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Late Quaternary vegetation and climate from temperate zone of the Kumaun Himalaya, India (with remarks on neotectonic disturbance)

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ABSTRACT. The past vegetation and climate that existed in the temperate zone of the Kumaun Himalaya, have been traced back to the early Holocene by means of palynological investigations of the lacustrine sediments at Sukha Tal in the Naini Tal District of Kumaun. Pollen data show that around 8700 ± 170 years B.P. the study area had a predominance of non-arboreal pollen with a poor presence of arboreal pollen which soonafter (around 7600 years B.P.) expanded, resulting in the establishment of mixed oak forests, with a corresponding fall in non-arboreal pollen. This indicates a change in climate to warm and humid conditions. Around 4200 years B.P. oak considerably declined with a rise in pine, reflecting a deterioration in climatic conditions. Near the onset of the Late Holocene, mixed oak forests returned, indicating that the climate soon ameliorated and again became warm and humid. The study site consists of a concealed fault and the contemporary zones of both arms of this fault are broadly comparable which further strengthens the reconstruction of the past vegetation and corresponding climate of the region.

KEY WORDS: palynology, past vegetation, past climate, early Holocene, temperate zone, Kumaun Himalaya, India

INTRODUCTION

Himalaya is an intercontinental and the world's highest mountainous chain covering part of Bhutan, China, India, Pakistan and the whole of Nepal. The Indian Himalaya extends from the northern border of Burma in the east to the eastern border of Afghanistan in the west and forms the northern part of the country. Kumaun (lying between 28°44′–31°25′N latitude and 78°45′–81°1′E longitude) marks the international boundary on 2 sides (in the east with Nepal and in the north with Tibet) and it contains subtropical, temperate and alpine zones.

Palynological investigations of Quaternary sediments from Kumaun have been carried out for about four decades and have involved several lake sites in the subtropical zone, but the temperate zone (ranging from 1500 metres above sea level to 3500 m a.s.l.) remains neglected except for recent investigations from a couple of profiles from Saria Tal (situated at 1738 m a.s.l.) which has enhanced our knowledge of the past vegetation and climate of the zone since the Middle Holocene (Gupta 2002a, 2007a). In order to obtain more knowledge, such a study has been extended to another site i.e. Sukha Tal (Fig.1), which is situated at 1981 m a.s.l., i.e. at 243 metres higher than Saria Tal. The record at this site extends our knowledge to the early Holocene (Gupta 2004a). A part of the sequence (i.e. from 3790 years B.P. – 2690 years B.P.) is represented twice (due to concealed fault, Fig.2) and pollen data generated from these contemporary portions are comparable to each other which strengthens the general interpretation. The present contribution provides a detailed account of the past vegetation and corresponding climate of the whole sequence with a repetition of the above mentioned parts in the investigated profile.

Sukha Tal is located in the Naini Tal District, at the west-north-west of Naini Tal Lake,

