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Thermal structure, sedimentology, and hydro-geochemsitry of lake priyadarshini, schirmacher oasis, Antractica

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Abstract

Analysis of thermal structure and estimation of heat budget for lake Priyadarshini, eastern Schimacher oasis during sixteenth Indian Scientific Antarctica Expedition (December' 96-March'97) reveal that weak thermal stratification prevailed in the lake for the major part of the period of observation during mid summer. However, the lake becomes unstratified as the winter period approaches. The heating cycle of the lake is a function of climate and morphometry of the lake itself. Detailed study of mineralogical and geochemical aspects of lake sediment cores have been carried out to elucidate the depositional processes and post-depositional changes within the total lake system, including its catchment. The in-situ parameters of lake water, concentration of some major ions and trace metals have also been analyzed in the present study to understand the hydrogeochemistry of the lake.

Introduction

The Schirmacher Oasis of Antarctica is a group of low-lying hills of 50-200m height and is interspersed with a number of freshwater glacial lakes. The available information indicate that the size of these lakes ranges form a few hectares to a few km^2 and the maximum depth of water in them ranges from a few meters to about 150m. Depending upon their topographic setting, they occur as inland lakes, ice margins lakes or epishelf lakes. Lake Priyadarshini, with the total water spread area or 0.75 sq. km., is one of the largest lake in the region and is closest to the Indian Station, Maitri. This lake, located at about 255 meters away from Maitri, is the lifeline of the Indian expedition as it completely caters to the water supply to the station. The lake has been described as a proglacial lake (Priddle and Heywood, 1980, inVerlencar et. al. 1996), formed at the edge of the ice cap during the deglaciation phase. The water and sediment input to the lake is entirely through melt water during warmer periods of spring and summer.

The fresh water lakes present in the Schimacher range of East Antarctica have drawn the attention of scientists from various disciplines. As on today, the knowledge of thermal behavior, sedimentation regime and geochemical parameters of Antarctic lakes and lacustrine sediments is inadequate. In the present work, thermal data were collected during the ice free period (Jan-Feb., 1997) from the Lake Priyadarshini. The available data give an estimate of basic heat budget of Priyadarshini, in particular, and provide an insight to the theramal structure of Antarctica lakes, in general. Sediment coring, dredging and water sampling were carried out at different sites in the Priyadarshini and a few lakes in the Western Schirmacher. Detailed mineralogical and chemical studies of the lake sediments provide important information about the sources of lacustrine sediments and processes operting within the lake system including its catchment area. In-situ parameters and analysis of few major and heavy metals in lake water were also carried out to know the lake water chemistry.

Thermal Structure and Heat Budget

The thermal cycle of the Antarctic lakes can be divided into two periods: the ice-covered period and ice-free period. It is well established that a lake's overall thermal response and resulting heat balance is the result of exceedingly complex interaction of many thermal and dynamic processes (Lerman, 1978). However, a first estimate of the heat-budget of a lake can be obtained with minimum of observational data and without regular year-round *in situ* monitoring of the lake itself. In the present study, thermal data were collected during ice-free period (Jan-Feb., 1997). The available data give an estimate of basic heat budget of the Lake Priyadarshini in particular, and provide an insight to the thermal structure of the Antarctic lakes, in general.

The Lake Priyadarshini undergoes alternate phases of freezing in winter and melting in summer periods. The top 2-2.5 meters of the lake freezes during the winter. The freezing of the shore area starts approximately during the second week of February and the lake freezes completely by the first week of April. The melting phase starts in the first week of November and the lake is in liquid state by the last week of December. The temperature sensors and a 10-channel digital temperature indicator were installed in the second week of January'97 close to the pump house (see S1 in Fig.l) for recording of lake water temperature. The temperature sensors were dropped in the lake with the help of a float. Out of 10 temperature sensors, the top 6 were fixed at an interval of 0.5m and the rest at lm. The depth of water column at this point was recorded as 4-5m. A 12 hour cycle of vertical temperature profile of the lake was established to see the gradual shifting of thermocline (zone of maximum vertical temperature variation)during the day and to select a particular time for daily observations. Plotting the vertical temperature profiles, the profile at 8.30 am reflects maximum variation and the same was selected for daily observations. The observations of vertical profile of the lake temperature were recorded daily for the period (15[lh] January - 18[''1] February). These *in-situ* thermal data have been further analysed to work out thermal structure and basic heat budget of the Lake Priyadarshini.

The hourly temperature data on a particular day (12 hr cycle) given in Table 1 and the data are plotted in Fig 2a. The variation of temperature with depth show that a weak thermocline is developed between 1.5 m to 4.0 m.; the difference in temperature of epilimnion (surface layer above thermocline) and hypolimnion (deeper layer below thermocline) is quite small (of the oreder of 1-1.9° C) A careful observation of the hourly temperature curves show that the temperature of lake surface steadily increases from morining, reaches its maximum (6.5° C) around 3 pm and then decreases. Apparently, it directly corresponds to solar heat variation during the day. At about 3 m depth, the lake water shows the maximum temperature of 6.7° C around 5 pm. This delayed response may reflect the heat-conduction behavior of the lake water. After 5 pm the temperature of the middle layer does not decrease significantly. At a depth of 5 m, the lake water temperature, which is always slightly higher than that of the lake surface, has increased up to 5.9° C and remained at that temperature from 3 to 5 pm and then decreased. It is expected that the lake will complete the cycle of temperature variation during 24 hr period. Figure 2a clearly shows that at 8.30 am the variation of lake water temperature with depth is maximum. Therefore, the temperature at 8.30 am has been taken as the representative temperature of the day.

Table 2 contains the temperature data form 15'" January '97 to 18'" February '97 on daily basis. The daily temperature data for the period have been plotted in Fig. 2b, which clearly reflects the variation of temperature during the period January to February. The important observations from Table 2 and Fig.2b are as follows:

(i) 15th Jan-25th Jan:The surface temperature of the lake water remained above 5°C.

(ii) 27'" January - 3rd February: The temperature of the surface and bottom water of the lake remained close to 4°C. The maximum temperature at intermediate depths was recorded as 5°C. The density of water is maximum at 4°C and therefore the surface water would have had higher density than the water at intermediate depths. It seems likely that limited mixing in the top 1.5 m may have occurred during this period.

Table 2. Daily Temperature (°C) Data from 15'" Jan. to 18th Feb.'97

Depth/ Date	0.5m	1.0m	1.5m	2.5m	3.0m	4.0m	5.0
15/1/97	5.4	5.4	5.3	5.8	5.9	5.9	5.7
16/1/97	5.5	5.5	5.4	5.8	6.2	5.9	5.8
17/1/97	6.3	6.1	6.1	6.4	7.2	6.6	6.3
18/1/97	6.2	6.1	6	6.4	7.5	6.5	6.2
19/1/97	5.8	5.8	5.8	6.2	7.1	6.1	6
20/1/97	5.8	5.8	5.7	6.1	7	6.1	6
21/1/97	5.2	5.1	5	5.5	6.3	5.6	5.5
23/1/97	5.6	5.5	5.4	5.9	7	6.1	5.7
24/1/97	5.9	5.9	5.8	6.3	7.2	6.6	6.1
25/1/97	5.2	5.1	5.1	5.5	6.4	5.7	5.6

27/1/97	4.2	4.2	4.1	4.6	5.2	5.7	4.8
28/1/97	4.3	4.3	4.2	4.7	5.7	5.1	5
29/1/97	4.3	4.3	4.2	4.6	5.7	5.3	4.9
30/1/97	3.9	3.3	3.7	4.2	5.4	4.5	4.6
31/1/97	3.2	3.2	3.1	3.6	5.3	4.2	4.3
1/2/97	2.7	2.6	2.6	3.1	4.7	3.7	3.7
2/2/97	2.5	2.5	2.4	2.8	3.5	2.8	3.2
3/2/97	2.4	2.4	2.3	2.3	3.3	2.7	2.8
sum	1.2	1.2	1	1.5	-	1.7	2
6/2191	2.3	2.3	2.2	2.1	-	3.4	2.8
7/2/97	2.1	2.1	2	2.4	-	3	2.7
8/2/97	2.2	2.1	2	2.4	-	2.4	2.9
9/2/97	2	1.8	1.8	2.3	-	2.4	2.7
10/2/97	1.9	1.3	1.7	2.2	-	2.8	2.6
11/2/97	2.3	2.1	2.1	2.7	-	3.4	3
12/2/97	1.8	1.8	1.7	2.2	-	2.3	2.6
15/2/97	0.8	0.8	0.7	1.2	-	1.5	1.6
16/2/97	0.9	0.9	0.8	1.2	-	-	-
18/2/97	0.8	0.8	0.6	1.2	-	-	-

iii) 5''' February - 15* February: During this period, even the subtle difference in temperatures of surface and deeper water diminishes and the lake started transforming into unstratified situation.

iv) 15''1 February - 18''' February: This marks the end of data collection period and by this time the surface water of the lake was close to freezing point (0.6° C), whereas the deeper water was still well above 1° C.

