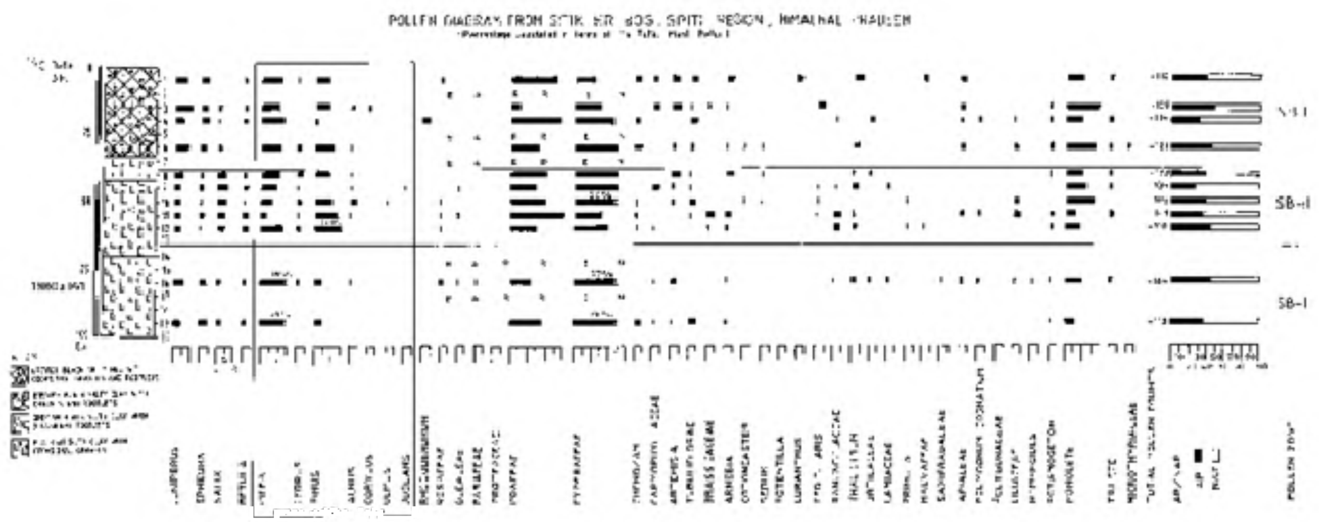

Figure 2. Pollen diagram from Sitikher bog, Spiti region (Percentage calculated in terms of the total plant pollen).

One sample at the depth of 75 to 90 cm has been dated to 1880 ± 160 yr BP (BS-1114) by radiocarbon method. Hence, based on this single date the rate of sedimentation has been calibrated to 1 cm/23 years for the core.

While processing the sample for ^{14}C dating, the rootlets have been completely eliminated by fine sieving of sample dispersed in large quantity of distilled water. The clayey mud was then centrifuged. Carbonates in the sample were eliminated by treating the same with 1% HCl at 90°C for 1 h. Standard laboratory procedure of ^{14}C dating was carried out for age determination[10].

The conventional technique of pollen analysis[11] through the use of 10% KOH, 40% HF solutions and acetolysis mixture (9 : 1, acetic anhydride and con. H_2SO_4) was followed to extract the pollen/spores from the sediments.

The pollen counts for the core samples vary from 105 to 164. The percentage frequencies of the recovered pollen taxa have been calculated in terms of total terrestrial plant pollen. The plant taxa have been grouped and shown as trees, shrubs, herbs and ferns in the pollen diagram (Figure 2).

On the basis of fluctuations in the representation of some prominent arboreals and non-arboreals, the available pollen sequence has been divided into three distinct pollen zones (SB-I, SB-II and SB-III). These pollen zones are prefixed with 'SB' after the name of site of investigation and are described below:

Pollen zone SB-I with a radiocarbon date of 1880 ± 160 yr BP and encompassing a time span of 2300 to 1500 yr BP is characterized by the dominance of non-arboreals. Cyperaceae (28–37%), Poaceae (12–18%), Chenopodiaceae/Amaranthaceae (Cheno/Am, 4%), *Arnebia* (2–3%) and *Artemisia* (2–4%) are the major constituents of the ground flora, whereas Tubuliflorae, Saxifragaceae, Ranunculaceae, etc. are recorded sporadically. The aquatic elements, *Potamogeton* and *Nymphoides* are met with in reduced values. Monolete fern spores 6–10% are frequent.

Among the arboreals, *Juniperus* (5–8%) and *Ephedra* (4%) have higher values in contrast to *Salix* and *Betula* (2% each). Fabaceae, Rosaceae and Oleaceae are sporadically represented. The temperate elements, *Picea* (19–21%) and *Pinus* (4%) are better represented compared to *Alnus* (2%) and *Cedrus* (1%).