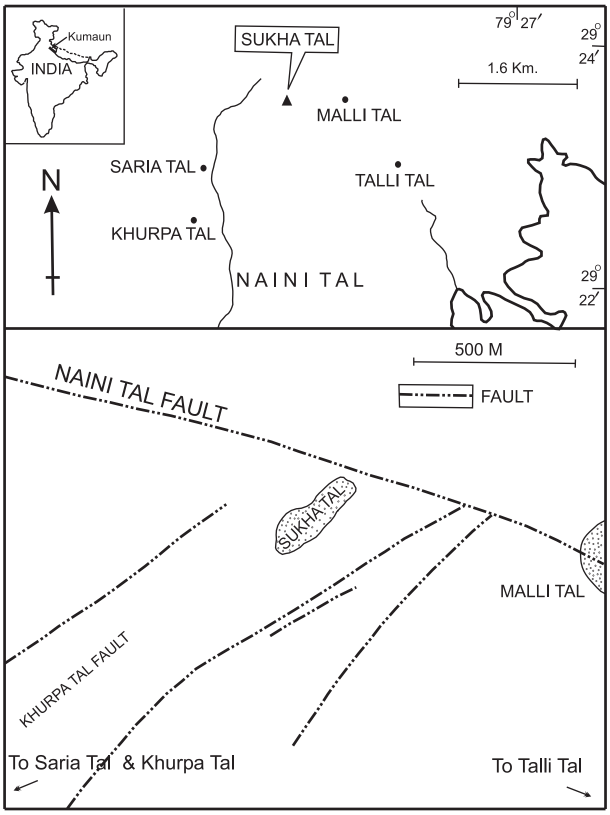

Fig. 1. Sketch map: upper part shows the location of Sukha Tal, in the Naini Tal District, Kumaun Himalaya; lower part shows the tectonic disturbances around the investigated site Sukha Tal (after Pal & Merh 1975, Valdiya 1988)

ca. 3 km from Malli Tal (i.e. the upper part of Naini Tal lake). Originally it was part of Naini Tal lake but it became separate later. As its name indicates, it is a dry lake (in Hindi, literal meaning of "Sukha" is dry) but contains water following rain for a short period. The lake area is demarcated by the depression which is ca. 200 metres long along the north-south direction and ca.100 metres broad along the east-west axis. A few years before, it was ca.10 metres deep but the water level never exceeded 3 metres, as most of the water escaped into Naini Tal lake. Presently it is filled up by rock debris, which has resulted in the elevation of the lake surface being relatively higher. The lake surface shows mud cracks in places.

The extant vegetation of Kumaun has been documented by many workers (Duthie 1918, Champion 1923, 1936, Osmaston 1927, Jain 1956, Bhargava & Gupta 1958, Champion & Seth 1968, Pandey et al. 1984). The vicinity of investigated site consists of mixed oak forest, dominated by *Quercus incana* with *Rhododendron arboreum. Pinus roxburghii*, *Cedrus deodara*, *Populus alba*, *Cupressus torulosa*, etc. are encountered around the lake. Climate of Naini Tal region is monsoonal temperate. The annual average rain-fall is about 279.4 cm. The heaviest precipitation occurs in June to September. Temperatures during winter have a minimum of 2.8°C and a maximum of 15.6°C; and during the summer the minimum is 10.6°C and the maximum is 26.7°C.

Geological investigations from the Kumaun are numerous (Middlemiss 1890, Gansser 1964, Tiwari & Mehdi 1964, Pande 1974, Fuchs & Sinha 1974, Hukku et al. 1974, Pal & Merh 1974, 1975, Raina & Dungrakoti 1975, Valdiya 1980, 1988, 2001, Valdiya et al. 1984, Thakur 1993, Singhvi et al. 1994, etc.). Studies show that besides Trans-Himadri Fault, Main Central Thrust, Main Boundary Thrust, and Himalayan Frontal Fault, there are numerous local thrust and faults which have been active during the Late Quaternary and have caused natural disturbances in the region. The district of Naini Tal consists of numerous lakes which owe their origin to various neotectonic activities (Ball 1878, Theobald 1880, Oldham 1880, Thomas 1952, Mathur 1955, Valdiya

