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SEDIMENTOLOGY AND GEOCHEMISTRY OF A CORE FROM MAYEM LAKE: AN ATTEMPT TO UNDERSTAND THE IMPACT OF MINING

M. GIRAP and G. N. NAYAK
Department of Marine Sciences and Marine Biotechnology, Goa University, Taleigao Plateau, Goa - 403 205

Abstract

Core 2 from the central portion of the Mayem Lake was used to understand the sediment characteristics, rate of siltation and impact of mining. The concentration of organic carbon decreases while that of sand (+230 #) increases with depth. This indicates a deposition of more fine-grained sediments (silt to clay size) along with organic matter during recent times. Concentration of major elemental oxides, viz., Fe, Mn, Co and Zn shows a decreasing trend while Si, Al, Na and K show an increasing trend in their concentration with depth. Relatively higher concentration of Fe, Mn along with a few trace elements, Co and Zn, in the recent sediments can be related to the supply of material from mine dumps in recent years.

Introduction

Lake sediments, in general, are considered to be a storehouse of information regarding the present and past parameters such as palaeoclimate and environment of deposition (Hough, 1963). Sly (1977) stated that closed lakes (lakes without any outlet to open sea) are readymade laboratories for studies on palaeoclimatic, hydrological and geological phenomenon, and environmental forensic investigations (Meiggs, 1980). Lake sediments also play active role in regulating cycles of trace metals and certain industrial effluents as oxide coatings on them; iron is especially ubiquitous in the oxygenated environment (Jenne, 1968, 1977). In such a lacustrine environment, core studies provide special help to establish the nature, type of pollution and hence the degree of contamination (Forstner and Wittmann, 1979) and also the rate of sediment influx.

The use of lacustrine cores to describe the rate of sediment influx through age dating has been studied by Evans and Rigler (1980); Johanson *et al.* (1990); Das and Singh (1994) and Sekar *et al.* (1994). Very few attempts have been made to study the impact due to mining (Banerjee, 1987; Rebello, 1989; Desai, 1991; Nayak, 1995) and the present study is an attempt in this direction.

The Mayem Lake is a closed system. It is situated in Bicholim taluka of North Goa district, Goa (topo-sheet No. 48 E/14 and 48 I/2). It lies between 73° 56′ 20″ E and 73° 56′35″E and 15° 34′ 20″ N and 150° 34′ 35″ N at an elevation of 15 m above MSL (Fig. 1).

