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Interpretation of past climatic changes around Tsokar Lake, Ladakh for the last 33 ka on the basis of chemical data

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ABSTRACT

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Environmental changes during Late Quaternary for Tsokar Lake, Ladakh, J & K have been inferred based on the variations of K, Na, Mg, Fe and Mn, organic and mineral matter and authigenic phosphorus contents in sediments and ^{14}C dates. The climatic conditions around Tsokar Lake, Ladakh has been deduced as dry arid immediately prior to 31·4 ka and alternated from dry arid to brief amelioration of climate till the beginning of Holocene.The climatic amelioration of Tsokar Lake around 16·8 ka correlates with the end of Philipi interstadial around 16 ka in Greece. The climatic amelioration around the last 10 ka also correlates with the infilling of lake basin of Rajasthan and Southern Ethiopia.

Key-words—Palaeoclimate, Holocene, Tsokar Lake, Chemical data.

रासायनिक आंकड़ों के आधार पर विगत 33,000 वर्षों में लद्दाख की त्सोकर झील के आस-पास घटित हुए जलवायुविक परिवर्तनों का निर्वचन

बालासुब्रामणियन शेखर

सारांश

अवसादों में उपस्थित पोटैशियम, सोडियम, मैग्नीशियम, आइरन तथा मैंगनीज़, कार्बनिक एवं खनिज पदार्थों और तत्रजनिक फ़ास्फोरस अंश की विविधता एवं कार्बन आयुनिर्धारण के आधार पर जम्मू-कश्मीर की लद्दाख अवस्थित त्सोकर झील में अन्तिम क्वाटरनरी युग के दौरान हुए पर्यावरणीय परिवर्तनों का पूर्वानुमान किया गया है. यह प्रस्तावित किया गया है कि लद्दाख की त्सोकर झील के आस-पास 31,400 वर्ष से ठीक पहले शुष्क एवं रूक्ष जलवायु थी तथा होलोसीन कल्प के प्रारम्भ होने तक शुष्क एवं रूक्ष जलवायु में संक्षिप्त सुधार हुआ. 16,800 वर्ष पूर्व के आस-पास त्सोकर झील की जलवायु में हुए सुधार को ग्रीस में 16,000 वर्ष के आस-पास हुए फिलिपी उपअन्तराहिमानी की समाप्ति से सहसम्बन्धित किया गया है. विगत 10,000 वर्ष के आस-पास हुए जलवायुविक सुधार को भी राजस्थान एवं दक्षिणी इथियोपिया की झील द्रोणी के आपूर्णन से सहसम्बन्धित किया गया है.

संकेत शब्द—पुराजलवायु, होलोसीन, त्सोकर झील, रासायनिक आंकड़े.

INTRODUCTION

PALAEOCLIMATIC data play a vital role in efforts to understand the natural variability of the Earth's climatic system and the potential for future change. Chemical analysis of lacustrine sediment was found to be a potential tool to reconstruct the climate and decipher the development of former ecosystem (Mackereth, 1965, 66; Engstrom & Wright, 1984; Engstrom & Edward, 1986; Sekar *et al.*, 1992, 94; Sekar, 1995). This paper describes the past climatic changes of Tsokar Lake, a high altitude brackish lake under cold desert climate in Ladakh on the basis of chemical data and its correlation with global climatic scenario.

MATERIAL AND METHODS

The 23·0 m long sediment core material for the present study was collected by the Geological Survey of India from Tsokar Lake situated at an altitude of 4572 m above mean sea level in Ladakh, J & K State (32°15' to 36° N and 75°15' to 80°15' E). Tsokar Lake occupies an area of 250 km² in Chang Thang Rapsu region 125 km SE of Leh and is surrounded by hills of Zanskar range (altitude 6000 m MSL) in trans-Himalayan region. The water is brakish as a result of continuous evaporation.

Sixteen samples at different intervals from the 23·0 m long core, (TP 6) were analysed to understand the variations in chemical constituents as well as organic and mineral contents. The sediments mostly comprised of clay with horizons of sand, gravel, pebbles and thin layers rich in leaf fragments. For further details on the core and its lithology reference is made to Bhattacharyya (1989).