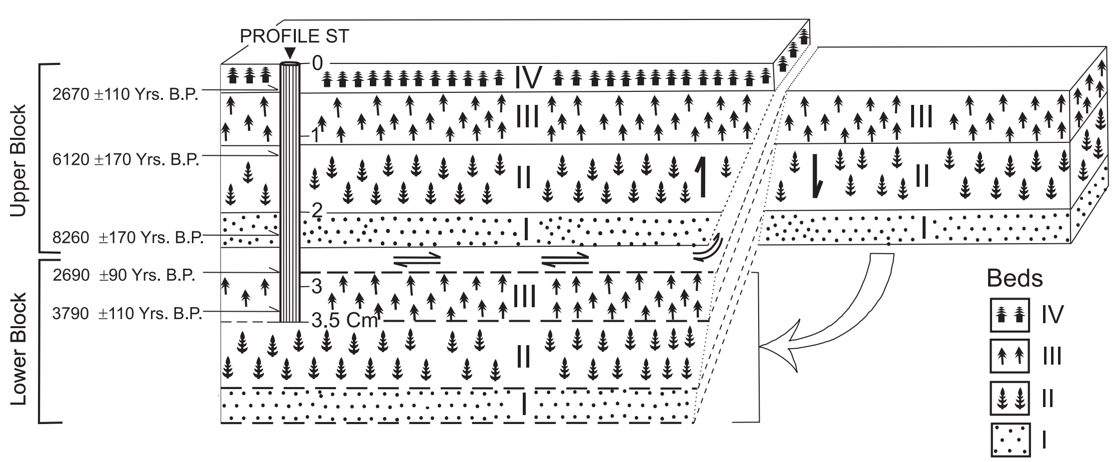

Fig. 2. Diagrammatic cross-section across Sukha Tal, Kumaun Himalaya showing the presence of concealed fault in the region

1988). Sukha Tal is formed due to the horizontal shifting of hard resistant rock and occupies a fault valley. The area around Sukha Tal is considerably disturbed (see the lower part of Fig. 1). The Naini Tal fault passing through Naini Tal lake is a long curved fault extending over many kilometres. A study of the subsurface sediments has revealed concealed neotectonic disturbances in the region i.e. a fold at Saria Tal and a fault at Sukha Tal (Gupta 2002b, 2006a).

In order to develop more data about the past history of the temperate zone of Kumaun, a multidisciplinary analysis was initiated. Beside palynological investigations, preliminary geochemical and palaeontological investigations have also been attempted (Gupta 2003a, b, 2004b, 2005a, b, 2006b, 2007b). Kumaun represents the eastern part of Uttaranchal and its western part is Garhwal. The past vegetation and climate of the temperate zone of Garhwal has been studied at Nachiketa Tal (2550 m a.s.l.), and Deoria Tal (2727 m a.s.l.). The former has provided the information about the past 1500 years ago (Sharma & Gupta 1995) while the latter has provided information about the past 6000 years (Sharma & Gupta 1997).

MATERIAL AND METHODS

The presently investigated profile was collected by the author in April 2000, from Sukha Tal, by trenching. The maximum depth reached was 3.5 metres because water seeped in. Samples were collected at 5 cm intervals. Sediments largely consist of silty-clay with or without sand, granules, and pebbles (breccia as well as conglomerate type).

DESCRIPTION OF SEDIMENTS

The lithological succession is as follows

0–42 cm	Silty-clay with sand
42–70 cm	Silty-clay with sand and granules (conglomerate type)
70–200 cm	Silty-clay with or without sand
200–240 cm	Silty-clay with sand, granules and fine pebbles (conglomerate type)
240–350 cm	Silty-clay with sand, granules and fine-coarse pebbles (breccia type)

LABORATORY TREATMENT OF THE MATERIAL AND CONSTRUCTION OF POLLEN DIAGRAM

About 10 gms material of each sample was boiled in 10% aqueous KOH solution to defloculate the matrix and then sieved. The filtrate was thoroughly washed and then treated with 40% HF solution to remove silica. Again the filtrate was washed thoroughly, than acetolysed using the conventional method of acetolysis (Erdtman 1943, 1960). The recovered palynodebris was mounted in 50% glycerin with a few drops of phenol for investigation

Palynodebris recovered from different samples in the profile were often quantitatively poor but qualitatively rich and contained well preserved palynomorphs. The frequency percentages of palynomorphs of different taxa are plotted in a pollen diagram (Fig. 3). The percentage values of particular taxa are calculated in relation to the total terrestrial pollen sum (including trees, shrubs and herbs, excluding aquatics and spores). Percentages of terrestrial pollen (arboreal and nonarboreal) and of aquatics and spores are calculated separately. Poaceae pollen > 40 µm in size are referred to as Cerealia type. On the basis of fluctuations of the prominent taxa, the upper unit has been divided into 4 zones which are numbered I, II, III and IV in ascending chronological order, prefixed after the site abbreviation ST. The lower unit coincides with zone ST-III of the upper unit, and is thus named zone ST-IIIa.