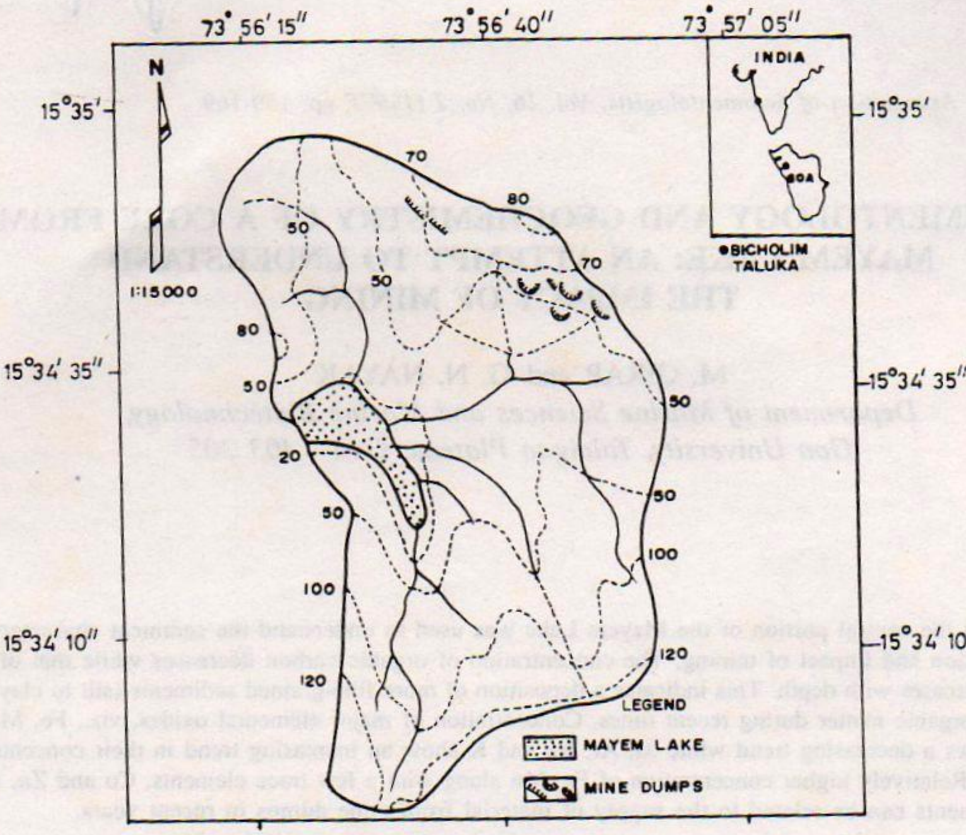

Fig. 1. Map of the Mayem Lake and its Catchment Area

Field Techniques and Laboratory Methods

Cores were collected using a gravity corer of 2 m length attached with a cutting bit and a core catcher. The location of the core sites is given in Figure 2. After retrieval, the cores were kept in a vertical position to drain-off excess water. The selected core (C-2) was sampled at a uniform interval of 3 cm. Each sample was further subdivided into three fractions. Keeping one fraction as a reference, the remaining fractions were analysed for size analysis using standard wet sieving (i.e., pipette method) and organic carbon content using wet oxidation method (Elwakeel and Riley, 1957). Geochemical analysis of every alternate fraction was carried out by Inductively Coupled Plasma Emission Spectrometry (ICP) using ISA Jobin Keun Jy 70 plus ICP spectrometer equipped with simultaneous polychrometer for major elements and with a high resolution sequential monochromator for trace elements. Major elements analysed were Si, Al, Fe, Ti, Mn, Na and K; while trace elements included Ba, V, Cr, Co, Ni, Cu, Zn, and Zr.

Geochemical data was processed for geostatistical analysis after normalization (Sahu, 1982). Certain selected elements (Fe, Mn, Cr, Ni, Co and Zn) were subjected to further analysis to ascertain the impact of mining. These included (a) Enrichment Factor-EF (Borole *et al.*, 1985), and (b) Index of geo-accumulation-I_{geo} (Muller, 1979) to assess the impact and extent of pollution.