In the present study ^{14}C measurements were carried out on two sediment cores namely TP 6 & TSD 1 from Tsokar Lake profile using standard procedure (Rajagopalan *et al.*, 1978). From the plot of ^{14}C dates vs depth (Figs 1 & 2) of the core TP 6, it is seen that the best fit line (1st order regression) is very close to measured ages (within 1s errors). The rate of sedimentation is found to be uniform with a value of 9·5 cm/ 100 yrs. The best fit line gives an age of 9·7 ka for the surface deposit. Since the core was collected from the dry lake margin, it is believed that the original surface was eroded away. This is also supported by the ^{14}C age of 7·080 ± 0·130 ka (BS-271) obtained for the surface sample elsewhere from the dry lake bed in Tsokar Lake.

For chemical analysis each sample was separated into three fractions, viz., authigenic, biogenic & allogenic components by fractionation techniques described by Engstrom & Wright (1984). The concentration of chemical constituents was measured in each fraction using atomic absorption spectrometer. Organic and mineral matter contents were analysed from the dried lump of the sample as described by Bengston & Enell (1986). The mineral matter is the ash content after the removal organic matter at 550°C and CO_2 from carbonates at 900°C in a muffle furnace.

ANALYSIS OF CHEMICAL DATA

The present study shows that the organic matter content varies from 1% to 9% and mineral matter content from 77% to 91% (Figs 3 & 4). The variation of elemental concentration (allogenic fraction) for Na, K, Mg, Fe, Mn, Cu & Zn is shown in Figs 3 & 4. Dry arid climatic conditions are indicated by an increase in concentration levels of Na, K and Mg. The mineral matter content is also high during these periods with a corresponding decrease in organic matter and phosphorus content. This inference is also supported by the palynological evidence of decline in the number of taxa and increase in steppe

Sample/Core No & Depth (M)	Material	C-14 Age & Error (ka) ($T_{1/2}$ = 5730 ± 40 Yrs)	Calibrated Age Range (ka)
BS - 5/TP 6 3·00	Carbonaceous Clay	12·18 ± 0·51	14·43-13·24
BS - 9/TP 6 5·15	-do-	16·26 ± 0·11	19·99-17·58
BS - 11/TP 6 12·00	-do-	21·14 ± 0·21	Beyond Calibration range
BS - 17/TP 6 21·85	-do-	31·49 ± 0·15	-do-
BS - 28/TSD 1 7·7-8·2	-do-	35·20 ± 3·5	-do-
BS - 29/TSD 1 13·5-13·75	-do-	>40·00	-do-
BS - 30/TSD 1 18·5	-do-	>40·00	-do-

Fig. 1—C-14 age results of TP 6 & TSD 1 bore core, Tsokar Lake, Ladakh.

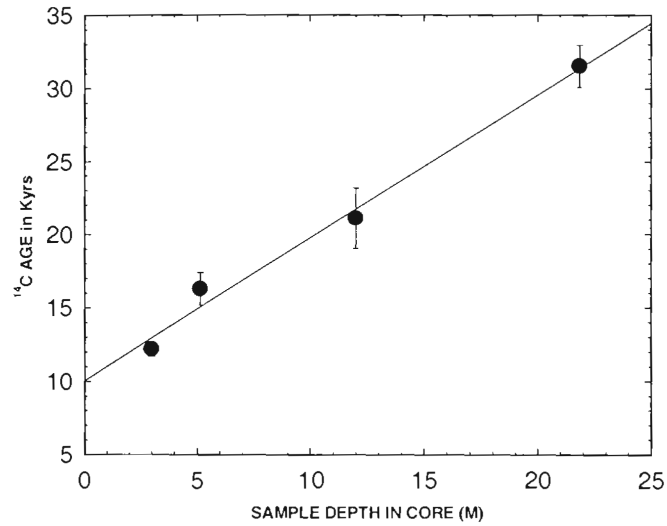

Fig. 2—Graphic representation of ^{14}C dates vs depth of Core TP6.

elements during these periods (Bhattacharyya, 1989). Amelioration of climatic conditions is indicated by the low level of these chemical constituents (Na, K & Mg) as well as an increase in organic matter and phophorus content. These climatic ameliorations have also been seen in pollen data which show an increase of shrubby taxa at the expense of steppe elements (Bhattacharyya, 1989). The distribution of Fe and Mn indicates the prevalent redox conditions of the environment. The variation of organic matter content reveals the succession of lake from oligotrophy to eutrophy. The variation of phosphorus content shows the changing vegetative conditions. From Fig. 4 eleven broad zones can be recognised (on the basis of variation of Na, K, Mg, organic and mineral matter) in relation to environmental changes (Fig. 3).

