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ON THE SURFICIAL SEDIMENTS OF THE FRESH WATER NAINI LAKE, KUMAUN HIMALAYA, INDIA

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The 1.4 km long and 0.45-0.25 km wide crescent shaped Naini lake in the Nainital district of Kumaun Himalaya, India is divided by an east-west running transverse Central Ridge into two sub-basins. These northwest and southeast sub-basins are storehouse of clayey sediments brought by a number of gullies and streams from almost all the direction. The studies of major, trace and rare earth elements besides the valuation of total Carbon, Nitrogen, Organic Carbon, Calcium Carbonate and the Clay Mineralogy show that the surface sediments of these two sub-basins differ slightly. The general distribution of most of the analysed elements is higher in the Mallital (NW) sub-basin as compared to the Tallital (SE) sub-basin, the exception being Total C, Ca and Sr which show a reverse trend. This study will form a valuable source of information for the future environmental studies related to such an important water body for the natives.

Key Words: Surficial Sediments; Fresh Water Lake; Kumaun Himalayas

Introduction

The Naini Lake, situated at an elevation of 2000-2600m is surrounded by the lesser Himalayan Formation. The bathymetric study of this Lake was attempted by Rawat (1987) on the basis of measurements of depth along ten tranverses across the lake. A map of 5m isobath interval was prepared on a scale of 3 cm to 100m. Besides this, maps of the year 1895 and 1969 were also prepared[1] based on the data recorded by Holland (1895 in Rawat 1987)[1] and procured from the Public Works Department, Nainital. On the basis of this study Rawat[1] predicted that the lake would be completely silted up in 380 years. This and another similar study[2] became a matter of concern since the lake is the only source of drinking water to the Himalayan city. Therefore, in collaboration with the Kumaun University, Nainital, Hashimi *et al.*[3] took up the task of bathymetric exploration of the lake by using the Atlas Deso-10 dual frequency echosounder and the Motorola Miniranger III with a repeated accuracy of $\pm$ 3m for positioning. A new bathymetric map with 1m isobath interval was the outcome of these studies which revealed an approximately 100m wide east-west running transverse submerged ridge (7 to 20m below the water surface) separating the lake into southeastern or Talli-Tal and northwestern or Malli-Tal sub-basins. The depths vary in these two from 11 to 25m in Tallital sub-basin and 4 to 27m in Mallital sub-basins. The maximum thickness of sediment recorded with the help of ORE sub-bottom profiler (3.5 KHz frequency) extends upto 15m in both the sub-basins. Interestingly, records at some places show complete absence of any type of sediments. A number of gullies join the lake basin from almost all the direction (Fig. 1) albeit more numbers are from eastern side of the lake loaded with considerable amount of sediments.

To find out the nature of the surficial sediments of the lake basin, samples were collected during the bathymetric surveys from both the sub-divisions. These were