The temperature profile shows that weak thermal stratification prevailed in the lake during major part of the period of observation. Earlier workers have suggested that weak thermal stratification may sometimes be associated with feeble salinity variations in the water column. The data presented by Verlancar et.al., (1995), for the Antarctic Polynya shows that low surface salinity was associated with the increase in temperature. Although no systematic data is available for Priyadarshini lake, the addition of fresh glacial melt during the summer period may lower the surface salinity slightly and therefore the surface layers show a slightly higher temperature. However, the stratification developing between 2.5 to 4.0 m may not be associated with salinity variation, Moreover, Priyadarshini is a typically fresh water lake and the salinity values are very low (2.01-2.03 ppt) which is unlikely to have any major effect on the temperature variation in the water column.

It seems therefore that during mid summer period the lake shows weak thermal stratification and as winter approaches (5''' February onwards as per our data), the lake water column becomes vertically homogeneous and the thermal stratification is destroyed. Keeping in view the fluctuation of the lake from stratifed to unstratified situation, the heat budget had been computed for both the cases for the respective periods.

To synthesize the heat budget of the lake during ice free period, all that is needed is a record of surface water temperature and the mean depth for unstratified lakes, and thermocline depth for stratified lakes. In addition the hypsometric curve is needed for stratified lakes in order to correct for decrease in area with depth (Lerman, 1978). For stratified case, the heat content calculation includes the surface temperature, the depth of thermocline, and a hypsometricd term. The heat content can be expressed as:

$$\Sigma Hs = Tsfc.\ Dth/2$$

By taking half of the thermocline depth the linear hypsometric term is included. Using Birge's definition of thermocline i.e. and imaginary plane within the lake located at a level intermediate between the two depths where the temperature variation is the greatest, the average thermocline depth is taken as 2.75m (see Fig.2a) for hourly variation of temperature and 3.25 m (see Fig.2b) for daily variation of temperature. These values are used for further computation of heat storage terms during mid summer period till 5''' February.

From 5''' February onwards the heat budget of the Priyadarshini lake has been computed for unstratified situation. For unstratified case, the heat content per unit area is taken as the product of the surface water temperature and mean depth (volumetric heat capacity 1.0 cal/cm):

$$\Sigma Hs = Tsfc.D\ (cal/cm^2)$$

The morphometric data (Table 3a & 3b) and the hypsographic curve (Fig.3a) of the lake Priyadarshini have been generated from bathymetric map (Verlencar et. at., 1996) of the lake basin. The mean depth of 2.12 m was computed by dividing the lake volume by its surface area. An additional dimension, the depth of the center of gravity (Zg), is obtained from the cumulative percent volume curve by marking the depth corresponding to the 50% cumulative percent volume (Fig. 4b). The parameter Zg has use in certain calculations pertaining to physical limnology (Gerald, 1978).

Table 3 : (a) Morphometric data from lake Priyadarshini, Antarctica

Depth (m)	Area (ha)	Percent
0.0	10.38	100.00
1.0	7.36	70.90
2.0	5.20	50.09
2.5	3.86	37.18
3.0	2.54	24.47
4.0	1.42	13.68
4.5	0.86	8.28
5.0	0.38	3.66
5.5	0.18	1.73
6.0	0.04	0.38

Table 3 : (b) Morphometric date from lake Priyadarshini, Antarctica

Stratum (m)	Volume (m^3 x lO^4)	Percent	Cumulatiave Percentage
0-1.0	8.87	40.20	40.20
1.0-2.0	6.28	28.46	68.66
2.0-2.5	2.26	10.24	78.90
2.5-3.0	1.60	7.25	86.15
3.0-4.0	1.98	8.97	95.12
4.0-4.5	0.57	2.58	97.70
4.5-5.0	0.31	1.40	99.10
5.0-5.5	0.14	0.63	99.73
5.5-6.0	0.05	0.22	99.95

Diurnal variation of heat storage for stratified condition (14'" January) is plotted in Fig. 4a which shows that heat content increases from morning till 6.pm in the evening and then it shows gradual decreasing trend. The profile shows its maxima at 2p.m. in the afternoon, as the surface temperature gradually increases with the increase in intensity of incoming solar radiation with time of day and it reaches its maximum value during this time the of the day. The plot of daily heat content variation from 15th January to 18th February (Fig. 4b) shows that during mid summer period, i.e. till 5th January, the heat content of the lake is quite high when it behaves as thermally stratified. From 5th February onwards, when the lake starts transforming into un stratified situation, the heat content gradually decreases as the ice covered period approaches. The heat content of the water at the time of freezing becomes nearly zero and the albedo increases sharply, thus reducing the absorption of solar radiation and further freezing. The local spikes in the heat content profiles are due to fluctuations of weather condition in some particular days. Further, it is interesting to note that the lake surface temperature is generally higher than the mean air temperature (Fig. 5). Even when the mean air temperature has dipped to subzero values, the lake surface temperature has remained positive. It appears therefore that freezing of the lake is not directly linked to variation in mean air temperature of the region.

The available data indicate that weak thermal stratification prevailed in the Lake Priyadarshini of Antarctica during major part of the period of observation and it transformed into unstratified one, as the ice covered period approaches. Estimates of several of the heat budget during Antarctica summer reveal that the lake gains heat by net incoming solar radiation and the heating cycle is a function of climate and morphometry of the lake itself. Although the available data are not sufficient to estimate the total annual heat budget of the lake, this limited analysis of summer heat budget represents the first estimate of the annual course of the heat storage terms and thermal structure of the lake which in turn may provide a model for the calibration of lakes as climate indicators, Further work using a long term and high resolution data set may be extremely rewarding.

Sedimentological Studies

The glacial lakes receive their sediment supply during warmer periods of spring and summer when ice melts and glacial streams are deposited first, followed by clayey layer at the top producing a 'varve' like deposit representing annual layers of depositional episodes. Obviously these varves are very useful indicators of sedimentation rate in the lake basin. Lake are also very sensitive indicators of the climate fluctuations which are very well manifested in the mineralogical and chemical variation of the sedements. Sediment cores contain important information about the past depositional environments, the events that occurred in the pre-cultural times in the lake and in its catchment area. The mineralogical and chemical aspects of the lake sediments play an important role to elucidate the many processes occurring within the total lake system, including its surrounding surface and groundwater drainage basins. The physical characteristics of sediments are important to interpret the sediment-water interaction processes, depositional and erosional episodes and facies variation. Detailed studies of sediment mineralogy pertaining to allogenic, endogenic and authigenic fraction of lake sediments are important to determine the sources of sediment phases and relative importance of each source. The sediment cores were therefore analysed for sedimentology, mineralogy and geochemistry to derive information regarding different parameters of lacustrine environment and processes.