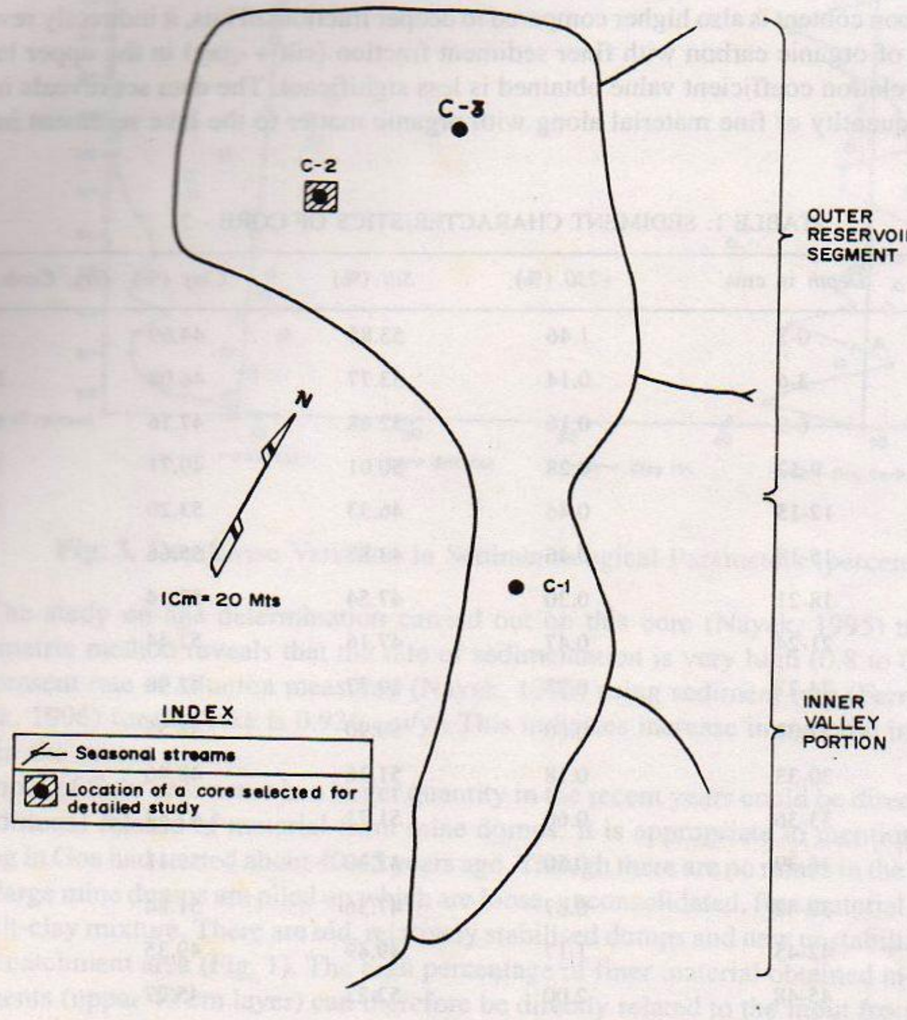

Fig. 2. Locations of the Core Sampling within Mayem Lake

Results and Discussion

The data obtained from sedimentological analysis is presented in Table 1. The sediment size varies from clayey silt at the surface to sandy silt at the bottom of the core. Sand fraction (+230 #) is less and remains almost constant upto a depth of 40 cm and then gradually increases downward (Fig. 3), which is also evident from the correlation obtained ($r = 0.7376$). Organic carbon content shows a trend reverse of the sand fraction, i.e., it decreases in its concentration with increasing depth ($r = -0.3902$). Earlier study (Girap *et al.*, 1994) carried out on the surface sediments of this lake showed close affinity between organic carbon and finer sediment fraction. However, in the present set of data such relation is less significant

($r = -0.0939$). Constant value of the sand fraction (+230 #) in the upper 40 cm column possibly reveals uniform sedimentation. From Table 1, it is clear that the silt + clay is the predominant fraction in the upper layer with the least sand fraction content. In this layer organic carbon content is also higher compared to deeper fractions. Thus, it indirectly reveals association of organic carbon with finer sediment fraction (silt + clay) in the upper layer, though correlation coefficient value obtained is less significant. The data set reveals input of a larger quantity of fine material along with organic matter to the lake sediment in the recent past.