In order to avoid contamination of sediments of the upper and lower units, a part of the profile i.e. 275–245 cm, was discarded for pollen analysis. Pollen zones of both units of profile are separately described below.

RADIOCARBON DATING

The radiocarbon dating of samples from the investigated profile was carried out in the Radiocarbon Laboratory of the Birbal Sahni Institute of Palaeobotany, Lucknow. Five samples were dated. Their details are shown in Table 1.

Table 1. Radiocarbon dates of the investigated profile

No.	Depth	Laboratory No.	Radiocarbon date
1.	35–40 cm	BS-2555	2670 ± 110 years B.P.
2.	125–130 cm	BS-1989	6120 ± 170 years B.P.
3.	230–235 cm	BS-1771	8260 ± 170 years B.P.
4.	280–285 cm	BS-1835	2690 ± 90 years B.P.
5.	335–340 cm	BS-2499	3790 ± 110 years B.P.

Radiocarbon dates are not in chronological order, so the profile in question is not a continuous sequence and is divisible into two units – upper (above 260cm) and lower (below 260 cm).

DESCRIPTION OF POLLEN ZONES

UPPER UNIT

Zone ST-I (depth 245–200 cm)

A radiocarbon date 8260 ± 170 years B.P. is obtained from the lower part (i.e. 230–235 cm depth) of the zone. This zone is characterized by the predominance of non-arboreal pollen