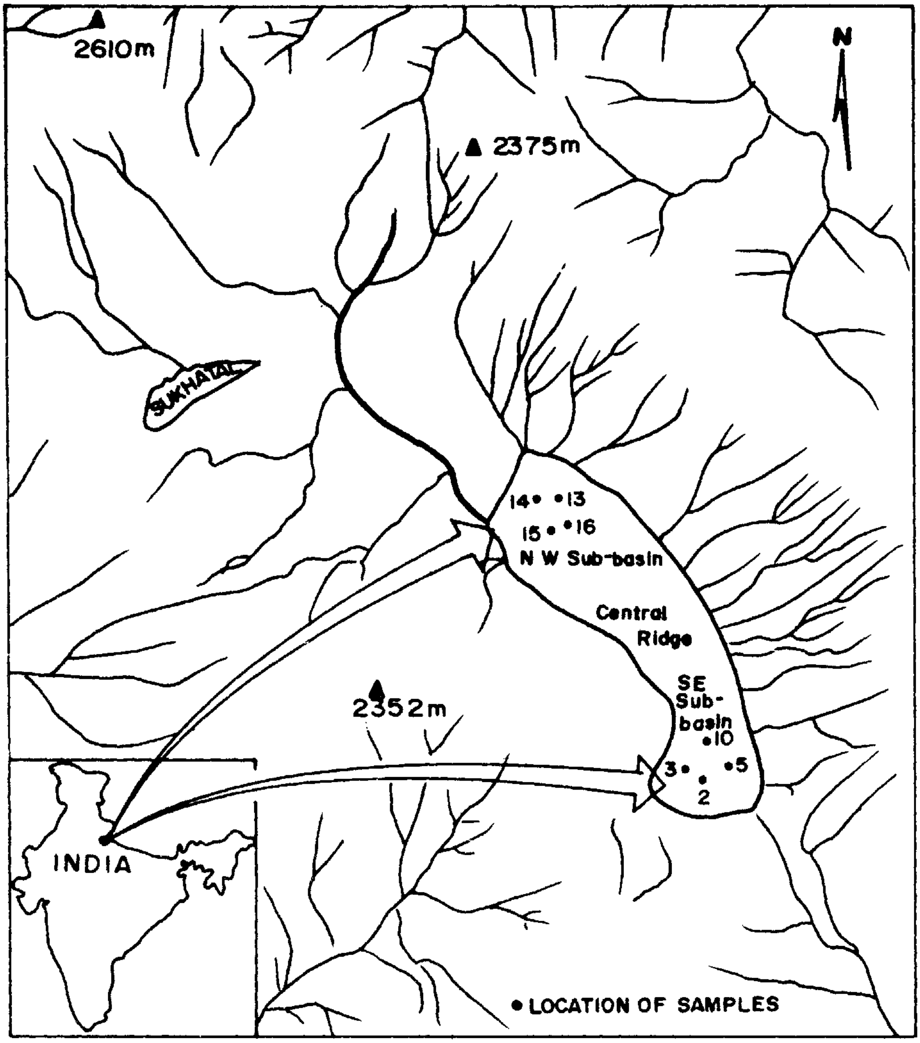

Fig 1 Location of the Naini Lake and drainage pattern

analysed for major, trace and rare earth elements alongwith the determination of total Carbon (inorganic and organic) and Nitrogen, Organic Carbon, Calcium carbonate and the clay mineralogy.

Geomorphology and Geology of the Catchment Area

The Nainital Hills form a synclinorium which is cut diagonally by a fault called Nainital Fault into two parts. The northwestern part is made up exclusively of argillaceous limestones and marlites whereas the southwestern part comprises of dolomite with limestones and black carbonaceous slates[4].

It is believed that the sub recent rotational movements were responsible for blockade of a stream called Balia, in its upper reaches, resulting in the formation of Naini Lake[4]. The Naini Lake (also the other lakes in the region) is related to neotectonic movements on the Main Boundary Thrust and with the genetically related faults.

Materials and Method

Eight sediment samples were collected during the bathymetric surveys of the Naini lake. Three sediment samples were collected by Van-Veen Grab, in the southeastern part or Tallital sub-basin and remaining sampels by gravity corer in the northwestern or Mallital sub-basin. For the present study only surface sections of the cores were used to keep the uniformity with grab samples.

All these sediments (clayey in texture) were oven dried, crushed into a fine powder in an agate mortar and their moisture content was determined. The aliquots were digested in a Teflon beaker using a mixture of HF, $HClO_4$ on a sand bath till a clear incipiently dried cake was formed. This was finally taken in 1 N HCl to provide 100 ml final solution. 75 ml of this solution was subjected for cation exchange chromatographic separation of rare earth element (REE) as described by Jarvis and Jarvis[5] and was analysed for major, trace and REE elements on a PE Plasma-400 ICP-AES sequential analyser.

Organic carbon was determined by El Wakeel and Riley's[6] method and later total Carbon and Nitrogen were analysed on a Carlo Erba 1106 Nitrogen Analyser. The organic carbon was calculated as the difference between total carbon and carbonate carbon, the latter was determined by using the Carbonate Analyser, with precision usually better than $\pm$ 1% in all cases.

The sediment samples were rendered free of organic matter by treating with Hydrogen peroxide for the clay mineral study and later oriented samples were prepared by pipetting the clay solution onto the glass slides and allowing them to dry in the air. These were scanned from 3° to 30° on Philips X-ray diffractometer by using nickel filtered Cu K_α radiations. To separate montmorillonite peak, the slides were glycolated and rescanned from 3°-20°, 2 θ. Weighted peak-area were used for semi-quantitative estimation of the amount of the mineral per cent[7].