TABLE 1: SEDIMENT CHARACTERISTICS OF CORE - 2

No.	*Depth* in cms	*+230 (%)*	*Silt (%)*	*Clay (%)*	*Org. Carb. (%)*
1	0-3	1.46	53.85	44.69	8.10
2	3-6	0.14	53.77	46.08	12.33
3	6-9	0.16	52.68	47.16	11.96
4	9-12	0.28	50.01	49.71	11.60
5	12-15	0.46	46.33	53.20	11.00
6	15-18	0.46	43.87	55.66	9.30
7	18-21	0.30	47.54	52.14	10.50
8	21-24	0.47	47.16	52.44	7.70
9	24-27	0.25	49.77	47.98	16.56
10	27-30	0.60	50.90	48.55	14.35
11	30-33	0.18	51.36	48.46	12.90
12	33-36	0.60	51.71	47.84	13.30
13	36-39	0.50	47.30	52.11	7.50
14	39-42	0.67	47.36	51.84	5.15
15	42-45	1.17	49.49	49.35	7.54
16	45-48	2.00	52.23	45.77	8.83
17	48-51	2.91	56.63	40.46	9.57
18	51-54	3.09	48.08	48.82	9.75
19	54-57	2.00	46.92	51.07	10.67
20	57-60	1.33	48.30	50.37	10.12
21	60-63	4.00	43.91	52.09	8.83
22	63-66	1.83	48.25	49.91	11.56
23	66-69	1.64	50.69	47.67	7.91
24	69-72	2.17	45.03	52.81	9.57
25	72-75	4.00	42.53	53.47	8.10
26	75-78	11.20	48.51	40.29	8.10

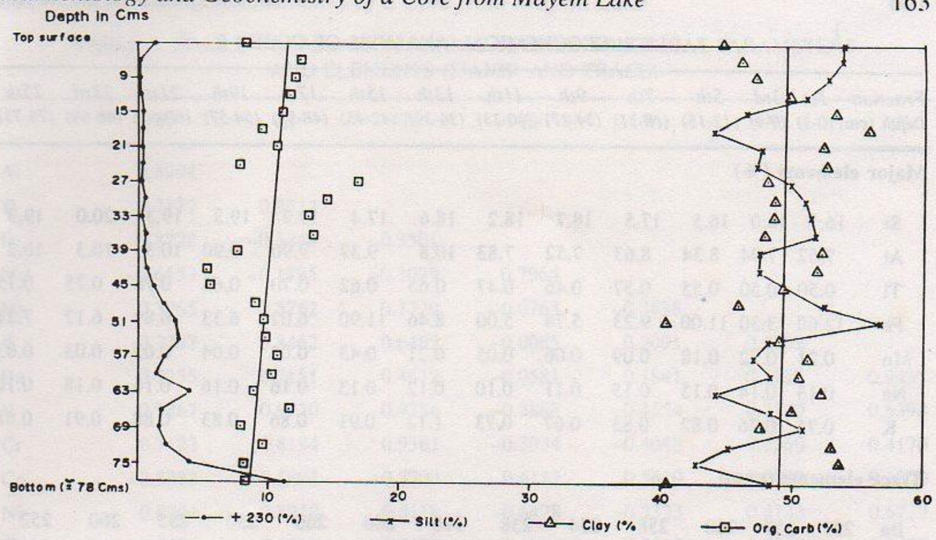

Fig. 3. Depthwise Variation in Sedimentological Parameters (percent)

The study on age determination carried out on this core (Nayak, 1995) using ^{210}Pb radiometric method reveals that the rate of sedimentation is very high (0.8 to 0.9 cm/yr). The present rate of siltation measured (Nayak, 1995) using sediment trap (Fernandes and Nayak, 1996) for this lake is 0.936 cm/yr. This indicates increase in material input to this lake in the recent past.

Input of finer sediments in a larger quantity in the recent years could be directly related to additional release of material from mine dumps. It is appropriate to mention here that mining in Goa had started about 40-45 years ago. Though there are no mines in the catchment area, large mine dumps are piled up which are loose, unconsolidated, fine material consisting of a silt-clay mixture. There are old, relatively stabilised dumps and new unstabilized dumps in the catchment area (Fig. 1). The high percentage of finer material obtained in the recent sediments (upper 40 cm layer) can therefore be directly related to the input from the mine dumps.