The measured concentrations of Na, K and Mg (allogenic fraction) at different depths in Tsokar Lake sediment core are given in Fig. 3. The errors in the analytical data are ± 5% on the absolute values mentioned. These data are presented in graphical form in Fig. 4 to show the variations in the concentrations of Na, K and Mg with depth. For an interpretation of this chemical data in terms of past environmental changes eleven broad zones have been identified on the basis of variations in Na, K & Mg concentrations (Fig. 3).

In zone 1, at the depth of 23·00-21·85 m the concentration levels of Na, K and Mg in allogenic fraction are 1·67%, 1·02% & 0·36% respectively. These values are higher than the average values (Na = 0·78%, K = 0·98% & Mg = 0·18%) for these elements in the core. Higher rate of evaporation of lake water than precipitation would have led to concentration of these elements in water which in turn would have increased the concentration of these elements in the allogenic fraction of the sediment. Mineral matter content was greater than 70% like other post glacial lakes (77%) during this period. This again indicates deposition of unweathered minerals in the lake bed. Bhattacharyya (1989) has also reported a dry alpine steppe dominance over marshy and bushy or shrubby taxa on the basis of pollen analysis of the core confirming the findings of the chemical data. Therefore, it may be inferred that dry arid climatic conditions prevailed during this time interval.

In zone 2, at 21·85-19·75 m depth there is a decrease in the concentration level of Na, K and Mg. Sodium content has decreased considerably from 1·67% to 0·62% and potassium and magnesium contents show marginal decrease from 1·02% to 0·98% and 0·36% to 0·31% respectively indicating dilution of the lake which could be due to increased precipitation. This would have led to an increase in organic activity in the lake and its environment viz. the proliferation of plant and animal life. The organic matter content (average) is also seen to be high (6·2%) (Fig. 3). The mineral matter content is 79%. The above climatic amelioration during this period has also been confirmed by the findings on the basis of pollen analysis Bhattachayya (1989). High values of *Juniperus* pollen suggest that the lake was rich in aquatic vegetation and low values of steppe elements indicate that the climatic conditions were much

Age Range (ka)	Depth Range (M)	Na (%)	K (%)	Mg (%)	Fe (%)	Mn (%)	Cu (%)	Zn (%)	Org (%)	Min (%)	Climatic Inference
32·6-31·4	23·0-21·9	1·67	1·02	0·36	0·60	0·12	0·17	0·63	—	77·0	Dry Arid
31·4-29·4	21·9-19·8	0·62	0·98	0·31	0·37	0·07	0·04	0·25	6·2	79·0	Amelioration
29·4-27·8	19·8-18·2	0·67	1·10	0·25	0·48	0·06	0·10	0·17	6·0	80·0	Dry Arid
27·8-18·6	18·2-08·8	0·72	0·86	0·02	0·30	0·05	0·06	0·25	2·0	81·5	Amelioration
16·9-16·4	07·0-06·5	1·33	1·02	0·20	0·14	0·05	0·02	0·15	3·0	84·0	Dry Arid
16·4-15·4	06·5-05·5	0·47	0·86	0·42	0·07	0·04	0·03	0·13	6·1	85·0	Amelioration
15·4-13·0	05·5-03·0	1·13	0·98	0·12	0·25	0·02	0·01	0·23	6·1	86·0	Dry Arid
13·0-12·0	03·0-02·0	0·77	0·98	0·12	0·39	0·03	0·03	0·38	4·0	91·0	Dry Arid
12·0-11·0	02·0-01·0	1·37	0·98	0·48	0·46	0·12	0·18	0·60	9·0	83·0	Wet Humid

Fig. 3—Allogenic fraction concentration and climatic reconstruction of Tsokar Lake, Ladakh.