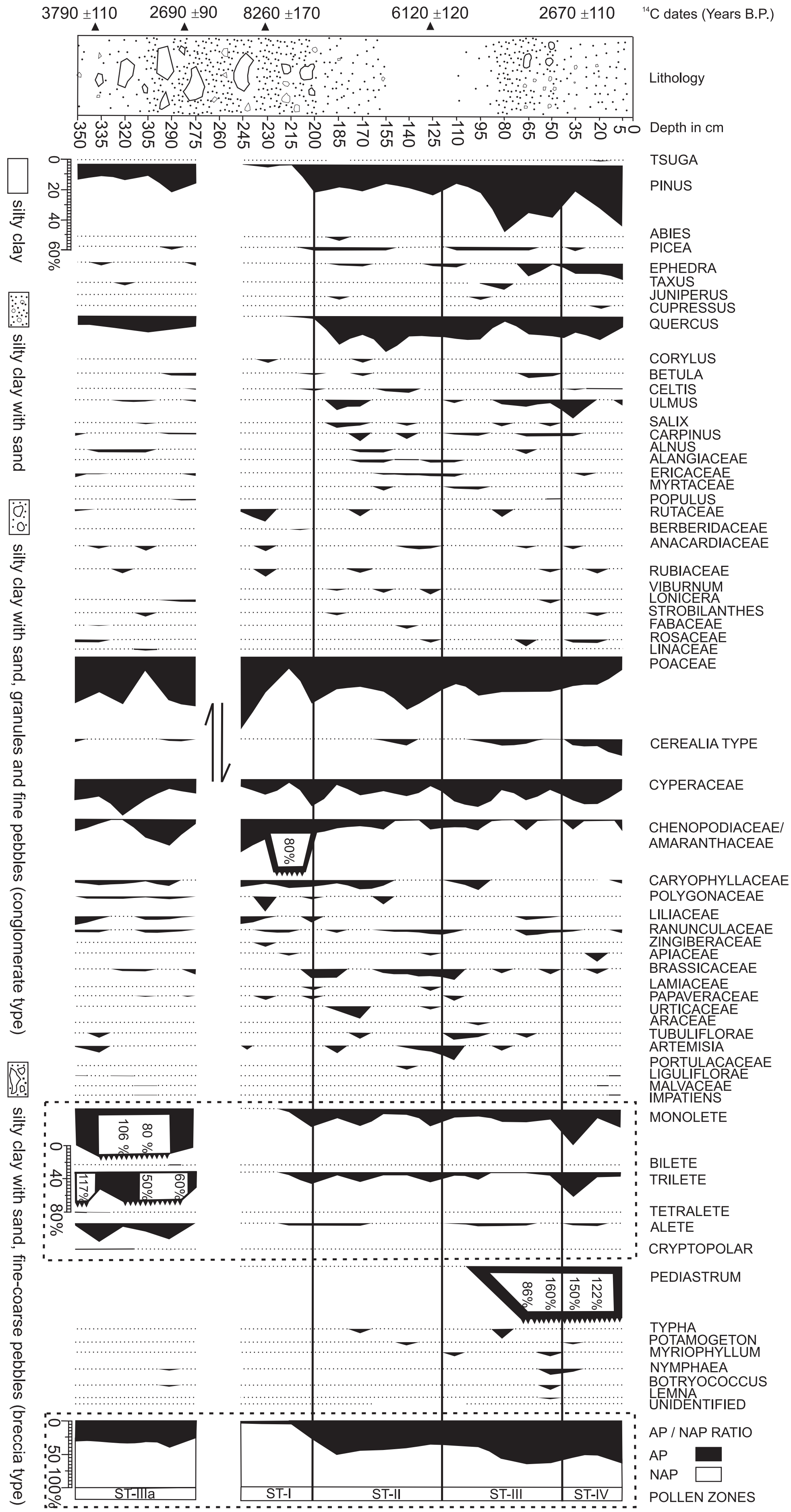

Fig. 3. Pollen diagram from Sukha Tal, Kumaun Himalaya

(70-97%). Arboreal pollen are low and represented mainly by the poor presence of *Pinus* (1–18%) and *Quercus* (1–4%). Other arboreal taxa represented in even lower values at the upper part of the zone are *Corylus*, *Betula*, *Celtis*, and *Picea* (1–2 % each).

Shrubby vegetation is well represented by pollen of Rutaceae (8%), Rubiaceae (5%), Anacardiaceae (4%), and Berberidaceae (1%).

Non-arboreal pollen encompass a predominance of Chenopodiaceae/Amaranthaceae (8–80%) followed by Poaceae (8–48%), Cyperaceae (2–16%), Polygonaceae (2–10%), and Caryophyllaceae (2–5%). Other taxa, e.g. Liliaceae, Brassicaceae, Ranunculaceae, Zingiberaceae, Apiaceae, Papaveraceae, *Artemisia*, and Lamiaceae are found in the low profile.

Spores come into existence in the upper part of the zone and consist of triletes and monoletes as well as aletes.

Zone ST-II (depth 200–117.5 cm)

Again only one ^{14}C date is available, which is 6120 ± 170 years B.P., from the upper part (125–130 cm) of the zone. This zone shows marked increase of arboreal pollen (42–58%) with a corresponding decline in non-arboreal taxa. *Quercus* (14–24%) and *Pinus* (12–18%) show abrupt increases. *Betula*, *Celtis* and *Picea* also expand. Besides, *Ulmus*, *Salix*, *Carpinus*, *Alnus*, Alangiaceae, Ericaceae, Myrtaceae, *Abies*, *Juniperus*, and *Ephedra* appear for the first time in this zone with low values. *Corylus* shows same presence as in the earlier zone.

Shrubby constituents exhibit a considerable decline as Rutaceae and Rubiaceae are reduced to half. However, *Viburnum*, *Strobilanthes*, Fabaceae and Rosaceae appear in the percentage counts.