Results and Discussion

Tables I (*a, b & c*) show the major, trace, REE and carbon contents in the sediments. Percentages of most of the analysed elements, except for total C, N, Ca and Sr (Tables I *a & b*) are higher in the Mallital sub-basin as compared to the Tallital sub-basin. Table I*c* however, shows the values of Carbon, Carbonate and Nitrogen being higher in Tallital sub-basin. The transverse Central Ridge dividing the lake into two sub-basins[3] could perhaps be responsible for this difference.

The distribution of Ca depends on biological remains and from minerals such as clay minerals and feldspars. The sediment collected was very fine grained and the coarse fraction obtained on 63 μm sieve showed few living biogenic remains consisting mainly of ostrocods, whose contribution for metal pool in the basin would be negligible. The possibility of detrital transport of Ca is ruled out due to its strong negative correlation with detrital minerals. It is evident, therefore, that there is some other source of deposition in the lake basin. The possible source of Carbonate, total Carbon and Organic Carbon perhaps could be decay of the tissues of fishes, weeds and *in situ* dissolution of the rocks. Total C and Organic Carbon have a linear

Table I*a*
Distribution of major and trace elements

Sample	AlO %	FeO %	MgO %	CaO %	MnO %	TiO %	Sr (ppm)	Zn (ppm)	Ni (ppm)	Cu (ppm)	Cr (ppm)	Ba (ppm)
NA-2	9.52	4.59	4.43	18.44	0.19	0.47	699	285	46	50	69	495
NL-3	8.87	4.43	3.65	23.04	0.13	0.41	900	315	42	54	68	490
NL-5	8.6	4.24	3.50	21.90	0.14	0.40	891	324	43	56	68	528
NL-14	11.81	5.84	4.27	11.1	0.18	0.56	353	494	56	75	92	591
NL-16	11.4	5.58	4.1	12.78	0.18	0.56	414	332	53	72	87	537

Table I*b*
Distribution of REE (ppm)

Sample	La	Ce	Nd	Sm	Eu	Gd	Dy	Yb	Lu	Ce/Ca	REE	Ce*
NL-2	29.3	61.0	24.9	4.92	1.06	4.23	3.46	1.52	0.22	2.02	132.6	0.02
NL-3	26.1	55.5	22.5	4.13	0.98	3.93	3.06	1.34	0.21	2.12	119.9	0.03
NL-5	27.0	54.5	23.6	4.32	0.96	4.50	3.14	1.31	0.19	2.02	121.5	0.01
NL-14	32.6	68.5	28.9	5.43	1.22	4.69	3.66	1.50	0.22	2.10	148.8	0.02
NL-16	34.3	71.1	29.0	5.69	1.28	4.80	3.84	1.64	0.22	2.07	153.9	0.03

Ce* = ce anomaly = log !ce/(2/3La + 1/3 Nd) ! based on shale normalised value. Elderfield *et al.* (1981)[9]

Table I*c*
Distribution of carbon and carbonate

Sample	Total C %	Total N %	Inorganic C %	Organic C %	$CaCO_3$ %	C/N
NL-2	7.72	37	3.44	4.28	31.9	20.86
NL-3	8.88	43	4.23	4.65	37.6	20.65
NL-5	9.25	49	4.25	5.00	36.2	18.88
NL-14	6.36	39	2.66	3.70	17.02	16.31
NL-16	6.32	38	2.31	4.01	19.21	16.63

relationship with the $CaCO_3$ contents. Their values increase with an increase in the $CaCO_3$ contents. The correlation matrix (Table II) shows Ca and Sr forming group A and the remaining elements forming group B. The two sub groups show a strong negative correlation with each other. Sr due to its similar ionic radii occurs associated