Sediment Coring and Dredging

Sediment coring and dredging was carried out at all the three sites S1, S2 and S3 in Lake Priyadarshini. A HYDRO-BIOS sediment corer was used to obtain the core. The corer was dropped in the lake with some additional weights attached to it and was allowed to sink in the lake bottom. After about 5 minutes, it was pulled back, sealed and brought back to the base camp. Similarly, the grab samples were obtained using a bottom sampler acc to Ekman Birge and were stored in polyethylene bags for further analysis after draining excess water. The core was also drained, dired, cut into pieces of 5 cm each and stored in polyethylene bags for sedimentological and sediment-geochemical analysis in laboratory. After draining the excess water the total core recovery was about 55 cm. from site S1, 50 cm form site S2 and 50cm form site S3. The core shows alternate layers of sediment and algal growth. It may be difficult to compare them with typical varves of lacustrine sequences because the sedimentation rates in these lakes is perhaps very slow and one layer of sediment may have taken years to accumulate. The pattern of algal growth looks confusing and they sometimes penetrate through the sediment layers. It is difficult to comment on the time frame of accumulation of the sediments at this stage without any chronological data ('dates'). Efforts are being made to carry out^{210} Pb/^{37} Cs dating of sediment cores. After getting some initial results,^{14} C dating may also be necessary.

Grain Size Analysis

The particle-size separation is usually the first step in mineralogical analysis of sediments. For particle size analysis first the sediment core samples of 5 cm length at sampling site S1 were oven dried in the laboratory at 60-65°C. Then the samples were grounded to fine powder and subjected to dry sieving by mechanical shaker for 10-15 minutes. In Lake Priyadarshini, the grain size distribution at sampling site S1 shows more or less uniform pattern (Fig.6) except a slight increase in clayey fraction with depth. Sediments are dominated by medium silt and clay fraction, thus they can be classified into "silty clay" category (after Gorsline, 1960, in McBride, 1983). These fine particles (silt and clay) in the sediments, due to their large surface area, will have a higher adsorbing capacity and are expected to have high concentrations of metals.

Sediment Mineralogy

For studying the mineralogy of fine grained, lacustrine sediments, X-ray diffraction technique was used. The size fraction <63µm was subjected to X-ray diffraction. Care was taken during the initial stage of particle size reduction not to damage the crystallite while grinding. The samples were grounded carefully by hand to have reproducible particle size distribution without damaging the crystal lattice. Bulk and "oriented" mounts of <63µm core samples from Lake Priyadarshini were then analysed thorugh X-ray diffractometer Model ISO-DEB YFLEX 1001 of RICH SEIFERT & Co. using Cr Ka radiaiton with monochromator in 30mA/40KV current to derive the information on sediment mineralogy. The X-ray diffraction pattern (Fig.7) shows the presence of quartz, feldspar, illite and chlorite mineral assemblages. The detrital quartz and feldspar represent the allogenic phases derived from gneissic and charnockitic rocks (Sengupta, 1986) in and around the lake basin. The dominant clay mineral present in illite which generally shows a slight increase in deeper (older) sediments. The input of illite can be attributed from till depostis or plutonic and mica-rich metamorphic bedrock of catchment area. Very low, paradoxial presence of chlorite can also be attributed to metamorphic bedrock or reworked glacial deposits or due to post-depositional changes of illite. Similar X-ray diffraction analysis of glacial varve sediments near Lake 91 also shows the presence of above mineral assemblages along with very little amount of mixed layer clays. The presence of mixed layer clays might indicate intermediate post depositional transformation stage.

In general, semi-quantitative X-ray diffraction results (Fig.8a) from the core samples show abundance of non-clay clasitc mineral like quarzt and feldspar relative to the clay minerals. The fact that these two minerals have persisted down to the clay-size fraction indicates little, if any, chemical weathering of glacially derived source material. This may be because of periglacial environment of the Antarctica region. A short summer period and limited moisture supply has not encouraged chemical weathering processes.

The ratios of basal peak heights of illite/chlorite, quatz/illite and quartz/chlorite in core sediments are plotted against depth in Fig.8b. A decrease in ratio of illite/chlorite at different depths may represent post depositional alteration of illite to chlorite due to seasonal variation in physico-chemical conditions. The increase in ratio of quartz/illite and quartz/chlorite indicate phases of more detrital inputs in the lake basin due to rainfall and runoff during wetter periods. Very high value of quartz/chlorite ratio near the upper layers of the sediment core may be related to provenance difference.

Organic Matter

The organic matter of sediment core samples were determined by treating them with H O, and measuring the weight loss due to oxidation by H,0, (Jackson, 1958). Depth-wise variation of organic matter content is shown in table 4 and plotted in Fig. 9, which shows a cyclic pattern of distribution with slightly higher organic matter content towards the surface. This cyclicity in organic matter content represents alternate phases of high and low organic productivity which may directly correspond to thawing and freezing cycle of the lake. During summer period, the lake water supports a heavy growth of algae because of exposure to atmosphere. Due to photosynthetic activity of algae the dissolved oxygen in lake generally increases and the lake becomes aerobic. The solubility of oxygen in turn depends upon water temperature and atmospheric pressure of oxygen. The accumulation of organic matter in sediment is thus strongly influenced by temperature and availability of oxygen (Manahan, 1974, Ingole & Dhargalkar, 1988).

Table 4 : Organic matter content in lake Priyadarshini core sediment, Antarctica

Sample	Core Depth (cm)	Organic Matter Content (%)
SIC1	0-5	22.91
SIC2	5-10	16.26
SIC3	10-15	15.42
S1C4	15-20	17.23
SIC5	20-25	14.49
SIC6	25-30	16.12
SIC7	30-35	17.63
SIC8	35-40	16.32
SIC9	40-45	16.80
SIC 10	45-50	17.12
SIC11	50-55	15.80

Heavy metal analysis

The sediment samples were oven dried (80-90°C), ground and sieved (<63 *μm)* initially for heavy metal analysis. The samples were then subjected to 'total digestion' as per the procedure developed by Tessier et. al., 1979. 1-gm (dry weight) of each sediment sample was first digested in a platinum curcible with a solution of concentrated Perchloric acid (2ml), and Hydrofluoric acid (10ml) to near dryness. Subsequently, a second addition of $HCI0_4$ (1ml) HF (10ml.) was made and the solution was evaporated until the appearance of white fumes. The residue was then dissolved in 12N HCI and diluted to 25ml. The resulting solutions was filtered and then analysed by flame. Atomic Absorption Spetrophotometry Model VARIAN Spectr AA-20 involving direct aspiration of the solution into an air-acetylene flame.

Sediment is a complex mixture of four possible substrate for heavy metal sorbtion including clays, organic matter, ferro-mangenese oxides and silicon hydrous oxides (Ramamoorthy et. at., 1978). The association of of heavy metals with sediments can range from weak Van der Waals force to strong covalent bonding. As a result of adsorptive bonding, co-precipitation by hydrous iron and manganese oxides, complexation in crystalline minerals, metals may be fixed by sediments.

The concentrations of extracted trace metals (Fe, Cd, Mn, Pb) in lake sediment core as obtained from AAS analysis are listed in Table 5. The depth-wise variation of metal concentrations is plotted in Fig. 10. The total metal concentration of sediments ranged from 146.50-514.00 mg/kg (Fe), 9.25-18.25 mg/FG (Cd), 157.50-562-50 mg/kg (Mn) and 52.50-77.50 mg/kg (Pb). Relatively higher concentration of iron and manganese in sediments is due to the presence of gneisses, granulites and charnokitic rocks in the region in which these metals are widespread in ferromagnesian minerals Fe and Mn are mobilized in the aqueous environment of the lake as a result of weathering and leaching of the surrounding catchment rocks and enter mainly as small oxide particles or as oxide coating on other particles. These iron and manganese oxides with large surface area represent additional scavenger phases for other metal ions. Pb and Cd show some correlation with Fe and Mn in depth-wise distribution. This indicates that PB and Cd may be preferentially bound to oxides of Fe and Mn. Very low concentration of Pb and Cd in the sediments may be attributed to some contamination clue to the proximity of the lake to Maitri station (perhaps due to possible oil spill from the vehicle workshop in the vicinity of the lake and also from moving vehicles). Besides, lead concentration in the sediment can also be attributed to natural atmospheric fallout and incorporation into the sediment.