Non-arboreal pollen show an abrupt depression in the Chenopodiaceae/Amaranthaceae (4–6%), Poaceae (16–32%) acquires the first dominant position. Polygonaceae and Liliaceae are also reduced. Caryophyllaceae show poor occurrence. Cyperaceae, Ranunculaceae, Apiaceae, and Papaveraceae maintain more or less the same representation. *Artemisia*, Brassicaceae and Lamiaceae flourish. Urticaceae, Cerealia type, Tubuliflorae, and Portulacaceae are encountered for first time in this zone.

Spores show a relative increase as triletes (4–12%) and monoletes (6–24%) expand throughout the zone. Alete spores remain more or less the same.

Aquatic vegetation appears near the middle of the zone with a poor presence of *Typha* and *Potamogeton* (2% each).

Zone ST-III (depth 117.5–42.5 cm)

During this zone *Quercus* shows a slightly increasing trend in the beginning and a considerable decline (4–14%) in the middle of the zone. However, *Pinus* declines in the beginning and becomes exceptionally high (22–42%) in the middle of the zone, reaching to more than double in relation to zone ST-II. Besides, *Ephedra* shows enhanced value. Myrtaceae, *Picea*, *Juniperus*, and Ericaceae have more or less the same values. *Betula*, *Carpinus* and *Ulmus* are better distributed. *Taxus* and *Populus* appear for the first time in this zone. Alangiaceae, *Alnus* and *Salix* show a lower occurrence.

Among the shrubby elements, Anacardiaceae shows a relative decline. Rutaceae and Rubiaceae remain more or less the same. Rosaceae show higher values. *Lonicera* appears for the first time in the percentage count.

The ground cover maintains a dominance of Poaceae (18–24%) but its percentage frequency is low in relation to the preceding zone. Cyperaceae clearly acquires the second dominant position with little enhancement. Brassicaceae is encountered in low frequencies. Chenopodiaceae/Amaranthaceae, Ranunculaceae, Caryophyllaceae, *Artemisia*, and Papaveraceae maintain more or less the same values. Cerealia type, Liliaceae and Tubuliflorae are increased. Araceae is first recorded in this zone.

Spores show a considerable decline as triletes remain poorly represented in the middle of zone. Monoletes also become low in relation to the preceding zone. Aletes maintain more or less the same in the whole profile.

Aquatic vegetation, as a whole shows an abrupt enhancement. *Pediastrum* appears and reaches to its peak (160%). *Typha* (7%) also attains high values. *Botryococcus*, *Nymphaea*, *Myriophyllum*, and *Lemna* are recorded for the first time in this zone.

Zone ST-IV (depth 42.5–5 cm)

The lower part of this zone (35–40 cm) is radiometrically dated to 2670 ± 110 years B.P. Arboreal pollen recover in contrast to the preceding zone. Values of *Quercus* (6–15%) and *Ulmus* (4–12%) increase while *Pinus* declines in the beginning (16%) but increases in the upper part (38%). *Ephedra* flourished throughout the zone with increased frequencies (up to 10%). *Celtis* is again present. Ericaceae is represented more or less same in the lower part of the zone. *Cupressus* appears for the first time in this zone. *Carpinus* and *Picea* are reduced.

Shrubby vegetation shows a relative decline. Rosaceae shows poor values with better distribution. Anacardiaceae and Rubiaceae maintain more or less the same representation. *Strobilanthes* reappears in this zone.

Non-arboreal pollen show a declining trend. Poaceae (8–20%) and Caryophyllaceae (2%) are reduced. However, Cerealia type (2–10%) is increased. Liguliflorae, Malvaceae and *Impatiens* first occur in this zone. Cyperaceae, Chenopodiaceae/Amaranthaceae, Ranunculaceae, and Brassicaceae are represented in more or less the same frequencies. Apiaceae reappears with better values.

Spores exhibit relative an increase of the triletes (6–32%) and the monoletes (10–42%) in the lower part of the zone but aletes remain more or less same.