To confirm the interpretation based on sediment characteristics, studies on geochemistry of elements was taken up. Concentrations of different elements are presented in Table 2. On an average, concentration of major and trace metals are in the following order:

Si > Fe > Al > K > Ti > Mn > Na and Zn > Cr > Ba > V > Ni > Zr > Cu > Co

Distribution of Fe and Mn concentrations is similar with two peaks, one near the surface and other at a depth of 45 cm (Fig. 4 A and B). Below this depth concentration decreases. Fe and Mn show good positive correlation ($r = 0.7964$) with each other and also with certain trace metals like Co and Zn (Table 3). It is seen from the data that along with Fe and Mn, Zn concentration is high near the surface (Fig. 5A) and Al and K concentration is high at 40 cm depth (Fig. 4A and B). This indicates large input of Zn along with Fe and Mn from new mine dumps.

TABLE 2: GEOCHEMICAL ANALYSIS OF CORE - 2

Fraction Depth (cm)	*1st* *(0-3)*	*3rd* *(6-9)*	*5th* *(12-15)*	*7th* *(18-21)*	*9th* *(24-27)*	*11th* *(30-33)*	*13th* *(36-39)*	*15th* *(42-45)*	*17th* *(48-51)*	*19th* *(54-57)*	*21st* *(60-63)*	*23rd* *(66-69)*	*25th* *(72-75)*
Major elements (%)													
Si	16.1	16.0	16.5	17.5	18.7	18.2	18.6	17.4	19.9	19.3	19.3	20.0	19.3
Al	7.62	7.94	8.34	8.63	7.52	7.83	10.8	9.37	9.90	9.90	10.3	10.3	10.2
Ti	0.50	0.50	0.55	0.57	0.46	0.47	0.65	0.62	0.70	0.68	0.76	0.75	0.75
Fe	12.60	13.30	11.00	9.23	5.74	5.00	8.46	11.90	6.02	6.33	6.89	6.17	7.27
Mn	0.21	0.22	0.18	0.09	0.06	0.05	0.21	0.43	0.04	0.04	0.03	0.03	0.03
Na	0.13	0.14	0.15	0.15	0.11	0.10	0.12	0.13	0.16	0.16	0.16	0.18	0.16
K	0.75	0.76	0.82	0.83	0.67	0.73	1.12	0.91	0.86	0.83	0.88	0.91	0.88
Trace elements (ppm)													
Ba	233	237	260	258	234	238	310	260	260	250	255	260	252
V	153	165	170	172	148	154	208	185	205	225	230	230	235
Cr	163	174	168	168	146	149	200	212	260	305	310	280	310
Co	30	35	37	31	29	27	35	26	17	16	15	15	15
Ni	117	122	132	139	137	136	155	145	149	152	151	155	149
Cu	52	56	54	52	46	48	58	58	58	64	60	68	62
Zn	240	146	142	127	120	118	130	130	148	132	135	132	125
Zr	103	108	110	112	110	125	165	130	135	138	160	153	143

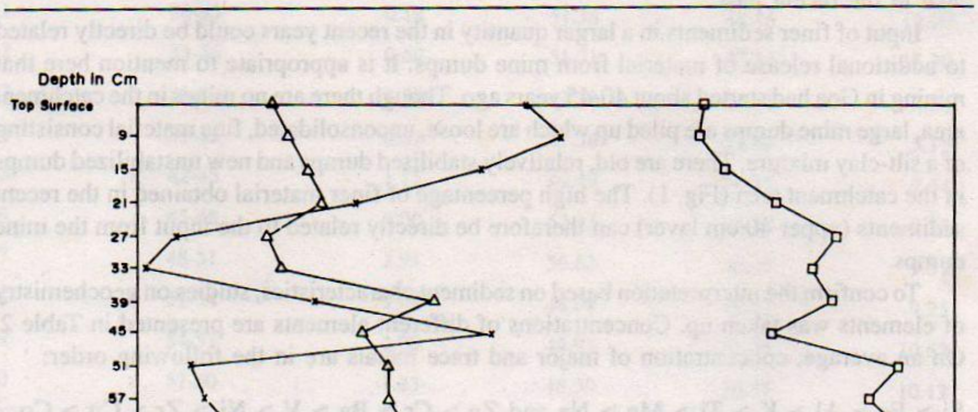

Fig. 4A. Depthwise Variation in Elemental Concentration (%)