Table II
Co-relation matrix

	Al_2O_3	Fe_2O_3	MgO	CaO	MnO	TiO_2	Sr	Zn	Ni	Cu	Cr	Ba	La	Ce	Nd	Sm	Eu	Gd	Dy	Yb	Lu	Ce/Ca
Al_2O_3	1.00																					
Fe_2O_3	0.99	1.00																				
MgO	0.64	0.59	1.00																			
CaO	−0.99	−0.97	−0.69	1.00																		
MnO	0.70	0.64	0.95	−0.77	1.00																	
TiO_2	0.99	0.97	0.72	−0.99	0.79	1.00																
Sr	−0.99	−0.98	−0.70	0.99	−0.77	−0.99	1.00															
Zn	0.70	0.74	0.26	−0.68	0.24	0.59	−0.67	1.00														
Ni	0.99	0.98	0.64	−0.99	0.72	0.97	−0.99	0.75	1.00													
Cu	0.91	0.93	0.28	−0.88	0.39	0.85	−0.88	0.78	0.91	1.00												
Cr	0.98	0.99	0.49	−0.96	0.56	0.94	−0.96	0.79	0.97	0.97	1.00											
Ba	0.77	0.80	0.26	−0.79	0.36	0.69	−0.76	0.93	0.84	0.88	0.86	1.00										
La	0.95	0.92	0.65	−0.96	0.78	0.98	−0.96	0.48	0.94	0.84	0.90	0.65	1.00									
Ce	0.97	0.95	0.69	−0.96	0.77	0.99	−0.98	0.51	0.95	0.84	0.92	0.63	0.99	1.00								
Nd	0.97	0.96	0.63	−0.99	0.74	0.98	−0.99	0.62	0.98	0.90	0.95	0.77	0.98	0.98	1.00							
Sm	0.94	0.91	0.73	−0.96	0.84	0.98	−0.96	0.46	0.93	0.79	0.88	0.63	0.99	0.98	0.98	1.00						
Eu	0.97	0.95	0.63	−0.96	0.72	0.99	−0.97	0.52	0.94	0.87	0.93	0.65	0.99	0.99	0.97	0.97	1.00					
Gd	0.74	0.73	0.29	−0.80	0.53	0.74	−0.77	0.51	0.80	0.82	0.79	0.79	0.83	0.75	0.86	0.80	0.77	1.00				
Dy	0.92	0.88	0.73	−0.94	0.85	0.97	−0.95	0.40	0.91	0.76	0.85	0.58	0.99	0.98	0.96	0.99	0.97	0.79	1.00			
Yb	0.80	0.75	0.79	−0.81	0.87	0.88	−0.83	0.15	0.76	0.56	0.68	0.30	0.91	0.92	0.83	0.93	0.90	0.59	0.95	1.00		
Lu	0.71	0.69	0.87	−0.68	0.75	0.76	−0.72	0.26	0.65	0.40	0.58	0.18	0.67	0.75	0.62	0.71	0.72	0.16	0.72	0.81	1.00	
Ce/Ca	0.34	0.34	−0.08	−0.19	−0.27	0.24	−0.23	0.47	0.26	0.43	0.40	0.22	0.10	0.22	0.15	0.04	-0.25	−0.17	0.02	−0.01	0.35	1.00

with the calcite, explains Sr's strong positive association with Ca. Al, on the other hand is an index element for the terrigenous source. The strong positive association of trace metals like Ni, Cu, Cr and Ba with detrital elements like Al, Fe, Mg and Ti indicates their detrital origin.

The black, fine clayey sediments at the time of collection had a strong odour of hydrogen sulphide, indicating prevailing anoxic conditions at the bottom of the lake. Total Carbon content shows almost equal percentages of carbonate carbon and organic carbon contents, the latter originated perhaps due to degradation of weeds and other biogenic remains.

The rare earth elements (REE) provide information as tracers of element source and reactivity. Total REE content in the Mallital sub-basin is higher (average 149.5 ppm) as compared to the Tallital sub-basin (average 123 ppm). All the REE show strong positive correlation (Table II) with Al, Fe, Ti and Mg suggesting their association with detrital component. The Shale normalized (North American Shale Composite: NASC) values of REEs in the basin (Fig. 2) show flat distribution patterns which normally is associated with the terrigenous source. Further, shale normalised pattern shows enrichment of light REE (LREE) compared to heavy REE (HREE). On the other hand, the chondrite normalised REE patterns for all the sediments (Fig. 2) analysed exhibit nearly similar distribution of REEs as that of NASC, indicating a lithogenous or detrital source. The only distinct fractionation could be seen for Eu which exhibits moderately negative anamoly. The reducing or anoxic conditions as revealed by high Organic carbon content (~4.5%) and presence of strong H_2S odour in the sediments might promote reduction of Eu^{+3} to Eu^{+2} followed by upward migration to release the reduced Eu back to water column[8]. The non oxidising environment also could be supported by nearly flat pattern without any significant anomaly in Ce distribution (Fig. 2, Table I*b*)[9].