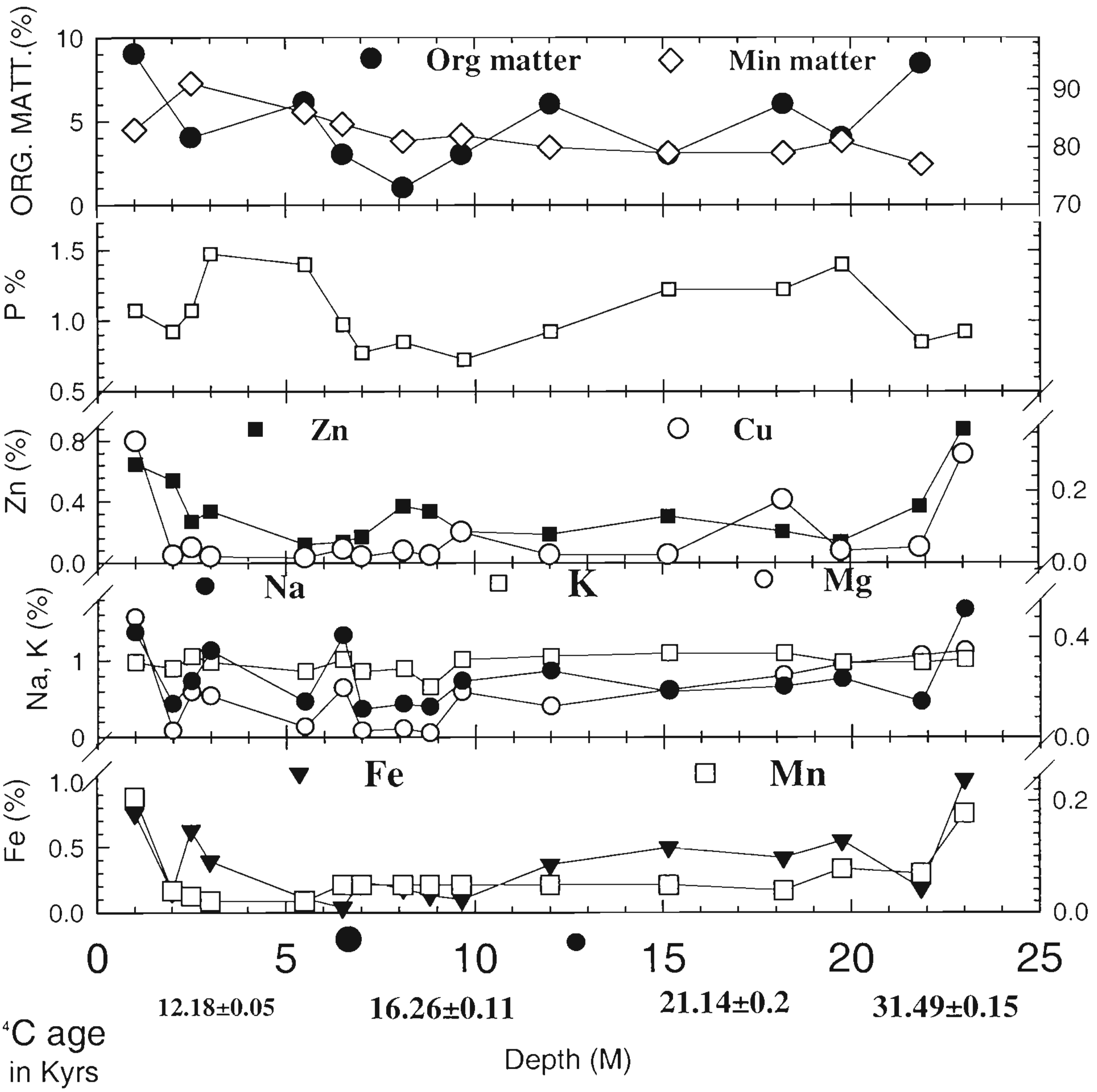

Fig. 4—Distribution pattern of organic & mineral matter.

more favourable for the growth of taxa than today in the Tsokar Lake Basin. It can be concluded that there had been an amelioration of climate during the above period of time.