TABLE 3: SIMPLE CORRELATION AMONG SEDIMENTOLOGICAL PARAMETERS AND ELEMENTS (MAJOR AND TRACE)

	Si	*Al*	*Ti*	*Fe*	*Mn*	*Na*	*K*
Al	0.6994						
Ti	0.7177	0.9334					
Fe	−0.8728	−0.3448	−0.3501				
Mn	−0.6553	−0.1795	−0.3099	0.7964			
Na	0.3965	0.5762	0.7729	−0.0763	−0.3438		
K	0.3287	0.8462	0.6462	−0.0085	0.2091	0.2702	
Ba	0.2755	0.7151	0.4612	−0.0581	0.1841	0.1125	0.9437
V	0.7267	0.9370	0.9756	−0.3888	−0.3554	0.7339	0.6398
Cr	0.7123	0.8184	0.9361	−0.3934	−0.4048	0.7560	0.4170
Co	−0.8083	−0.5895	−0.7703	0.6117	0.5610	−0.6032	−0.1020
Ni	0.8701	0.8910	0.8118	−0.6478	−0.3323	0.4143	0.6739
Cu	0.5434	0.8011	0.8632	−0.1984	−0.3030	0.8360	0.5438
Zn	−0.4836	−0.3219	−0.2281	0.5358	0.2525	−0.0071	−0.1969
Zr	0.7419	0.9242	0.8221	−0.4937	−0.2516	0.3478	0.7831
Sand	0.5804	0.6194	0.8046	−0.3144	−0.3991	0.6087	0.2321
Clay	−0.0424	0.2502	0.1860	0.0117	0.0032	0.0625	0.3124
Org. Carb.	−0.1203	−0.6799	−0.6678	−0.2586	−0.2854	−0.4769	−0.7465
Depth	0.8769	0.8188	0.8772	−0.6374	−0.4359	0.5361	0.4492

	Ba	*V*	*Cr*	*Co*	*Ni*	*Cu*	*Zn*
V	0.4565						
Cr	0.2004	0.9540					
Co	0.1047	−0.7598	−0.8774				
Ni	0.6202	0.8253	0.7186	−0.6333			
Cu	0.3481	0.9061	0.8807	−0.6456	0.6198		
Zn	−0.2767	−0.2867	−0.1940	0.1749	−0.6073	−0.0936	
Zr	0.6684	0.8499	0.7237	−0.5673	0.8819	0.6799	−0.3854
Sand	0.0172	0.7630	0.8701	−0.8278	0.4765	0.5930	0.0479
Clay	0.3263	0.2692	0.1496	0.1105	0.2661	0.1342	−0.4514
Org. Carb.	−0.5359	−0.6042	−0.5118	−0.2930	−0.3619	−0.6047	−0.2913
Depth	0.2800	0.8919	0.8859	−0.8744	0.8781	0.7099	−0.4824

	Zr	*Sand*	*Clay*	*Org.Carb.*
Sand	0.5440			
Clay	0.2567	0.0171		
Org.Carb.	−0.5446	−0.4801	−0.0939	
Depth	0.8145	0.7376	0.1909	−0.3902

