source using the process of SRS. The cell is made of stainless steel and can be used up to pressure as high as 400 kg cm^{-2}. The general idea is to study the role of various physical parameters of the nonlinear media and the laser parameters in these scattering processes. A frequency doubled Nd : YAG laser has been used as the pump source and SRS studies have been carried out in gaseous nitrogen. The Stokes and anti-Stokes signals including the higher orders were separated using a three-prism spectrograph. Measurements were made both on the forward and backward scattered Raman signals. Detailed investigations were carried out to study the role of various physical and laser parameters on SRS gains and the results have been the subject of several publications. Finally the phase conjugate nature of SRS signals was studied in detail by doing distortion correction experiments[2]. The distortion correction property of the first Stokes beam is shown in Figure 1. It can be seen that the correction ability of these backward scattered signals is good despite a large frequency shift, thus confirming their phase conjugate nature.

1 Bloembergen, N., *Am. J of Phys*, 1967, **35**, 989–1023.
2. Sokolovskaya, A I, Brekhovskikh, G L. and Kudryavtseva, A D, *IEEE J Quant. Electron*, 1987, **QE-23**, 1332–1343

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Chemical analysis and ^{14}C dating of a sediment core from Tsokar lake, Ladakh and its implications on climatic changes

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The climatic changes around Tsokar lake, Ladakh have been inferred on the basis of analysis of elemental, organic and mineral content variations in 23-m-long sediment core covering a time span of 32 ky in the past to the beginning of Holocene. Nine zones have been identified for the interpretation of the chemical data in terms of climatic change. The results show that climate was generally dry arid prior to 30.4 ky BP and during the intervals of 28.5 to 18.9 ky BP, 16.4 to 15.9 ky BP, 14.9 to 12.6 ky BP and 11.6 to 10.7 ky BP followed by brief ameliorations of wet-humid phase during intervening periods.

CHEMICAL analysis of lacustrine sediments was found to be a potential tool to reconstruct the climate and to decipher the development of former ecosystems[1–4]. In fact it has been shown that the conclusions derived from chemical analysis are in close agreement with those derived from such other proxy data based on pollen, diatoms, microfossils, etc. The basis for this study lies in the fact that the concentration and nature of chemical constituents in the sediments are the cumulative effect of both biotic and climatic changes. Any variations in chemical constituents of sediments both in quantity and type reflect changes not only in aquatic environment but also in the surrounding terrestrial environment.

So far in India not much work has been carried out on the chemical analysis of lacustrine sediments. Only one report was published on the past climatic and environmental changes during the last 500 y from Paradip Island, Orissa[5]. In this paper an attempt has been made to reconstruct climatic as well as environmental conditions in the trans-Himalayan region during late Pleistocene using chemical analysis data supplemented with ^{14}C dates on a 23-m-long bore core (TP 6) collected from Tsokar lake, Ladakh.

The sediment core was collected by the Geological Survey of India (GSI) from Tsokar lake situated at an altitude 4572 m above mean sea level (MSL) in Ladakh, J & K State (32° 15′ to 36° N and 75° 15′ to 80° 15′ E). The Tsokar lake occupies an area of 250 km^2 in Chang Thang Rupsu region about 125 km SE of Leh and is surrounded by hills of Zanskar range (altitude 6000 m MSL) in trans-Himalayan region. The water is brackish as a result of continuous evaporation.

Sixteen samples at different intervals from the 23-m-long bore 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[6].

As carbon contents were low, excepting for one sample with biogenic remains, ^{14}C age measurements could be carried out only on four samples in this profile using standard procedure[7].

From the plot of ^{14}C dates vs depth (Figure 1) it is seen that the best fit line (1st order regression) is very close to measured ages (within 1 σ errors). The rate of sedimentation can therefore be considered to be constant with a value of 9.5 cm/100 y. The best fit line gives an age of 9.7 ky for the surface deposit. Since the core was collected from the dry lake margin, we believe that the original surface was eroded away. This is also supported by the ^{14}C age of 7080 ± 130 y (BS-271) obtained for the surface sample elsewhere from dry lake bed in Tsokar.