The distribution of heavy metals in core sediment seems to be intricately linked to short term seasonal fluctuation of physico-chemical condition, redox condition and other parameters. The depth profiles of the heavy metal concentration show a cyclic pattern.

Table 5 : Concentration of heavy metals in lake Priyadarshini sediment core

Sample	Depth (cm)	Fe	Cd	Mn	Pb
S1C1	0-5	146.50	10.50	157.50	67.50
S2C2	5-10	374.00	9.25	385.00	65.00
S3C3	10-15	420.75	10.00	430.00	75.00
S4C4	15-20	431.75	10.00	360.00	65.00
S1C5	20-25	417.25	9.75	360.52	52.50
S1C6	25-30	463.50	11.00	425.00	67.50
S1C7	30-35	395.75	12.00	357.50	62.50
S1C8	35-40	514.00	12.25	517.50	77.50
S1C9	40-45	477.25	11.50	432.50	65.00
S1C10	45-50	495.00	18.25	562.50	70.00
S1C11	50-55	370.00	16.50	362.50	62.50

Concentration in mg/kg

The profiles of these show some correlation with organic matter content, as most of these metals are probably bound with organic matter forming organo-metallic complexes. This verifies well the hypothesis of Hart (1982, in Provini and Gaggino, 1984) that organic matter is related to the sedimentation of heavy metals. The elevated metal concentration in core sediments at different depths may correspond to seasonal melting phases. During melting phases relatively higher levels of dissolved oxygen in water may cause high productivity of organic matter. In such oxidizing environment, under high pH and Eh condition, Fe and Mn are precipitated and get enriched in the sediments. The oxides of Fe and Mn which in turn are good scavenger for other heavy metals may have caused elevated concentration of Pb and Cd at the sediments surface. Under oxidizing conditions, Pb and Cd are known to be less mobile, hence their migration to liquid phase is also less. The concentration profiles of Fe and Mn show very low values towards the surface which may be due to highly reducing condition or due to the combined influence of change in lake level and fluctuations in the groundwater contribution to the lake system.

Hydro-Geochemistry

During the summer period, the Lake Priyadarshini has two major inflows, one from the western side and the other from the SSW side. In both the cases, the inflow is through smaller lakes. The inflowing lake in the western side are fed directly by the glacier, whereas those in the SSW side are fed by the snow accumulation on the surrounding hills and also from the glacier through other small lakes. A small contribution to the lake may also be from the melting of snow accumulation on the leeward side of slopes around the lake. After the Lake Priydarshini is full, it outflows into a smaller lake through a lobe in the northern side. The outflow ultimately feeds the ice shelf through three lakes.

Three points were fixed in Priyadarshini for water sampling, one each in the eastern (S1), central (S2) and southern (S3) parts of the lake. The general bathymetry of the lake suggests atleast three pools of water in the lake and sampling points were fixed accordingly using floats. The maximum depth of water column at S1, S2, and S3 were recorded as 4.5,4.7 and 4.0 meters respectively. First set of sampling from S2 and S3 was done on 17th January and from S1 on 20th January. The second set of samples was collected on 15'" February, 1997. Water samples from bottom, middle and surface layers were collected using a water sampler and in-situ measurements of pH, temperature, TDS, salinity, conductivity etc. were taken in the boat itself using a portable water quality analyser. The bottles were rinsed with the lake water itself before the collection of samples. All the samples were later acidified with cone. $HN0_3$ for further laboratory analysis of major elements and heavy metals using Atomic Absorption Sectrophotometer. An additional set of sample was collected from each site for isotopic analysis. These samples were not acidified but sealed properly to avoid any inclusion of air bubbles. Since lake provides a 'summary' of the surrounding terrestrial environment, its character is strongly influenced by the 'inflow' water. Therefore, surface water samples from lakes inflowing into Priyadarshini were also collected for analysis. Similarly, the outflow from Priyadarshini and first, second and third lakes after Priyadarshini were sampled. For comparison, some of the lakes in the western Schimacher were also sampled.

In-situ water quality parameters are given in Table 6. The pH of the lake water ranges from 5.91 to 7.75. This suggests near neutral pH condition of the lake during the period of observation. At sampling site S1 and S2, the pH in the bottom water was high while the reverse was observed at S3. Such changes may reflect the chemical composition of bedrock sediments. Conductivity, TDS and salinity values were quite low in sampling sites indicating fresh water nature of the lake.

Table 6 : *In-situ* water quality parameters of lake Priyadarshini, Antarctica

Sample	Temp. (deg. C)	pH	Cond. (ms)	TDS (PPt)	Salinity (PPt)
Site S1					
Surface	6.5	5.91	2.68	1.34	2.01
Middle	5.8	5.98	2.69	1.34	2.01
Bottom	6.1	7.75	2.71	1.35	2.03
Site S2					
Surface	5.8	6.35	2.71	1.35	2.03
Middle	5.6	6.92	2.74	1.37	2.05
Bottom	6.4	7.05	2.67	1.33	2.00
Site S3					
Surface	5.7	6.92	2.71	1.35	2.03
Middle	5.9	6.86	2.72	1.36	2.04
Bottom	6.1	6.84	2.72	1.36	2.04

The concentration of major elements (Ca, Mg, Na, K) and heavy metals (Fe. Mn, Cd, Pb) concentration of sixteen representative samples are presented in Table 7. The concentration of major elements in these samples ranged from 0.19-1.58 ppm for Ca, 0.01-0.16 ppm for Mg, 1.33-14.19 ppm for Na and 0.27-1.56 ppm for K, which are very low with the exception of slightly higher values of Na. Tha spatial variation in abundance of major elements is most likely due to the morphometirc and hyrologic changes. The concentration of heavy metals in the samples in very low; the values range from 0.40-3.10 ppm for Fe, 0.10-0.29 ppm for Mn, 0.01-0.04 ppm for Cd and 0.05-0.43 ppm for Pb, indicating insignificant contaminant input in the lake water. The release of sorbed heavy metals from the sediments into the bulk water is dependent on partition coefficients, which in turn are related to sediments characteristics, the type of heavy metals, and other environment parameters (Ramamoorthy et. at., 1978). The heavy metals trapped at the sediment surface are constantly remobilized through decomposition and desorption at the sediment-water interface. Most of the metals are re-released to the water column because transport into the sediment by molecular diffusion is very slow. This release is not apparent in the water because the rate transport is so great that the released metal is effectively, diluted by the large volume of water in the lake to the background levels (Morfett et. at., 1998). The low values of the metal in the lake water may also be attributed to the fact that these lakes outflows during the summer period. There may be a steady state condition between inflowing and outflowing water, which may also be responsible for the very low concentration of the metal in lake water.

The hydro-geochemical work on lake water was essentially aimed at routine monitoring of the Lake Priyadarshini and its comparison with other lakes in the Schirmacher region. An additional angle was to establish correlation with Sediment geochemistry, particularly the heavy metal concentration. More correlation is expected in terms of isotopic analysis of lake water and sediments. The analyses are underway at BARC, Bombay.