Pollen zone SB-II, covering a time period from 1500 to 900 yr BP also exhibits the dominance of non-arboreals, Poaceae (15–30%), Cyperaceae (26%), Cheno/Am, *Artemisia*, *Thalictrum* and Ranunculaceae (1–4% each) and Tubuliflorae (1–3%). However, the thermophilous arboreals, e.g. *Salix* (4–6%) and *Betula* (1–4%) show increased values, whereas *Ephedra* (1–2%) and *Juniperus* (3–5%) decline in this zone. The temperate conifers, *Picea* (3–13%), *Pinus* (8–17%) and *Cedrus* (2–3%) are consistently represented. *Alnus* (2–5%) has improved frequencies than before.

Fern spores (Monolete 6–16% and Trilete 1–20%) are more preponderant than in SB-I.

Pollen zone SB-III, covering the time period from 900 yr BP to present, brings out the decline in the moist-loving elements such as sedges (35–12%), *Salix* (10–13%) and *Betula* (2%) and a corresponding increase in *Juniperus* (4–10%) and *Ephedra* (3–5%). *Rhododendron* 4% is met with in one sample only. Poaceae (10–28%) has fluctuatingly high frequencies. Likewise, the other common steppe elements, Cheno/Am (2–4%), *Artemisia* (2–5%), Tubuliflorae (1–4%), Apiaceae (3%) are recorded in good values. The conifers, *Picea* (12%), *Pinus* (11%) and *Cedrus* (1–3%) have reduced frequencies than that in SB-II.

The pollen analytical investigation of the 1-m deep sediment core from Sitikher bog near Kunzum Pass has brought out interesting inferences in respect of short climatic oscillations in the region since 2300 yr BP. The available pollen sequence has demonstrated that between 2300 and 1500 yr BP, this region had an alpine steppe vegetation chiefly constituted of grasses, sedges, Cheno/Am, *Artemisia* together with patchy occurrence of scrubby elements, *Juniperus* and *Ephedra* on dry rocky slopes. The broad-leaved arboreals, *Betula* and *Salix* were either scantily present in these steppes or most probably were confined to moist and shady habitats, particularly along the water courses. Ferns were growing in isolated patches in shady and damp situations. From the vegetational scenario it is obvious that the region was under the regime of cold and dry climate during this period.

The frequent record of pollen of *Picea*, *Cedrus* and *Pinus* signifies their transportation by upthermic winds from the lower elevations where these taxa grow abundantly. There is no nearest source of pollen for these taxa in the region other than the temperate belt in lower elevations.

Subsequently, between 1500 and 900 yr BP the alpine steppe vegetation continued to thrive in the region. However, the thermophilous broad-leaved elements, *Betula* and *Salix* expanded into the steppes, whereas a simultaneous decline in the dry scrubby elements, *Ephedra* and *Juniperus* had also occurred. This type of change in the overall vegetation composition envisages that the climate turned to warm and moist with the onset of this phase. The profusion of ferns as well as better representation of the constituents of the herbaceous complex such as grasses, sedges, Ranunculaceae, *Thalictrum*, Liliaceae and *Potamogeton* support this inference. Also, the enhanced frequencies of conifers, *Picea*, *Cedrus* and *Pinus* together with *Alnus* further imply the extension of the temperate forests/tree line to somewhat higher elevations in response to the climatic amelioration.

Since 900 yr BP onwards, the climate again changed to cold and dry as evidenced by the expansion of *Ephedra* and *Juniperus* into the alpine steppe. A corresponding decline in the moist-loving broad-leaved taxa such as *Betula*, *Salix* and sedges had also occurred with the prevalence of severity of climatic condition. The tree line might have descended to lower elevations because of changing climate in the region.

The present study on a small sediment core from Sitikher bog has brought out significant palaeoclimatic inferences covering the span of late Holocene. Three broader climatic phases, viz. cold–dry, warm–moist and cold–dry have been recognized throughout the pollen sequence. Around 2300 to 1500 yr BP, i.e. 350 BC to 450 AD, cold and dry climate prevailed in the region and mountain glaciers descended to lower elevations under the impact of the harsh climatic regime. Around 1500 to 900 yr BP, i.e. 450 to 1050 AD, the glaciers started retreating as a consequence of amelioration of the climate which became warm and moist. In response to this change, the mountain glaciers receded and the tree line ascended to the higher elevations. In the global context, this climatic amelioration corresponds more or less with the duration of Medieval Warming, which has been recorded in most parts of the world between 740 and 1150 AD (ref. 12). Subsequently, since 900 yr BP, i.e. 1050 AD onwards, the climate again became cold and dry. Under the influence of such a change in climate, the mountain glaciers as well as tree line advanced towards the lower elevations. This cooling of climate falls within the period of Little Ice Age which has been recorded globally between 1550 and 1850 AD (ref. 13).