For chemical analysis each sample was separated into three fractions, viz. authigenic, biogenic and allogenic components by fractionation techniques described by Engstrom (op. cit.). The treatment given to the clay samples for chemical analysis is shown in the flow diagram (Figure 2). The concentration of chemical constituents was measured in each fraction using atomic absorption spectrometer. Organic and mineral matter contents were analysed from dried lump of the sample as described by Bengston *et al.*[8]. The mineral matter content is the ash content that remained after removal of organic matter at 550°C and CO_2 from carbonates at 900°C respectively in a muffle furnace from weighed quantity of oven dry sample. The error in the analytical data was ±5% on the absolute value mentioned.

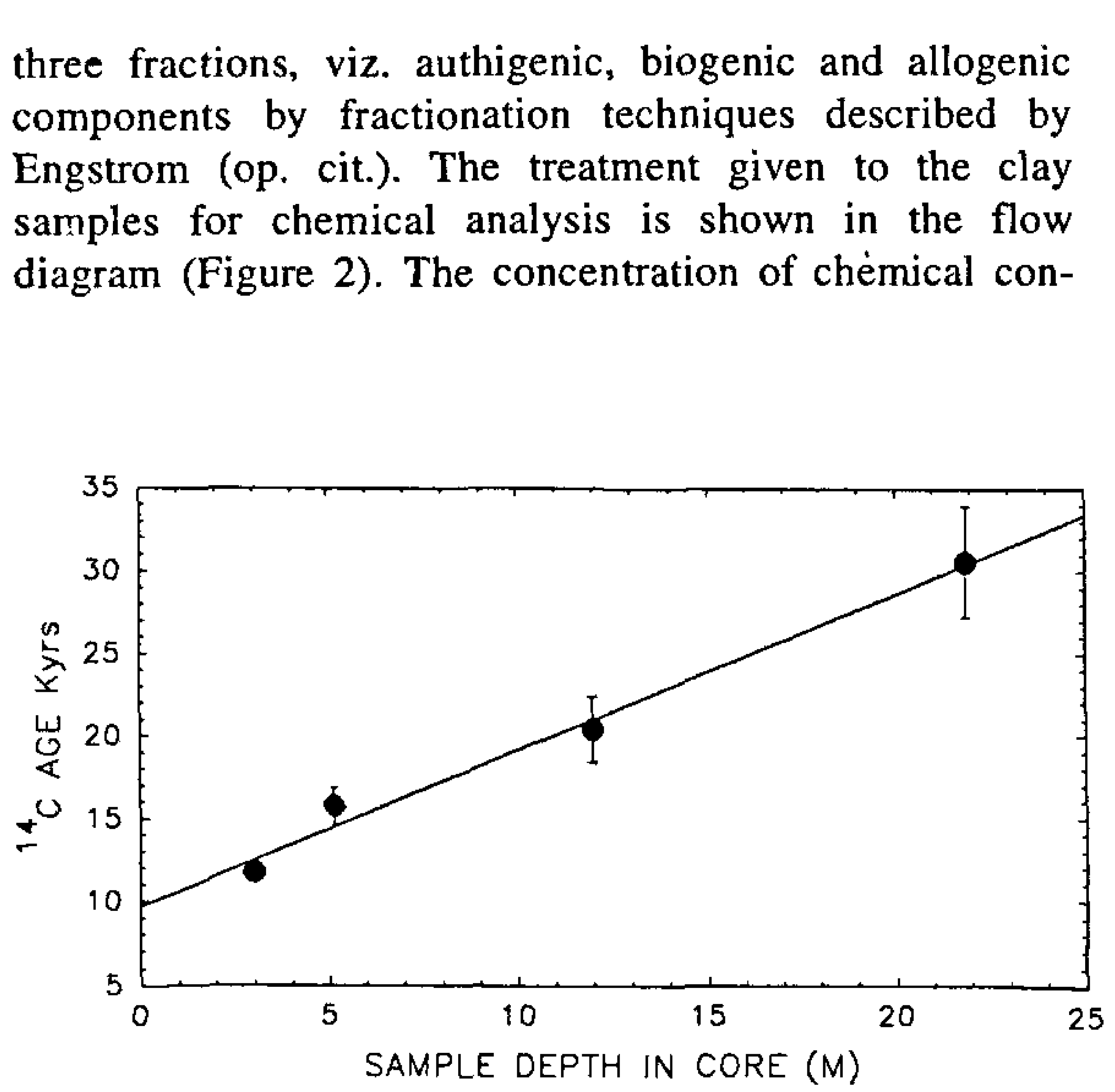

Figure 1. Radiocarbon ages of sediment core, TP-6, Tsokar lake, Ladakh.