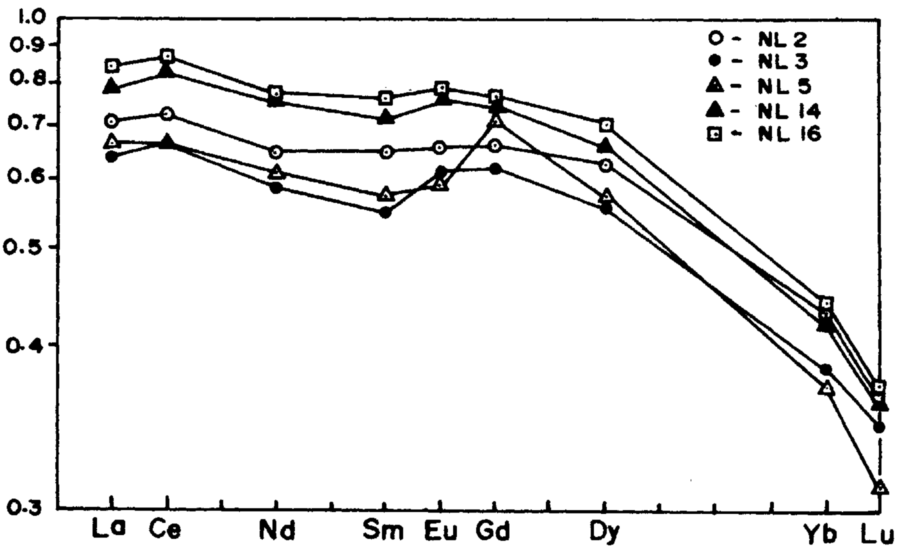

Fig 2 NASC normalised REE pattern in the sediments

The clay mineral assemblage consists of montmorillonite, illite, kaolinite and chlorite besides the mixed layer minerals, which are typical high altitude clays. To find out the distribution pattern the weighted peaks of montmorillonite, illite and kaolinite + chlorite were considered[7]. Illite is the most abundant clay mineral followed by kaolinite + chlorite and montmorillonite. The general distribution pattern (Table III) of these minerals does not show much variation. There is also very little variation in the percentage of these minerals in the two sub-basins except for little variations in the montmorillonite. This similarity in the mineralogy of two basins could be due to the mixing of the sediments brought by a large number of gullies into the lake from the surrounding rocks.

Table III

Clay mineralogy

Sample	Depth (m)	Moisture %	Sampler used	Montmorillonite %	Illite %	Kaolinite + Chlorite %
NL-2	11.0	1.06	Grab	15.9	52.2	31.9
NL-3	16.1	1.07	Grab	13.5	54.0	32.3
NL-5	11.4	0.18	Grab	11.8	68.8	19.4
NL-10	20.5	1.14	Corer	0.7	51.1	48.2
NL-13	26.3	1.15	Corer	3.0	52.1	44.9
NL-14	23.0	0.92	Corer	1.8	29.1	69.1
NL-15	25.9	1.25	Corer	11.4	57.1	31.4
NL-16	25.8	0.98	Corer	11.0	54.8	34.2

Above evidences show that the material received through gullies disperses and degrades as fine clay particles into the lake basin. The depth of the sub-basin in the northwest end of the lake is unusually more (19-20m) although it receives maximum sediments through largest gully. Bathymetric study showed that there are also some areas which do not show any trace of sediment accumulation[3]. Neither there is much change reported in the bathymetric profile of 100 years. The present study also shows the fine nature of the bottom sediments. This indicates that the material received through large gullies gets degraded rapidly due to bottom environment. Therefore, it could be speculated that the lake is not shallowing at a rate reported by the earlier investigators. The possibility exists that the lake floor is still subsiding approximately at the same rate it receives the sediments.

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