$n = 13$ Level of significance at 99% – 0.641 99.99% – 0.760

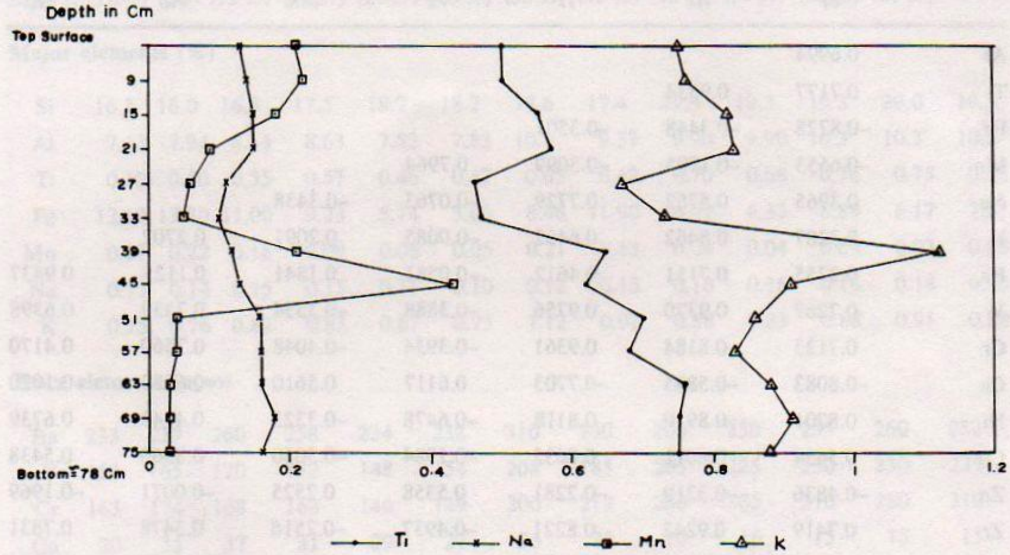

Fig. 4B. Depthwise Variation in Elemental Concentration (%)

Among other major elements, Al, Na, Ti and Si show a gradually increasing trend with depth (Fig. 4A and B). The trace elements except Co and Zn show similar and gradually increasing trend with the depth (Fig. 5A and B). Si, Al, Ti show positive correlation among themselves and with majority of the trace elements, which, in turn, show positive correlation with depth. This supports dominance of coarser quartzo- feldspathic sediments with the increase in depth.

The higher elemental concentration obtained at a depth of 40-45 cm could be directly related to the release from old dumps which were piled during early stage of mining and enrichment of elements in the core near the surface can be related to release from new dumps which are being created now.

An attempt is made to compute some of the geostatistical factors to get information on elemental enrichment and its impact on the lake sediments.

Enrichment factor and index of geo-accumulation (I_{geo}) calculated are presented in tables 4 and 5, respectively. It is clear from table 4 that sediments of the top layer are enriched in Fe, Mn, Co and Zn, while from table 5 it is seen that sediments in the top layer can be grouped in class 0-1 of Muller (1979), thereby indicating the unpolluted to moderately polluted nature.

From the results and discussion presented above, it can be concluded that the core study carried out with special reference to grain size characteristic and geochemistry along with factors computed has helped to understand the rate and extent of impact of mining on the Mayem Lake.

TABLE 4: ENRICHMENT FACTOR CALCULATED FOR TOP AND BOTTOM FRACTIONS

Metals	*Enrichment Factor (EF)*		*Remarks*
	Top	*Bottom*	
Fe	2.79	1.20	Top layers show enrichment indicating mining impact
Mn	1.68	0.18	
Cr	1.70	3.12	Bottom layers are enriched
Ni	1.76	1.71	
Co	1.57	0.58	Top layers are enriched indicating anthropogenic input
Zn	1.74	0.68	

TABLE 5: I_{geo} INDEX CALCULATED FOR TOP AND BOTTOM FRACTIONS

Metals	*Index of Geo-accumulation*	
	Top	*Bottom*
Fe	0.83	0.04
Mn	0.72	–2.08
Cr	0.12	1.05
Ni	0.19	0.55
Co	0.00	–1.00
Zn	0.75	–0.18