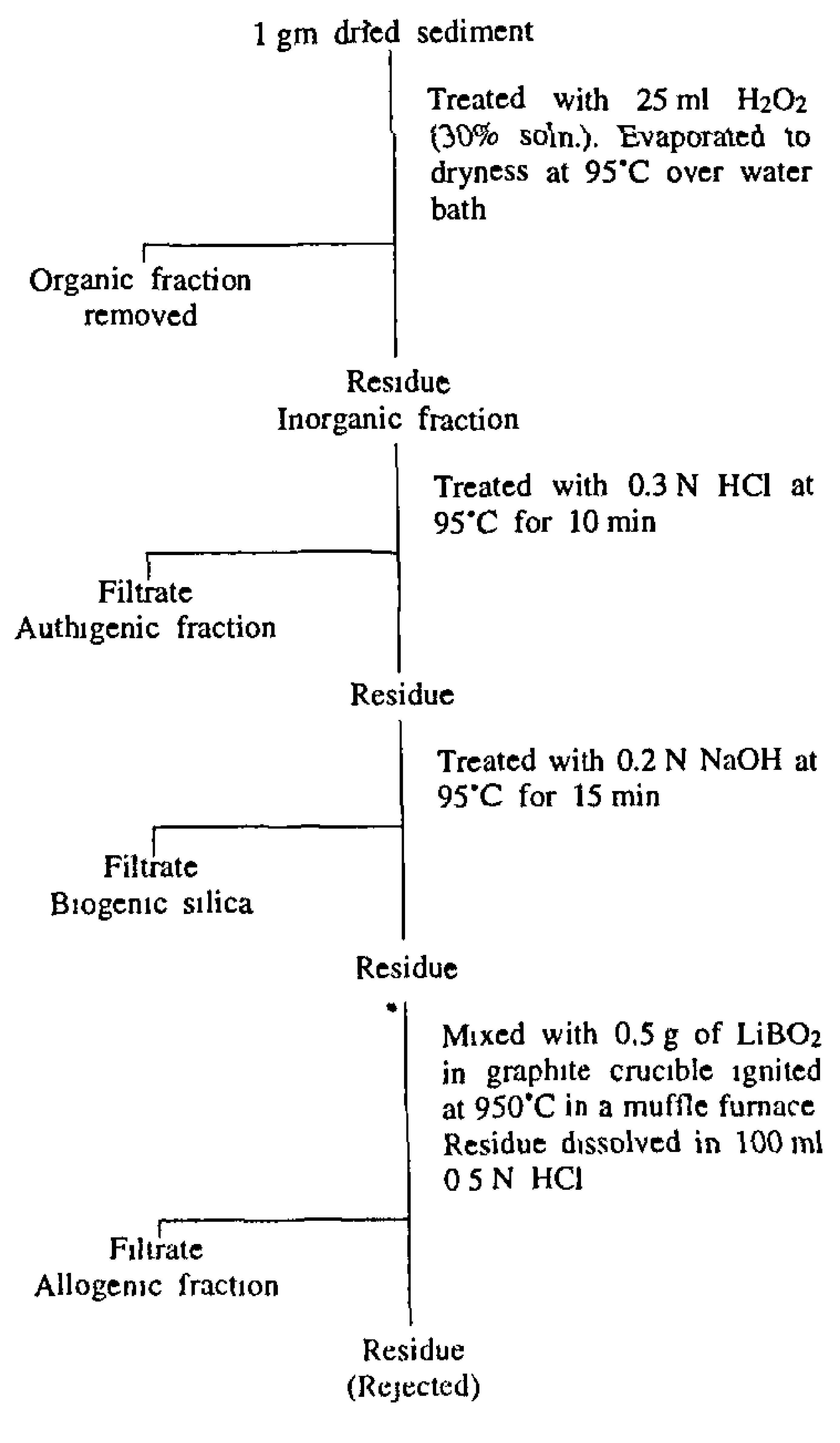

Figure 2. Sample preparation flow chart.

The present study shows that the organic matter content varied from 1% to 9% (Table 1 and Figure 3). Similarly mineral matter content was found to vary from 77% to 91% (Table 1 and Figure 3). The variation of elemental concentration (allogenic fraction) for Fe, Mn, Cu, Zn, Na, K and Mg is shown in Table 1 and Figure 3.

Dry arid climatic conditions are indicated by an increase in concentration levels of Na, K and Mg (in allogenic fraction). The mineral matter content is also high during these periods with a corresponding decrease in organic matter content. This inference is also supported by the palynological evidence of decline in the number of taxa and increase in steppe elements during these periods (Bhattacharyya op. cit.). Amelioration of climatic conditions is indicated by the low level of these chemical constituents (Na, K and Mg) as well as an increase in organic matter 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 op. cit.).

It is seen from the elemental analysis and organic and mineral matter content variations that the climatic condition was alternating from dry arid to amelioration in Tsokar lake region. From Figure 3 nine broad zones can be recognized (on the basis of variations in Na, K, Mg and organic and mineral contents) in relation to environmental changes (Table 2).

The climatic and vegetational changes based on chemical constituents variation discussed above and data from published pollen analytical study from TP6 (Bhattacharyya op. cit.) are summarized in Table 2.