In zone 3, at 19·75-18·20 m there is again slight increase in the level of concentration of Na & K from 0·62% to 0·67% and 0·98% to 1·10% respectively and a decrease in concentration of Mg from 0·31% to 0·25%. But there is also an increase in the organic matter content during this period (4·0% to 6·0%) and the mineral matter content has decreased from is 81% to 79% during this period. The palynological evidence shows that climate had turned colder than before and shows a substantial decline in *Juniperus* pollen and increase in steppe elements during this period (Bhattacharyya, 1989). These features strongly indicate a tendency towards dry arid climatic conditions leading to deterioration of climate during this period.

In zone 4, at 18·20-8·8 m has been consistently very low level of these chemical constituents (Na = 0·72%, K = 1·07% and Mg = 0·19%). But organic matter content has decreased from 6% to 4·5% and mineral content is same (79%) as in the earlier zone. *Juniperus* pollen rises again with a decline of steppe elements. These features indicate a reversal towards amelioration of climate in the above interval of time essentially on the basis of low concentrations of Na, K and Mg.

In zone 5, at 8·8-8·1 m depth, the concentration of these chemical constituents has increased namely Na, K and Mg from 0·40% to 0·43%, 0·66% to 0·90% and 0·017% to 0·033% respectively. Therefore it can be inferred that the climate was dry arid during this interval.

In zone 6, at 8·1-7·0 m depth, sodium, potassium contents have decreased from 0·43% to 0·37% and 0·90% to 0·86% respectively. However magnesium content has slightly increased from 0·033% to 0·041%. The above trend indicates amelioration of climate during this time interval.

In zone 7, at 7·0-6·5 m depth there is an increase in concentration level in above chemical constituents (Na = 1·33%, K = 1·02% and Mg = 0·20%). But there is a slight increase in organic matter content (from 2% to 3%) in this period. The mineral matter content is also high (84%) as indicated in the elemental concentration in the above duration. The increase in concentration levels of Na, K & Mg indicates the reversal of climate to dry arid climatic conditions during this period.

In zone 8, at 6·5-5·5 m depth there is a marked decrease in concentration of Na & K (Na = 0·47%, K = 0·86%) but there is an increase in Mg content (0·42%). The organic matter content has also increased during this time (from 3·0 to 6·1%) indicating the lake was supporting good aquatic biota (leafy fragments and seeds of *Potamogeton* are identified in pollen analysis confirming the existence of aquatic biota). The pollen data also shows an increase of shrubby taxa at the expense steppe elements (Bhattacharyya, 1989). Therefore, we can infer that there was a pronounced climatic amelioration during this period of time.

In zone 9, at 5·5-3·0 m depth there is a large increase in concentration of Na (1·13%) and moderate increase in K content (0·98%) and decrease in Mg content (0·12%). But there is no corresponding decrease in organic matter content (6·1%). The mineral matter content is also high (86%) during this period. Therefore, we can infer that though conditions conducive to organic growth remained the same. There was a tendency towards dry arid conditions during this period on the basis of increase in Na & K concentrations and mineral matter content.

In zone 10, 3·0-2·0 m there is a decrease in concentration of Na viz. (from 1·13% to 0·77%) while K & Mg concentrations remained unchanged (K = 0·98% and Mg = 0·12%). The organic matter content has decreased from 6·1% to 4·0% during the above zone. The overall mineral matter content is highest (91%) during this period. In view of the above findings we can conclude that amelioration of climatic conditions prevailed during this period.

In zone 11, 2·0-1·0 m there is a large increase in concentration level of Na & Mg (viz. Na = 1·37% & Mg = 0·48%) and K concentration remained unaltered (0·98%). But there has been an increase in organic matter content (9%) with a corresponding decrease in the mineral matter content to 83% during this period. These indicate reversal of climate to dry arid climatic condition.