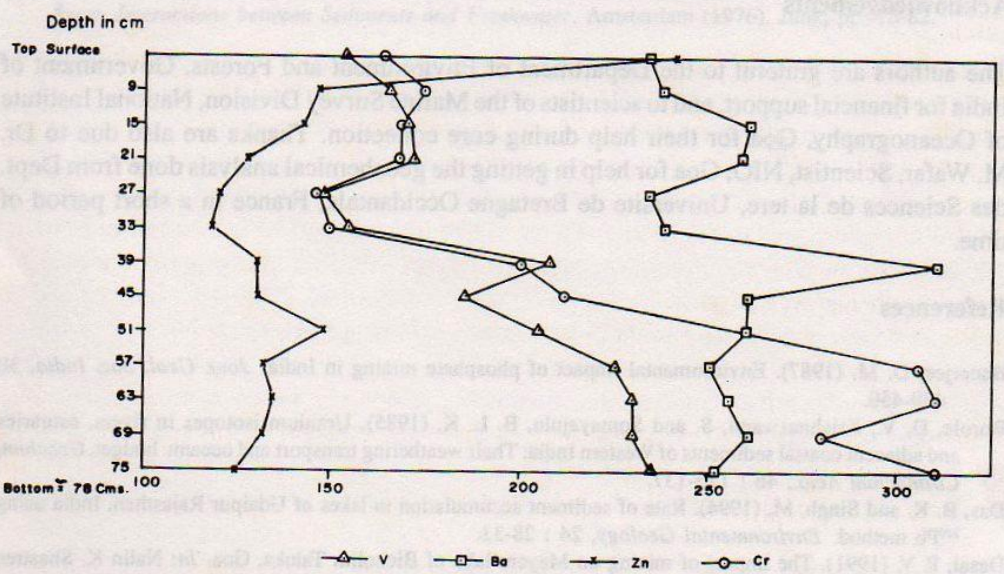

Fig. 5A. Depthwise Variation in Trace Metal Concentration (ppm)

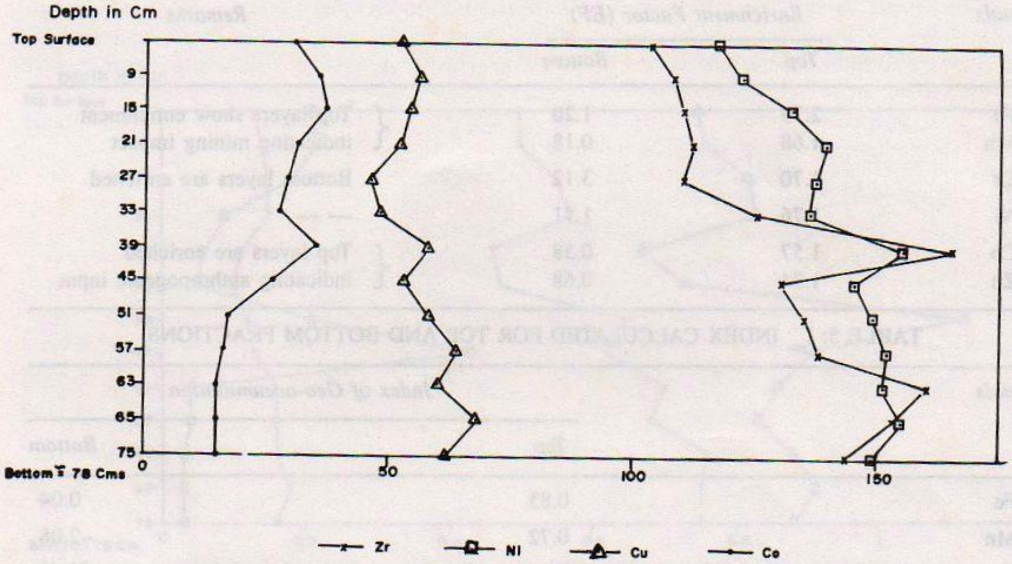

Fig. 5B. Depthwise Variation in Trace Metal Concentration (ppm)

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