The variation of redox conditions of the lake basin can be inferred from the distribution of Fe and Mn concentrations. In the sediments of Tsokar lake the concentration of Mn is less than average lithospheric concentration (1.0 mg/g Mn) in most cases and Fe is also well below the average lithospheric concentration (50 mg/g). Low Fe and Mn contents throughout the profile indicate that weak reducing conditions were prevalent in the lake resulting in transportation of these elements in the ionic form.

The present study based on the variation 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

Table 1. ^{14}C age, elemental concentration (allogenic fraction), organic and mineral content of TP 6 bore core, Tsokar lake, Ladakh

Depth (m)	^{14}C age (ky)	Na (%)	K (%)	Mg (%)	Fe (%)	Mn (%)	Cu (%)	Zn (%)	Org (%)	Min. cnt. (%)
1 0	10 67	1.367	0 98	0 478	0.759	0.206	0.337	0 649	9.0	83
2 0	11 62	0 433	0 90	0 025	0.157	0 039	0 019	0 541		
2 5	12 09	0 733	1 06	0 181	0.628	0.029	0.042	0 271	4.0	91
3 0	12.57	1 133	0 98	0 165	0.392	0 020	0.016	0 338		
5 5	14 94	0.467	0 86	0 041	0 105	0 020	0 013	0 118	6.1	86
6 5	15 89	1.333	1 02	0 198	0 037	0 049	0 037	0 135	3.0	84
7 0	16.36	0 367	0.86	0 041	0 235	0 049	0.016	0 169		
8 1	17 40	0 433	0.90	0 033	0 183	0.049	0 032	0.372	1.0	81
8 8	18 07	0.400	0 66	0 017	0 131	0 049	0 019	0 338		
9 7	18 87	0 733	1.02	0 184	0 097	0.049	0 084	0 203	3.0	82
12.0	21 10	0 867	1.06	0 124	0.366	0.049	0.021	0.186	6 0	80
15 15	24 09	0 600	1.10	0 190	0 497	0.049	0 021	0.305	3 0	79
18 20	26 98	0 667	1 10	0.247	0.419	0 039	0 174	0 203	6 0	79
19.75	28 45	0.767	0 98	0.293	0.549	0 078	0.032	0.135	4.0	81
21.85	30 44	0.467	0.98	0 327	0.183	0.069	0.042	0.372	8 4	77
23 00	31.53	1 667	1.02	0.346	1 020	0.177	0.301	0.880		