Table 7 : Concentration of major and trace metals in lake water

Sample	Date	Major elements				Heavy Metals			
		Ca	Mg	Na	K	Fe	Mn	Cd	Pb
S1 (Bottom)	20/1/97	0.20	0.05	6.37	1.56	2.90	0.15	0.04	0.43
S1 (Middle)	20/1/97	1.00	0.06	8.86	1.03	3.10	0.12	0.02	0.13
S1(Surface)	20/1/97	0.19	0.06	14.19	0.76	1.80	0.15	0.01	0.05
S1(Bottom)	15/2/97	0.53	0.07	3.07	0.43	0.70	0.14	0.02	0.05
S1(Middle)	15/2/97	BDL	0.02	8.83	0.73	3.10	0.18	0.03	0.05
S1(Surface)	15/2/97	BDL	0.07	3.85	0.55	1.80	0.18	0.02	0.12
S1 (Bottom)	15/2/97	0.46	0.07	3.33	0.41	0.50	0.10	0.02	0.07
S1(Middle)	15/2/97	0.05	0.01	3.64	0.79	2.80	0.10	0.03	0.12
S3 (Surface)	15/2/97	BDL	0.08	2.77	0.37	0.40	0.13	0.02	0.12
Lake L5	17/1/97	0.57	0.16	8.67	0.85	2.10	0.17	0.02	0.11
Outflow L1	16/2/97	0.03	0.03	4.17	0.57	2.20	0.19	0.03	0.10

2nd Lake after outflow	20/1/97	0.29	0.09	3.27	0.67	1.67	1.12	0.03	0.13
Lake L4	17/1/97	0.02	0.05	1.99	0.63	2.40	0.29	0.03	0.09
Epsilon Lake	7/2/97	BDL	0.07	1.33	0.54	1.90	0.25	0.03	0.19
Lake L3	17/1/97	0.05	0.05	' 3.50	0.78	2.40	0.23	0.03	0.19
Lake55	31/1/97	'1.58	0.10	3.30	0.27	BDL	0.24	0.03	0.12

** BDL-Below detection limit*
*** Concentration in ppm*

Concluding Remarks

The thermal studies have given some interesting results on the thermal structure and heat budget of the Lake Priyadarshini. Further work on thermal behavior of the lake using long term and high resolution data set coupled with some meteorological data may be extremely rewarding to unravel many thermal and dynamic processes operating in Antarctica lakes alongwith the understanding of freezing and melting pattern of these lakes. As on date, the sedimentological and sediment geochemical work on sediment cores from Lake 91 and varve samples from the shore of lake 91 and Lake Priyadarshini is imcomplete. A complete synthesis of all the results would yield significant information about the depositional environment and post-depositional changes (if any) in the Schirmacher region. A major handicap at the moment is unavilability of 'dates' from the sediment cores and varve sampels collected during the expedition. The isotopic dating of the sediments cores and varve samples would be extremely valuable to delimit the time frame of depositional events. Efforts are on to carry out these analysis in collaboration with BARC, Bombay.

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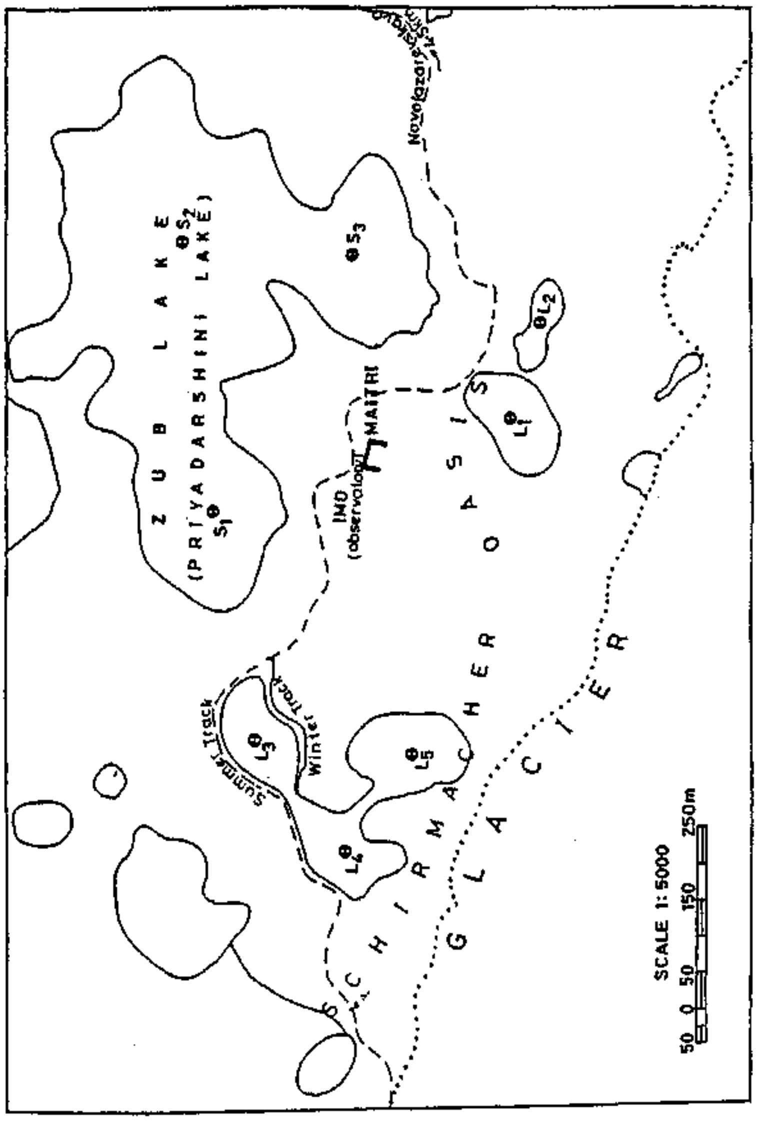

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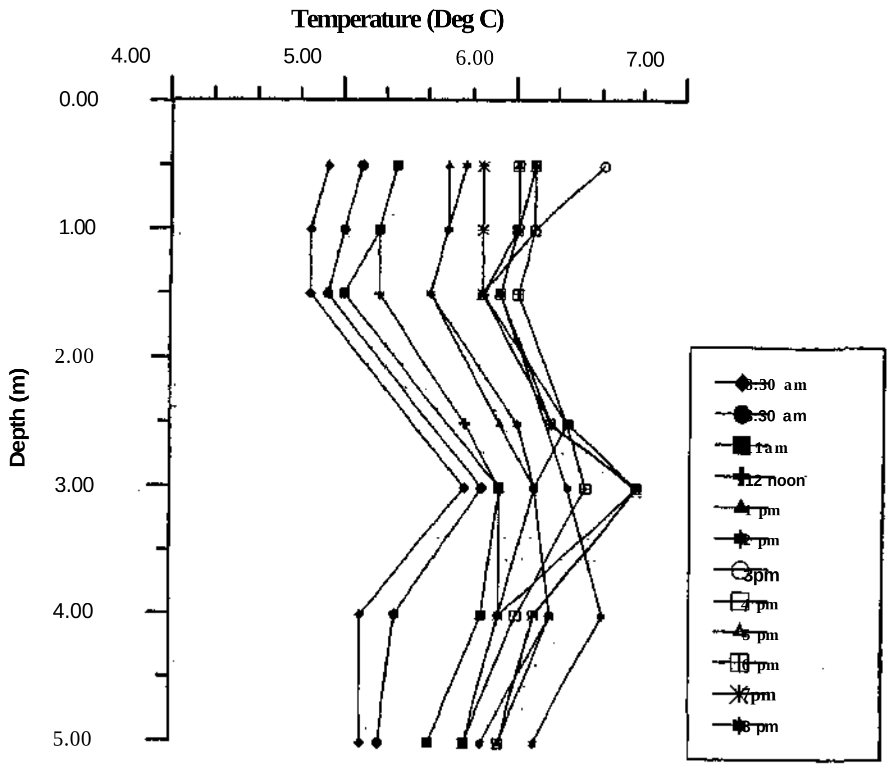

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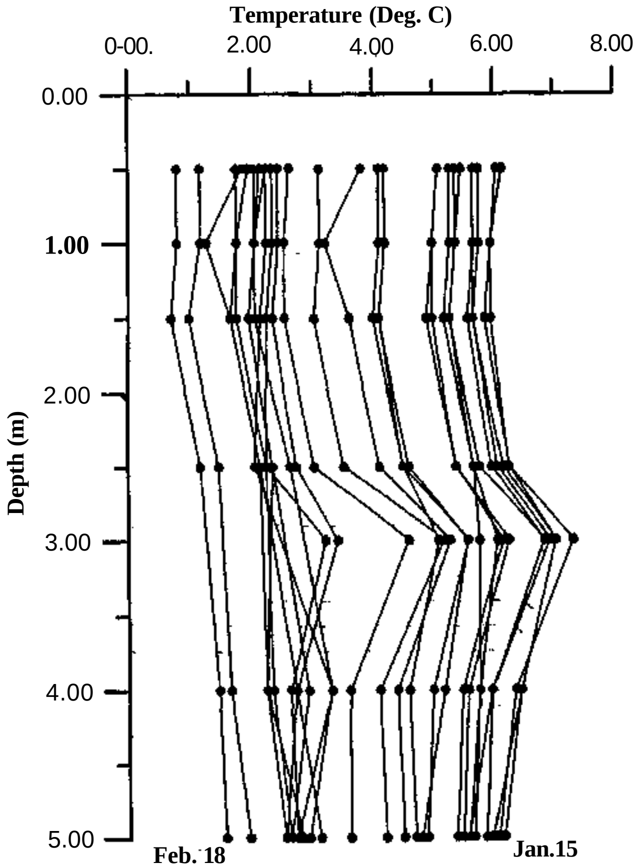