The three climatic zones as revealed by the Sitikher bog bear close similarity with Takche lake sediment, which is aerially 10 km away with an altitudinal descent of 140 m (Figure 3). There is a temporal difference between the two sites because of their varied geomorphic setting. Sitikher is located in the higher altitudinal zone close to the mountain pass and is obviously colder than Takche which is situated near the valley bottom of the Spiti river. The older cold and dry climatic phase of Takche (TLK-I) extends from around 2000 yr BP as against Sitikher which starts around 2300 yr BP (SB-I). This phase terminates around 1000 and 1500 yr BP at the two sites, respectively. Similarly, the warm and moist phase which commences around 1000 yr BP in the case of Takche, starts around 1500 yr BP in Sitikher. While the latest cold and dry phase extends from 400 yr BP in the case of Takche, it commences around 900 yr BP in the case of Sitikher. Thus, there is a temporal difference of approximately 500 years between the corresponding climatic zones of Sitikher and Takche, and is noteworthy from the point of view of altitudinal control of climatic variance in the same region.

There is another site in the proximity of Sitikher from where palaeoclimatic data are available. This site is located at Batal in the adjoining Chandra valley bottom, which is also 10 km away with an altitudinal drop of 150 m. In this case, four climatic zones have been recognized[7], out of which the top three zones are comparable with Sitikher and Takche sediment cores. The oldest fourth zone (BT-I) does not show any resemblance with either Sitikher or Takche climatic zones. There are two possible factors responsible for this climo-temporal difference. Firstly,

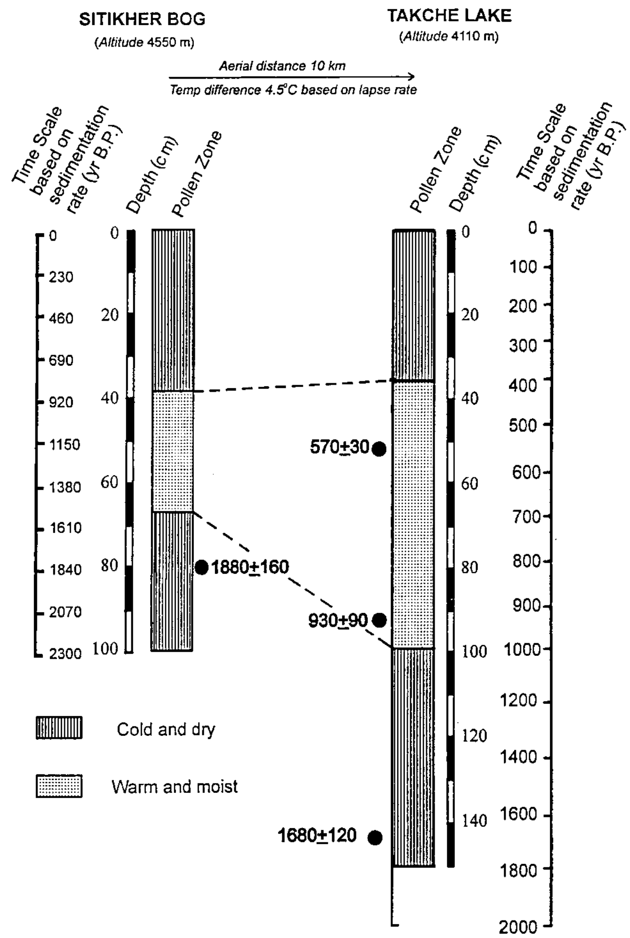

Figure 3. Correlation of Sitikher and Takche sediment cores.

there is some error in the calculation of temporal boundaries based on sedimentation rate in the Batal sediment core. Secondly, the Chandra valley shares a relatively different climatic and geomorphic set-up, being more moist than Spiti region. However, if recalculation of time-based sedimentation rate is considered, the climo-temporal boundaries may show close relationship at the sites of Takche, Sitikher and Batal. Correlation of the various climatic zones represented in the three sediment cores may not match well in a regional scale due to the varied tectono-geomorphic setting of the Himalaya. However, correlation of a few global events like Medieval Warming and Little Ice Age seems to be working well for the Spiti region.

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