*Inferred ages.

Table 2. Environmental reconstruction

Age/depth (ky BP)	Range (m)	Na (%)	K (%)	Mg (%)	Relative conc./ climatic inference
31.5–30 4	23 0–21.9	1.67	1 02	0.35	high/dry arid
30 4–28.5	21.9–19 8	0.62	0 98	0.31	low/amelioration
28.5–18 9	19 8–9.7	0.73	1.05	0.21	high/dry arid
18.9–16 4	9.7–7.0	0.37	0 86	0 02	low/amelioration
16.4–15.9	7.0–6.5	1.33	1.02	0.20	high/dry arid
15 9–14 9	6.5–5 5	0 47	0.86	0.42	low/amelioration
14.9–12 6	5 5–3 0	1.13	0.98	0 12	high/dry arid
12 6–11 6	3 0–2.0	0.77	0 98	0 12	low/amelioration
11 6–10.7	2 0–1.0	1 37	0 98	0.48	high/dry arid

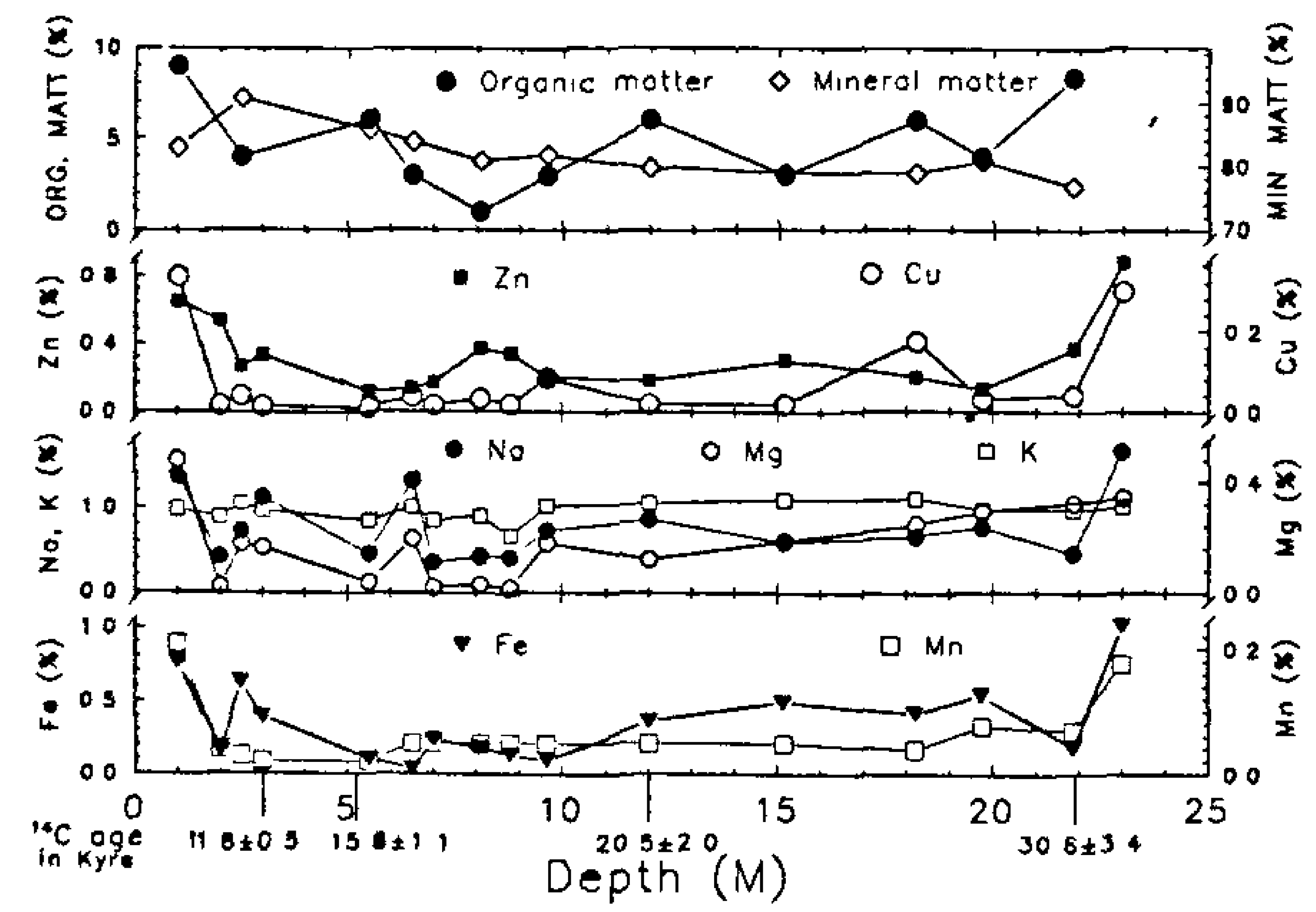

Figure 3.

during late Pleistocene. The lake was eutrophic between 21.85 and 19.75 m covering the time span of 30.4 to 28.5 ky BP and might have supported luxuriant aquatic vegetation as several seeds of *Potamogeton* along with large number of leafy fragments have been reported in the sediment (Bhattacharyya op. cit.). Between 19.75 and 8.10 m (28.5 to 17.4 ky BP), there is a gradual decrease in the organic matter content indicating a turn towards oligotrophic condition that may have been brought about by an increase in salinity. From 8.1 to 2.5 m, 17.4 to 12.1 ky BP 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 alkaline metal concentration. Mineral matter content is also in the range of > 70% as expected for post glacial lakes (Mackereth op. cit.).