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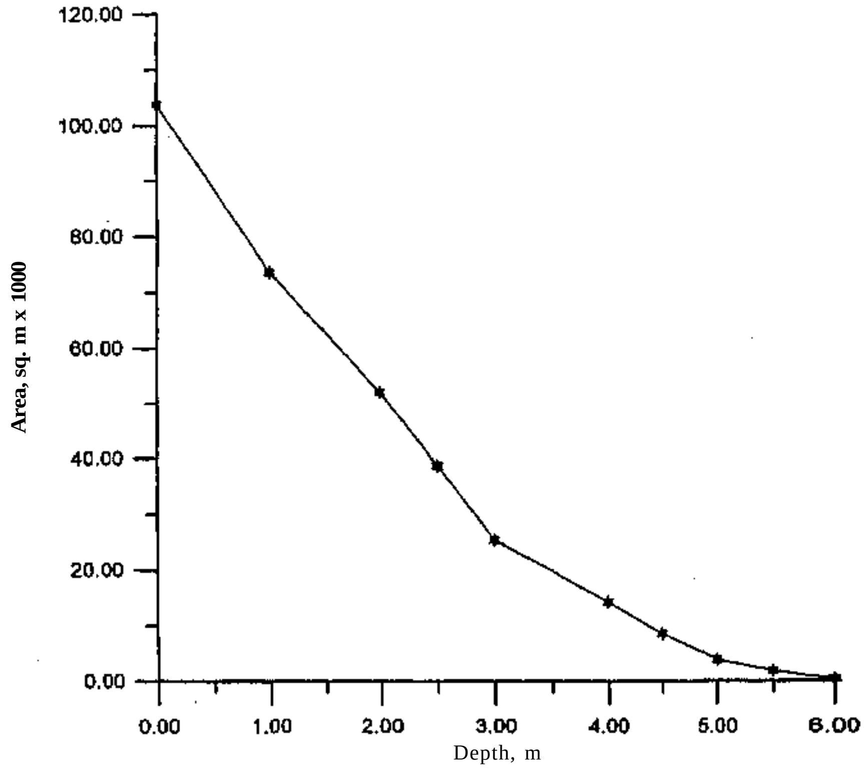

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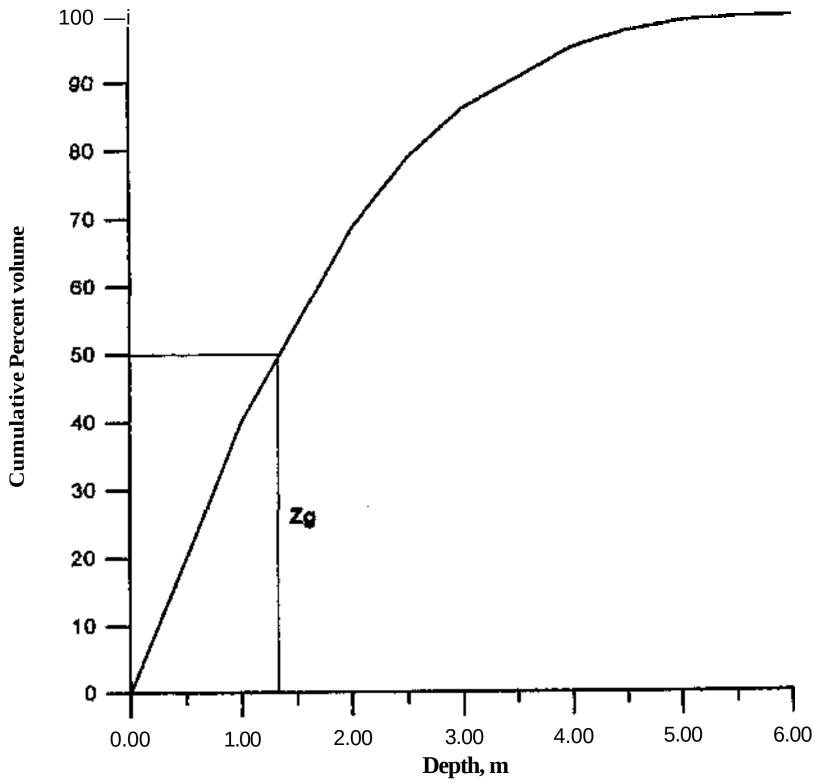

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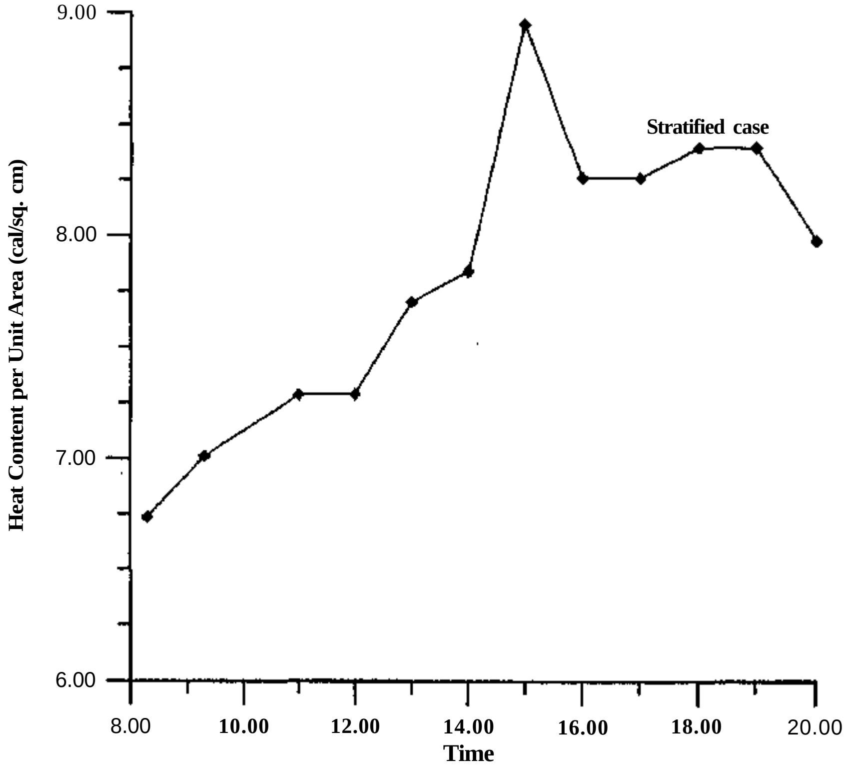