The climatic changes based on the variation of chemical constituents discussed above in the eleven zones and data from published pollen analytical study from this bore core (Bhattacharyya, 1989) are summarized in Fig. 3. It can be concluded on the basis of variation in the concentrations of Na, K and Mg, organic matter and mineral matter content and palynological data that climatic conditions around Ladakh was dry arid during 32·5 to 31·3 ka , 29·4 to 27·8 ka , 18·6 to 17·9 ka, 16·9 to 16·4 ka, 15·4 to 13·0 ka , and 12·0 to 11·0 ka and interrupted with brief ameliorations in climate to wet humid condition during intervening periods.

Redox conditions on the basis of Iron and Manganese contents

The differential mobility of iron and manganese can be used to reconstruct a profile of redox conditions in the drainage basin of the lake. The mobility of iron and manganese is very low in direct solution under oxidizing conditions due to very low solubility of the oxidized forms of both the elements. Under reducing conditions both elements become mobilized and pass into solution; manganese is more mobile than iron. The rate of transport of these elements will depend upon unstable conditions (erosional activity) on one hand and the redox conditions prevailing in the drainage system on the other.

The distribution of manganese and iron in Tsokar Lake sediments is shown in (Fig. 3). The error in the analytical data is ± 5% on the absolute values mentioned. The concentration of manganese varies from 0·21 to 0·02% (average = 0·064%). It is less than the concentrations encountered in glacial clays (1·0 mg/g of Mn, Rankama & Sahama, 1949) in most of the cases and iron concentration varies from 1·02% to 0·10% (average = 0·36%). It is also well below the concentrations found in glacial clays (50 mg/g, Rankama & Sahama, 1949). It indicates weak reducing conditions were prevalent throughout the profile resulting in transportation of these elements in the ionic form.

Lake succession on the basis of organic matter content

The organic matter content was analyzed in dried lumps of samples collected at 11 depths in the sediment core of Tsokar Lake, following the procedure described earlier (Bengston & Enell, 1986). The weight loss of the sediment on ignition at 550°C for 2 hours corresponds to organic matter content. It was found to vary from 1% to 9% for the Tsokar Lake samples. The results are shown in Fig. 3.

The succession of lakes from oligotrophy to eutrophy can be understood on the basis of variation of organic matter content. During the periods of aridity or deforestation (unstable landform conditions), the percentage of organic matter will reduce due to mass deposition of inorganic material caused by highly erosive conditions in the lake drainage. In this period the lake will be oligotrophic. Under stable landform conditions (favourable condition for luxuriant growth of vegetation), woodland or permanent grassland will be developed. Organic matter content will increase leading to eutrophic condition. Therefore, from the variation of organic matter content in lake sediments oligotrophic or the eutrophic condition of the lake can be inferred. The present study based on the variations in the organic matter content reveals that Tsokar Lake had undergone several successions from oligotrophy to eutrophy. This might be due to changes in climate during Late Pleistocene. The lake was eutrophic between 21·85-19·75 m covering the time span of 31·4 to 29·4 ka. The lake might have supported the existence of luxuriant aquatic vegetation as several seeds of *Potamogeton* along with large number of leafy fragments have been reported in the sediment (Bhattacharyya, 1989). Between 19·75-8·10 m (29·4 to 18·0 ka) there is a gradual decrease in the organic matter content indicating changing conditions towards oligotrophy. From 8·1 to 2·5 m, covering a time span of 18·0 to 12·5 ka there is a gradual increase in organic matter content showing a tendency towards eutrophication of the lake. The above trend has also been reflected in the variation of Na, K and Mg concentrations.

Reconstruction of trophic conditions on the basis of authigenic phosphorus content

The authigenic phosphorus content in the sediments is primarily through biotic cycling. Thus the authigenic phosphorus is a potential proxy for trophic conditions in the past unlike detrital phosphate mineral which does not contribute to primary productivity. The separation of allogenic mineral and inorganic phosphorus from authigenic forms (inorganic and organic) is most critical (Williams *et al.*, 1976) in order to interpret the phosphorus data of the sediment in terms of changing trophic conditions.