Thus it can be concluded on the basis of elemental variation, organic, mineral content and palynological data that climatic condition around Ladakh was dry arid prior to 30.4 ky BP, during 28.5 to 18.9 ky BP, 16.4 to 15.9 ky BP, 14.9 to 12.6 ky BP and 11.6 to 10.7 ky BP and interrupted with brief ameliorations in it between 30.4 and 28.5 ky BP, 18.9 and 16.4 ky BP, 15.9 and 14.9 ky BP, and 12.6 and 11.6 ky BP.

1. Mackereth, F. J. H., *Philos. Trans*, 1965, **250**, (B. 765), 165–213.
2. Mackereth, F. J H., *Proc. R. Soc. (London)*, 1966, **B161**, 295–309.
3. Engstrom, D R. and Wright, H. E. Jr, in *Lake Sediments and Environmental History* (eds Haworth E. Y. and Lund J. W. S), Leicester University Press, UK, 1984, pp 11–67.
4. Engstrom, D R and Edward, Swain, B, *Hydrobiologia*, 1986, **143**, 37–44.
5. Sekar, B., Rajagopalan, G., Nautiyal, B. D. and Dube, B. K., *Curr. Sci.*, 1992, **63**, 571–573
6. Bhattacharyya, A, *Palaeogeogr. Palaeoclimatol Palaeoecol*, 1989, **73**, 25–38.
7. Rajagopalan, G, Mitre, Vishnu and Sekar, B., *Radiocarbon*, 1978, **20**, 398–404.
8. Bengston, Lars and Enell, *Magnus*, John Wiley, New York, 1986, pp 423–451.