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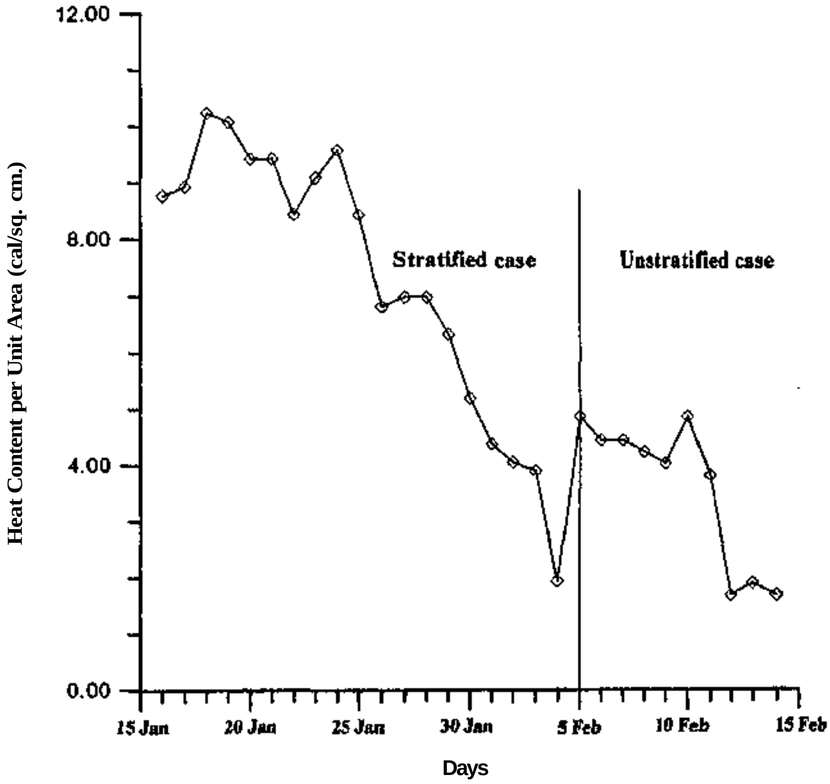

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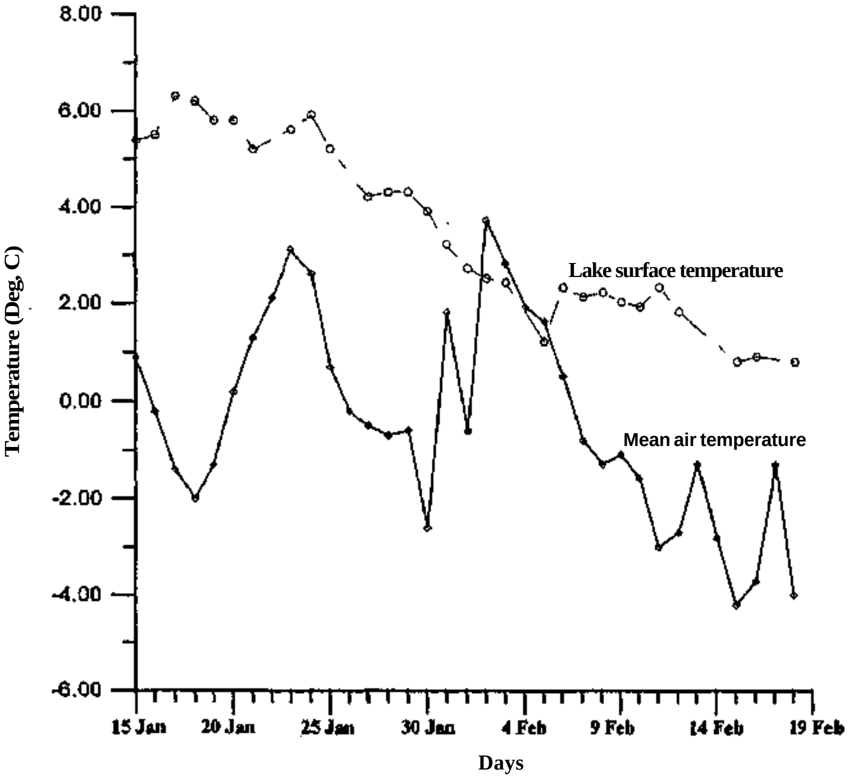

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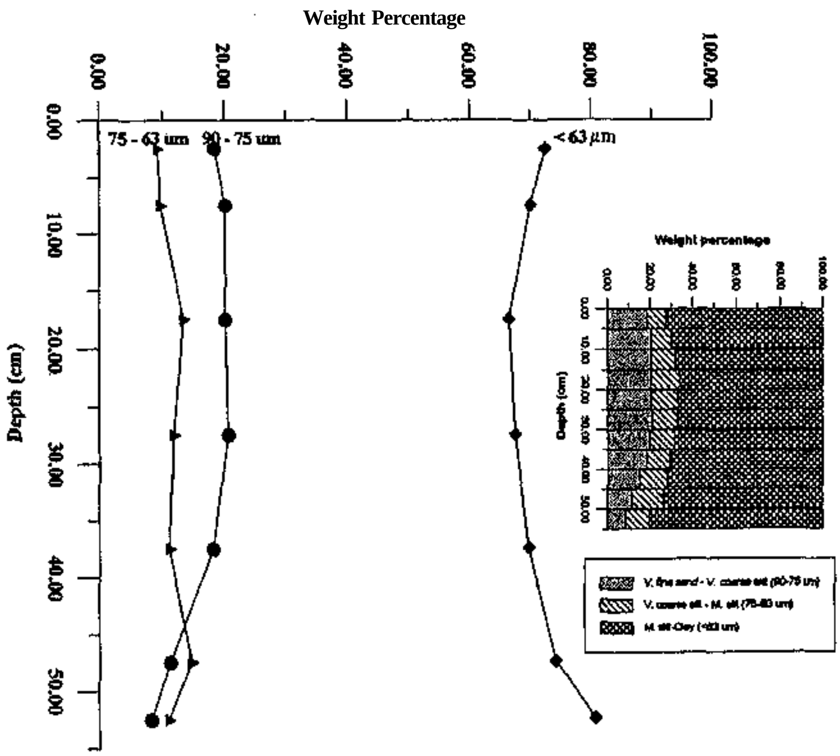

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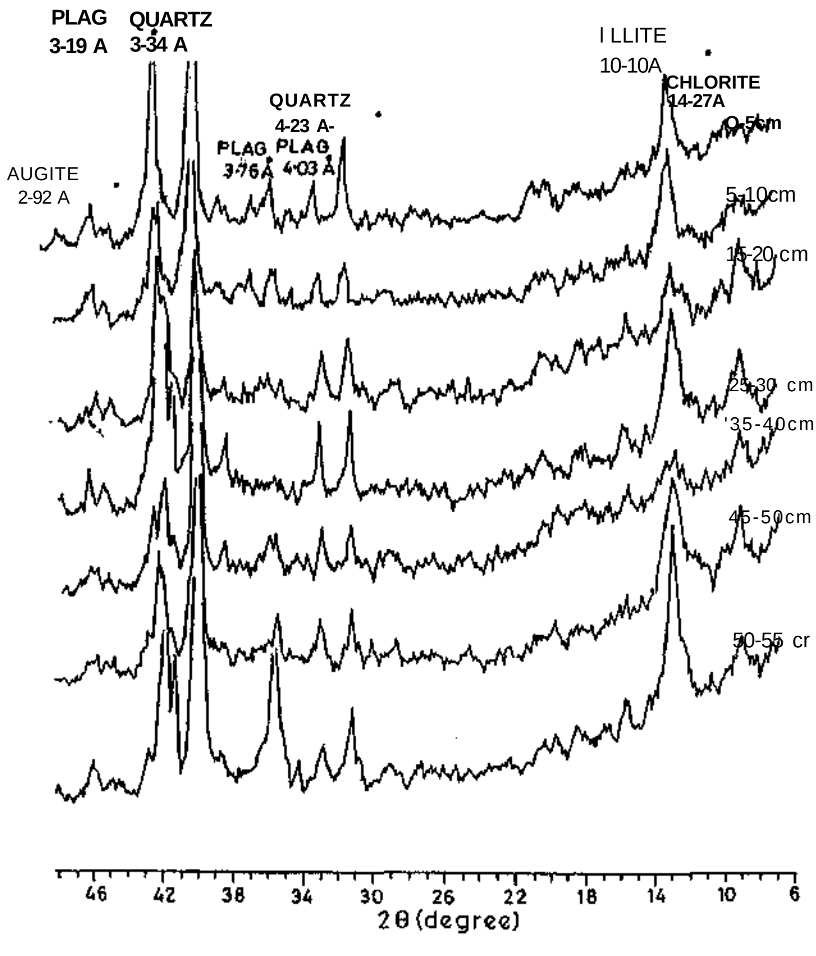