As long as a constant proportion of dissolved phosphorus in the water is permanently deposited in the sediments, sedimentary phosphorus profile should reflect levels of past lake productivity. However because phosphorus retention in the sediments is strongly controlled by adsorption onto iron oxides, variation in iron content, manganese content and redox conditions bring about changes in phosphorus accumulation independent of its concentration in water (Engstrom & Edwards, 1986; Mackereth, 1966; Bortleson & Lee, 1974; Tessenow, 1972; Carignam & Flett, 1981). The retention and release of phosphorus in limnetic sediments are also influenced by the rates of diffusion and turbulent mixing (Lee *et al.*, 1976; Stevens & Gubson, 1976; Holdren & Armstrong, 1980; Thesis & McCabe, 1978).

In spite of numerous problems associated with phosphorus sedimentation several palaeolimnological studies have found good agreement between sedimentary phosphorus and other historical evidence for trophic development (Williams *et al.*, 1976; Bradbury, 1978; Shapiro *et al.*, 1971; Ulen, 1978). The anthropogenic enrichment of lakes from the discharge of municipal or industrial sewage appears to be one event that is sufficiently dramatic to leave conclusive evidence in the phosphorus record.

For the analysis of phosphorus in sediment samples from Tsokar Lake, each sample was separated into three fractions *viz.*, authigenic, biogenic and allogenic components by fractionation techniques as described by Engstrom & Wright (1984). The authigenic phosphorus content was measured using UV spectrophotometer. The error on the analytical data is ± 5% on the absolute value mentioned. In Fig. 5 the measured concentrations of phosphorus and a plot of the values (Fig. 4) at different depths are given.

Iron and Manganese concentration is very low in Tsokar Lake sediments. This indicates weak reducing conditions of the lake and under such condition phosphorus retention would be high. It is seen from the phosphorus and organic matter content variations that the changing trophic condition was alternating from favourable to deterioration in the Tsokar region (Fig. 3). We can conclude that on the basis of variations in concentrations of authigenic phosphorus and organic matter content that trophic conditions in Tsokar Lake were favourable for the growth of taxa during 31·4 to 29·4 ka , 16·9 to 12·0 ka and unfavourable during 32·6 to 31·4 ka, 29·4 to 16·9 ka and 12·0 to 11·0 ka. These are summarized in Fig. 5.

Age Range (ka)	Depth Range (m)	P Cnt (%)	Relative Conc·/ Trophic Condition
32·6-31·4	23·0-21·9	0·89	Low/Unfavourable
31·4-29·4	21·9-19·8	1·13	High/Favourable
29·4-18·6	19·8-08·8	1·03	Decrease/Unfavourable
18·6-16·9	08·8-07·0	0·76	Decrease/Unfavourable
16·9-13·0	07·0-03·0	1·16	Increase/Favourable
13·0-12·0	03·0-02·0	1·16	Low Org Cnt/ Unfavourable
12·0-11·0	02·0-01·0	1·08	High Org Cnt/ Favourable

Fig. 5—Trophic conditions of Tsokar Lake, Ladakh on the basis of authigenic phosphorus content.

Trace elements

The concentration of trace elements namely Cu, Zn, Cd and Cr indicates toxic levels of the environment. We have measured the concentration levels of Cu and Zn for the present study to understand the toxic levels of the area. The average copper concentration (allogenic fraction) of the Tsokar Lake sediment core TP-6 is 405 ppm, within the normal concentration ranges encountered (50-500 ppm) in lake sediments (Bengtson & Enell, 1986). The overall normal copper concentration indicates low toxic levels prevalent throughout the lake. High concentrations of copper were measured at 1·0 m (at surface 3374 ppm) and at 23·0 m (3005 ppm) depth. It is difficult to explain these high values in the present context.

The average zinc concentration of Tsokar Lake is 3260 ppm (Fig. 3). This is within the normal range of Zn than the concentration ranges encountered (200-5000 ppm) in the lake sediments (Bengtson & Enell, 1986). Therefore, we can infer that low toxic conditions were prevalent throughout the lake as also indicated in the copper concentrations. This is also expected due to high altitude conditions and the period of study is from 10·0 to 30·0 ka.