Aquatic vegetation is well represented. *Pediastrum* maintains its dominance (122–150%) and *Nymphaea* more or less the same values. *Potamogeton* reappears.

LOWER UNIT

Zone ST-IIIa (depth 350–275 cm)

Two radiocarbon dates are available – one each from the lower and upper part of the zone. The former (i.e. from 335–340 cm depth) is dated to 3790 ± 110 years B.P. and latter (i.e. from 280–285 cm) to 2690 ± 90 years B.P.

This zone shows a dominance of non-arboreal pollen. Among the arboreal pollen *Quercus* (6–10%) and *Pinus* (8–18%) are the chief elements. The frequency of the former approaches its values in zone ST-III. However, *Pinus* and *Ephedra* are poor. Other arboreal taxa i.e. *Carpinus*, *Ulmus, Salix*, *Alnus*, *Betula*, and *Picea* are sporadically encountered in low values (1–2%) like in comparable zone (ST-III).

Shrubby vegetation is represented by Rutaceae, Rosaceae, *Lonicera*, and Anacardiaceae in more or less comparable values to zone ST-III. Linaceae appears.

Ground cover shows a dominance of Poaceae (8–31%) followed by Cyperaceae (6-25%) and Chenopodiaceae/Amaranthaceae (2–18%). Other non-arboreal taxa i.e. Cerealia type, Caryophyllaceae, Liliaceae, Ranunculaceae, Brassicaceae, Papaveraceae, Tubuliflorae, and *Artemisia* are also comparable to zone ST-III, except that Polygonaceae is represented in the percentage count.

Spores show a great abundance in relation to the other zones in the profile and show a dominance of triletes (26–117%) over monoletes (42–106%) and aletes (6–24). Besides, biletes and tetraletes are encountered with low values.

Aquatics are meagrely represented by *Nymphaea* and *Botryococcus* (1% each).

DISCUSSION AND CONCLUSIONS

The temperate zone of Kumaun lies in the southern part of the Lesser Himalaya which is bordered by the Main Boundary Thrust. The latter is tectonically active and causes natural disturbances in the region which have continued during late Quaternary. There are considerable natural disturbances around Sukha Tal and this lake itself consists of a concealed fault, which took place some time after 2690 ± 90 years B.P. (Gupta 2006a). The two arms of this fault acquired a position one above the other due to displacement of rock (Fig. 2). The presently investigated profile represents both arms (blocks) of the fault, though the upper block is covered completely while the lower block is covered by the upper part only. Since sediments of both blocks show a normal order of superposition, palynomorphs deposited in them are thus also in normal superposition.

The palynological investigation has provided interesting data about the past vegetation and corresponding climate from both units of the sequence (i.e. both blocks of fault). The upper unit provides data from around 8700 years B.P. to the top while the lower unit provides data from 3790 ± 110 years B.P. to 2690 ± 90 years B.P. The vegetation succession and climatic fluctuations suggested from the pollen analysis are as follows.

At the beginning of sequence i.e. zone ST-I (around 8700 years B.P.) the area had a predominance of non-arboreal plants. Arboreal taxa were poorly represented mainly by *Pinus* and *Quercus*. Shrubby vegetation included Rubiaceae, Rutaceae and Anacardiaceae. The ground cover had a dominance of Chenopodiaceae/Amaranthaceae followed by Poaceae with low values of Cyperaceae, Caryophyllaceae, Polygonaceae, Ranunculaceae, Liliaceae and Apiaceae, etc. Spores were absent at the beginning but appeared in the upper part of the zone. The whole scenario reflects an open type of vegetation in the region, possibly with a cold and moist climate during this period.

During the next zone, ST-II (around 7600 years B.P.) the area enjoyed a marked enhancement of arboreal taxa with a corresponding fall in non-arboreal taxa. Among the arboreal taxa, *Quercus* and *Pinus* were the chief elements. Ericaceae, *Ulmus*, *Carpinus*, *Alnus*, *Betula*, and *Celtis* were close associates of oak while *Picea, Abies* and *Ephedra* may have been associates of pine. Shrubs, grasses and sedges became reduced compared to the earlier zone and Poaceae was dominant. Spores showed an increase of triletes and monoletes. Aquatic vegetation appeared near the middle in low values. The change in vegetation pattern suggests that mixed oak forest established in the region, possibly as a result of the warm and humid climate.