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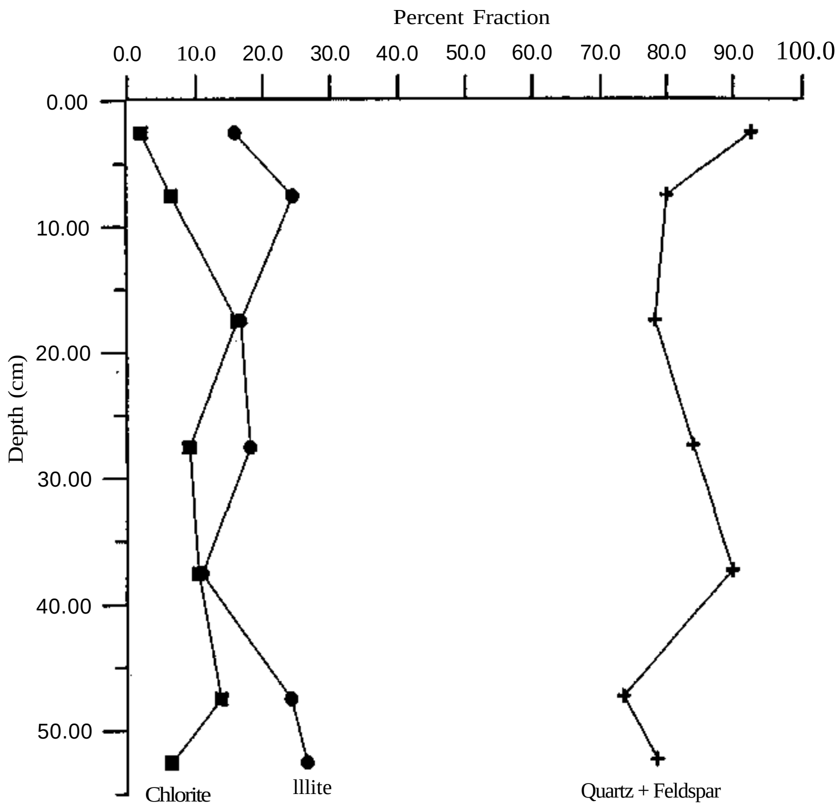

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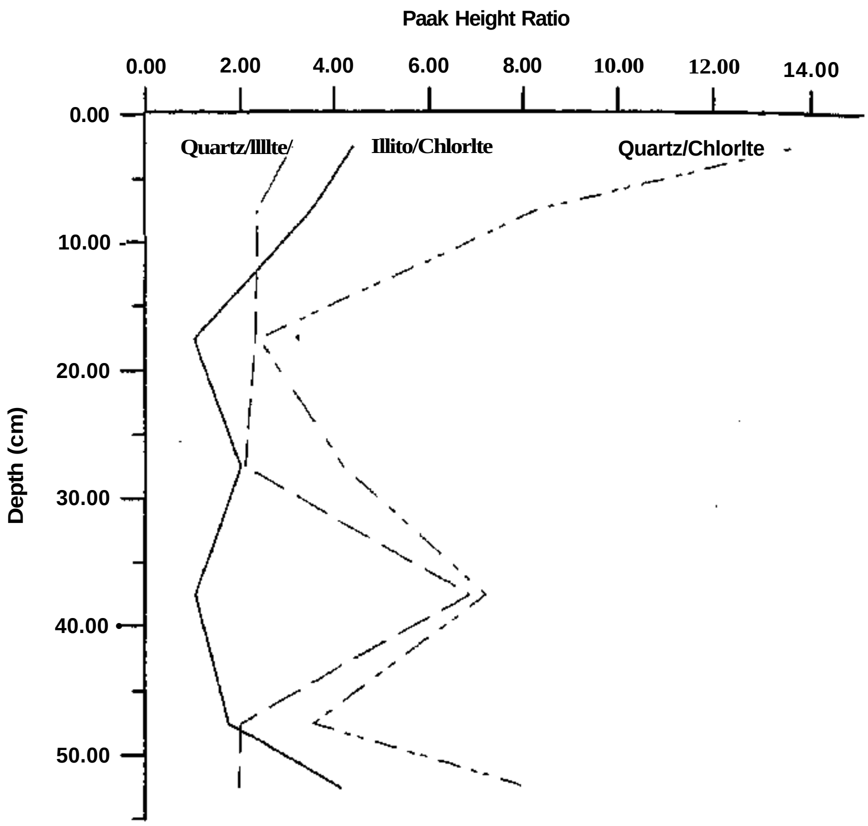

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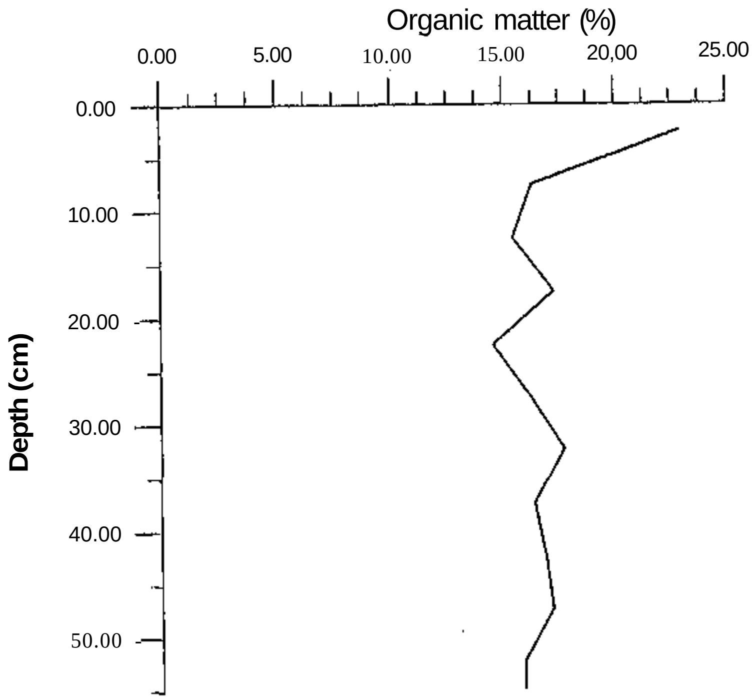

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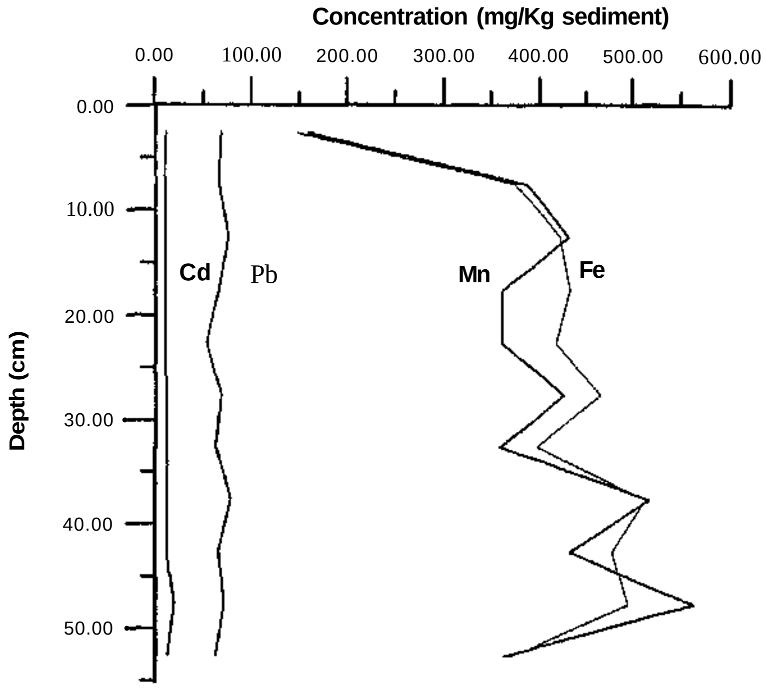

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