COMPARISON WITH OTHER SITES AND DATA

The climatic amelioration during the last 33·0 ka around Tsokar Lake found on the basis of chemical analysis data has also been reported in the peninsular region of the subcontinent also (Bhattacharyya, 1989). The concentrations of Na, K and Mg were low during this period. Rise of *Juniperus* pollen and a decline of steppe elements also indicated amelioration of climate. This amelioration of climate is also supported palynologically by the rise of broad-leaved taxa in the Kashmir Valley (Dodia *et al.*, 1985). Folster *et al.* (1977) have reported that palaeosols were deposited under a cold humid, cold dry or warm climate.

^{13}C values in palaeosols in Kashmir Valley dated to 31·0 to 19·0 ka range from -16·2‰ to -25·3‰ (Krishnamurthy & De Niro, 1982). It has been observed that ^{13}C in trees and shrubs ranges from -24‰ to -34‰ whereas plants found in deserts and salt marshes have ranges from -6‰ to -19‰. ^{13}C values of lacustrine sediments reflect changes in climate and vegetation (c.f. Friedman, 1983). The ^{13}C values of -21·9‰ to -16·6‰ in several palaeosols from lower to higher horizons dated to 31·0 ka show increasing aridity but the value of -25‰ during the last 19·0 ka supports shift towards a relatively humid climate (Krishnamurthy & De Niro, 1982). Chemical analysis data also shows the same trend. The low level of Na, K and Mg and decline of steppe elements show amelioration of climate during this period. Van Campo (1986) has reported that the climate in the north west India was very arid from 18·0 to 22·0 ka. The predominance of C4 signatures from peats of southern India during 16-20 ka indicates a very arid phase during the last glacial maximum (Sukumar *et al.*, 1993). An additional support in favour of arid climate is provided by the following evidences; high salinity in the Arabian Sea during the last 18·0 ka (Duplessy, 1982) and northern Bay of Bengal (Cullen, 1981), intense sand-dune formation in Rajasthan (Misra *et al.*, 1982) and a decline of the mangrove vegetation in south west India (Van Campo, 1986).

Bhattacharyya (1989) has reported some climatic trends common to both Ladakh and many Mediterranean climate areas. The climatic amelioration between 28·0 to 30·0 ka in the Tsokar Lake based on biogenic deposits in the core and also on chemical analysis (decrease in concentration of Na, K and Mg, high organic content, higher values of *Juniperous* pollen and low values of steppe elements indicate amelioration of climate during this period) and palynological analysis compares with the Denekamp interstadial widely recognised in Europe (Van der Hammen *et al.*, 1971; Roger, 1976; Kolstrup, 1980) and with the Krinides interstadial from northern climate (Wijmstra, 1969). This climatic amelioration also correlated with high lake level observed during the same period in the lake East (Street, 1979). Corresponding to the interstadial between 21·29 and 18·38 ka in the lake, in Greece precipitation and increased to some extent around 20·0 ka to decrease again after about 18·0 ka (Van Zeist & Bottema, 1982) and this is also correlated with a rise in lake level in the Mediterranean region (Street, 1979). In the Netherlands slightly lower temperatures are indicated after 19·0 ka (Kolstrup, 1989) suggesting deglaciation has taken place between 19-18 ka. These are very close to estimates of maximum interstadial in the Tsokar region.

The climatic amelioration at around 15·8 ka in Ladakh also correlates with the end of the Philipi interstadial around 16·0 ka in Greece (Wijmstra, 1989). Around 16 ka a more negative $\delta^{13}C$ signatures in the peats of southern India which indicates C3 vegetation dominance, indicating a progressively more moist climate (Sukumar *et al.,* 1993). During the last 10·0 ka the climatic amelioration in Ladakh also correlates with the infilling of lake basin of Rajasthan (Singh *et al.*, 1972) and Southern Ethiopia (Street, 1979).

CONCLUSIONS

Climatic changes during the last 33·0 ka in the trans-Himalayan region have been discussed in the present study based on chemical data. These results corroborate well with other proxy data derived from the same bore core earlier. Thus multiproxy data is very useful in deciphering detailed palaeoclimatic condition in the Himalayan region. Chemical analysis will be suitable even for the sites where the biota are not preserved. The above study is based on only one site. In future, chemical analysis from different sites would provide broad scenario of regional climatic change which could be analysed in terms of global perspectives.

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