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Possible role of Delhi–Haridwar subsurface ridge in generation of Uttarkashi earthquake, Garhwal Himalaya, India

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Himalayan orogen, a product of continued NE-SW compression, has certain zones in its foreland, which frequently experience seismicity. Geophysical and aeromagnetic data suggest extension of Peninsular rocks as NE-SW trending ridges in the Himalaya in these zones. The epicentral zone lying above the ridge end, has generated many NE-SW extensional structures within the NE-SW compressional field. As the Himalayan orogeny has not yet ceased and the compression continues, the resultant geological phenomena are manifestation of basement-cover interaction. The authors visualize a structural high at shallow depth at the ridge end. The release of stresses, retained by such structures under elastic strain causes seismicity in the Himalayan belt.

FORELAND topography plays a leading role in shaping the tectonic features in the frontal zone of the advancing thrust sheet. The pronounced subsurface irregularity in the form of 'ridge'-like features, generate distinct deformational structures in the overriding thrust mass. The extensive geological, geophysical and aeromagnetic investigations in the Indo-Gangetic plains (Himalayan foreland basin) have revealed continuation of the Peninsular rocks across the strike of the outer hill ranges under the thick alluvium[1–4]. One such feature named as Delhi-Haridwar Ridge, buried at shallower depth in the western part of Uttar Pradesh (UP) hills, has produced distinct deformational structures in the overlying thrust sheets due to the resistance offered by the underlying base during the thrust movement. The subsurface features in this area therefore are important in moulding the tectonic features of the overriding nappes. The terminal zone of the Delhi-Haridwar Ridge behaved like a buttress for the impinging south-directed thrust sheets, ever since the thrust sheets translated southward. The release of the stress[5] accumulated under elastic strain may be the prime cause of the Uttarkashi earthquake of 20 October 1991. The present communication discusses some of the structural observations made along this ridge in the overriding thrust sheets specially near the terminal zone and explains the cause of the earthquake.

The Delhi-Haridwar Ridge is a linear, NE-trending aeromagnetic anomaly[6–9] marking the western boundary of the Ganga basin. This is an offshoot of the Aravalli orogenic range. The Ridge has very gentle slope towards NE and thus striking at right angle to the Siwalik belt as well as the Lesser Himalayan and Central Crystalline thrust sheets. The maximum thickness of the Neogene and Holocene sediments near the frontal Lesser Himalaya[10] is about 4 km but reduced to less than 3 km on the ridge as indicated by the subsurface contours (Figure 1). The ridge extends presumably up to beneath Pala Dam site at 4 km NE of Bhatwari in the Bhagirathi valley. This conjecture is based on geophysical studies carried out by a number of workers[4,8,9,11,12] and the structural features recorded by present authors. Considering 1° average palaeoslope of the Ridge, as calculated between Delhi and Mohand in the foothills and assuming its further extension towards NE, the terminal point of this Ridge must be at the depth around 8 to 10 km in the zone of crystalline rocks. This depth corresponds with the seismological data which restrict the focus of majority of earthquakes in this zone[11,13] at 10 to 12 km. Similar basement configuration of the Peninsular rocks is reported along Gola valley in Amritpur area, Kumaun[14,15] as inferred from the upthrow of about 10 km of the basement rocks along the Main Boundary Thrust (MBT), thus suggesting shallow depth of the basement. Gravity low in Bhatwari-Harsil area[12] suspected as representing depth wise extension of granitic and gneissic rocks of the Central Crystalline belt, as compared to a gravity high with positive isostatic anomaly in the southern Lesser Himalaya possibly implies Aravalli rocks extending underneath and not the Central Crystallines lying in the north at tectonically higher