The subsequent zone, ST-III (around 5525 years B.P., i.e. middle Holocene) exhibited broadly the continuation of the preceding vegetation in the beginning, but it recorded a considerable decrease in the forest cover near its middle. *Quercus* in particular and other broad-leaved trees in general abruptly declined. *Pinus* increased to more than double in relation to the earlier zone. Non-arboreal taxa maintained a dominance of Poaceae but with low values, while Cyperaceae and Cerealia-type both increased. Spores became reduced while aquatics increased and acquired peak values in the upper part of the zone. The reconstruction resembles the preceding conditions in the beginning of the zone but around 4200 years B.P. forest became more open, possibly in response to a deterioration in climate. Aquatics expanded due to local factors.

Zone ST-IIIa, coinciding in radiocarbon dates to the upper part of Zone ST-III, shows a broad resemblance in its arboreal as well as its non-arboreal vegetation, except that *Pinus* is represented by relatively low values which are striking as it has a strong tendency to exhibit a drifted presence, due to the long-distance transportation of its pollen (Gupta & Sharma 1993), so its low frequency appears to be due to its poor presence in/around the place of deposition, compared to that in ST-III. The interpretation is that the area supported comparable mixed oak forest vegetation with a warm and humid climate. The abundance of spores and the paucity of aquatics were due to local conditions which were more suitable for spore-producing taxa and not for aquatic plants. Further, the differences in the frequency of *Pinus*, spores and aquatics indicate that the upper and lower units of the investigated profile belong to different arms of the fault which were originally located apart and their respective places had dissimilar local climatic conditions. Such dissimilarity is further strengthened by the sedimentation rate which was around six times faster (1 mm in 10.3 years) at the place represented by zone ST-IIIa than in the place represented by zone ST-III (1 mm in 59.6 years).

In the period of the uppermost zone, ST-IV (around 2900 years B.P.) the area supported *Quercus* and its broad-leaved associates. *Pinus* was reduced in the beginning, but it increased later. Non-arboreal taxa followed a declining trend but cultural taxa (particularly Cerealia-type) abruptly increased in the upper part. Spores also increased. Aquatics flourished but showed a relative decline later. Such changes may reflect the restoration of mixed oak forest in the region in response to an amelioration of climatic conditions.

The vegetational sequence shows considerable change in the different zones which is reflected in the AP/NAP ratio. However, zones ST-III does not exhibit a clearance of oak in its middle due to the enhanced representation of conifers. Anthropogenic activities (reflected by cultural taxa particularly Cerealia type) were present since the middle of zone ST-II (i.e. upper part of early Holocene) but they showed an abrupt increase of Cerealia type in the upper part of the zone ST-IV where oak showed a relative decline. It appears that local trees had been removed for agricultural practices in this region. Data generated from present study are comparable to interpretations of past vegetation and climate reported from other temperate regions in the Himalaya.

The climatic inferences drawn from the present study broadly corroborate global climatic events. During the climatic optimum (recorded between 8000–6000 years B.P.), there is an increase in arboreal taxa reflecting the establishment of mixed oak forests under a warm and humid climate. Such conditions did not continue and resulted in a considerable decline of broad-leaved trees at around 4200 years B.P. reflecting forest decrease due to an abrupt climate cooling. The Little Ice Age (recorded between 1850–1450 years A.D. i.e. ca 100–500 years B.P.) is reflected by a decline of mixed oak forest during this time. The expansion of anthropogenic activities (ca 200 years B.P. onwards) is also reflected, as evidenced by the increase in cultural taxa particularly Cerealia-type during this time.

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