

## Bathymetric Study of the Neotectonic Naini Lake in Outer Kumaun Himalaya

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**Abstract:** The Naini lake is a product of rotational movement on a NW-SE trending Nainital Fault, quite after the establishment of the drainage of a mature stream named Balia Nala. Detailed bathymetric study, permits division of this crescent-shaped lake into two subbasins separated by an approximately 100 m wide transverse underwater ridge, 7 m to 20 m below the lake surface. The southeastern and northwestern parts, 11 to 25 m and 4 to 27 m deep, respectively, are filled with unconsolidated sediments, 15 m thick on an average. The semiconsolidated sedimentary layers locally exhibit slumping on slopes and deformation in channel beds. These features together with the transverse Central Ridge, the deep channel cutting through it, the small scarps and terraces or step-like features on the slopes of the narrow V-shaped underwater valley in the southeasiern part and its thick filling in parts due to blockade resulting presumably from fault movements, and the existence of deformed and displaced acoustic reflectors are interpreted as indicating quite recent movements along the Nainital Fault. Hitherto unidentified pinnacle-like objects penetrating through or perched atop sediments, are suggestive of either tectonic displacement and squeezing or of the hazard of mass movements which have occurred. A number of small but rapidly growing deltas along shores indicate accelerated pace of sediment input, resulting from quickened erosion in the catchment area.

**Key words :** Naini Lake, Neotectonism, Bathymetric Study, Kumaun Himalaya.

### INTRODUCTION

The 2000-2600 m high Nainital Hills, forming the southern front of the Kumaun Himalaya (Figure 1), is characterized by a complex tectonic architecture related to recurrent movements on the active Main Boundary Thrust and related tear faults (Valdiya, 1981, 1988). The Naini lake is the product of neotectonic rotational movements along one of these faults which have caused impoundment in the upper reaches of the mature stream named Balia. The Naini-Balia basin is experiencing serious hazards of recurrent mass-movements and resultant rapid filling of the lake. Indiscriminate construction activities and disconcerting indifference of the people towards proper disposal of wastes and

pollutants have aggravated environmental deterioration of the Naini Lake.

The present collaborative study first of its kind in the Himalaya was undertaken to gain insight into the underwater topography, the magnitude of sediment-filling and to the signatures of movements on the active Nainital Fault that gave rise to the lake. The team has achieved the crucial objective of obtaining a picture of the underwater topography to serve as the base-line for future comparison.

### GEOLOGICAL SETTING AND TECTONICS

The structure of the lake basin is extremely complicated, as would be evident from its varied portrayal by earlier workers (Middlemiss,

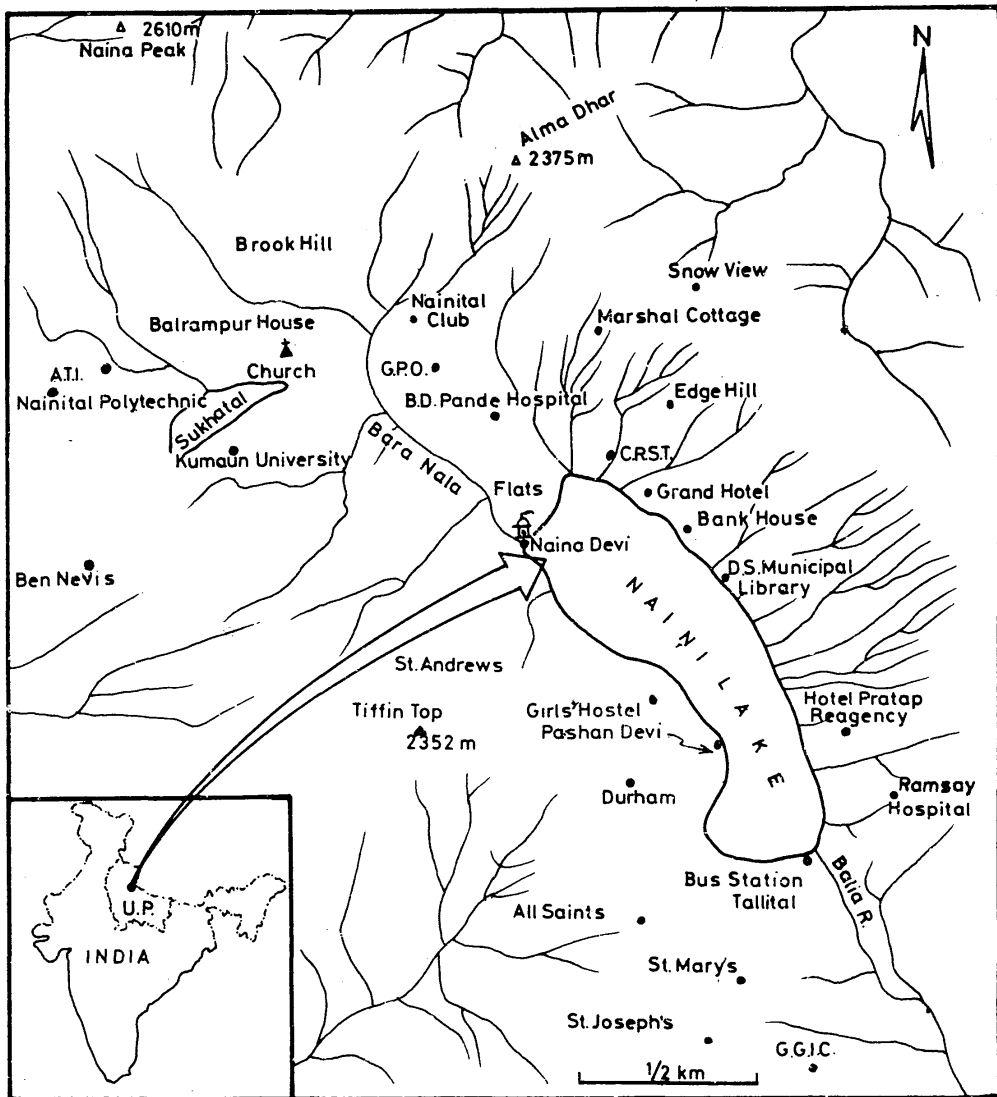


Fig. 1 Location of the Naini lake in the frontal range of the Kumaun Himalaya. Gullies descending transversely and the Bara Nala have been dumping sediments with pollutants of all grades in large quantities (After Valdiya, 1988).

1890; Hukku *et al.*, 1974; Pande, 1974; Fuchs and Sinha, 1974; Sharma, 1981; Valdiya, 1988). The synclinal Nainital Hills (Figure 2), comprising complexly tightened and faulted folds, is diagonally cut by the Nainital Fault into northeastern Naina Peak - SherkaDanda Ridge made up almost exclusively of the Lower Krol and the southwestern Deopatta - Ayarpatta Ridge

constituted of the Middle and Upper Krol with the Tal (Valdiya, 1988). The Lower Krol consists of argillaceous limestones and marlites, while the Upper Krol and Tal are made up of dolomites with limestones and black carbonaceous slates.

The study area is a much faulted terrain (Figure 2). The NW-SE trending Nainital Fault

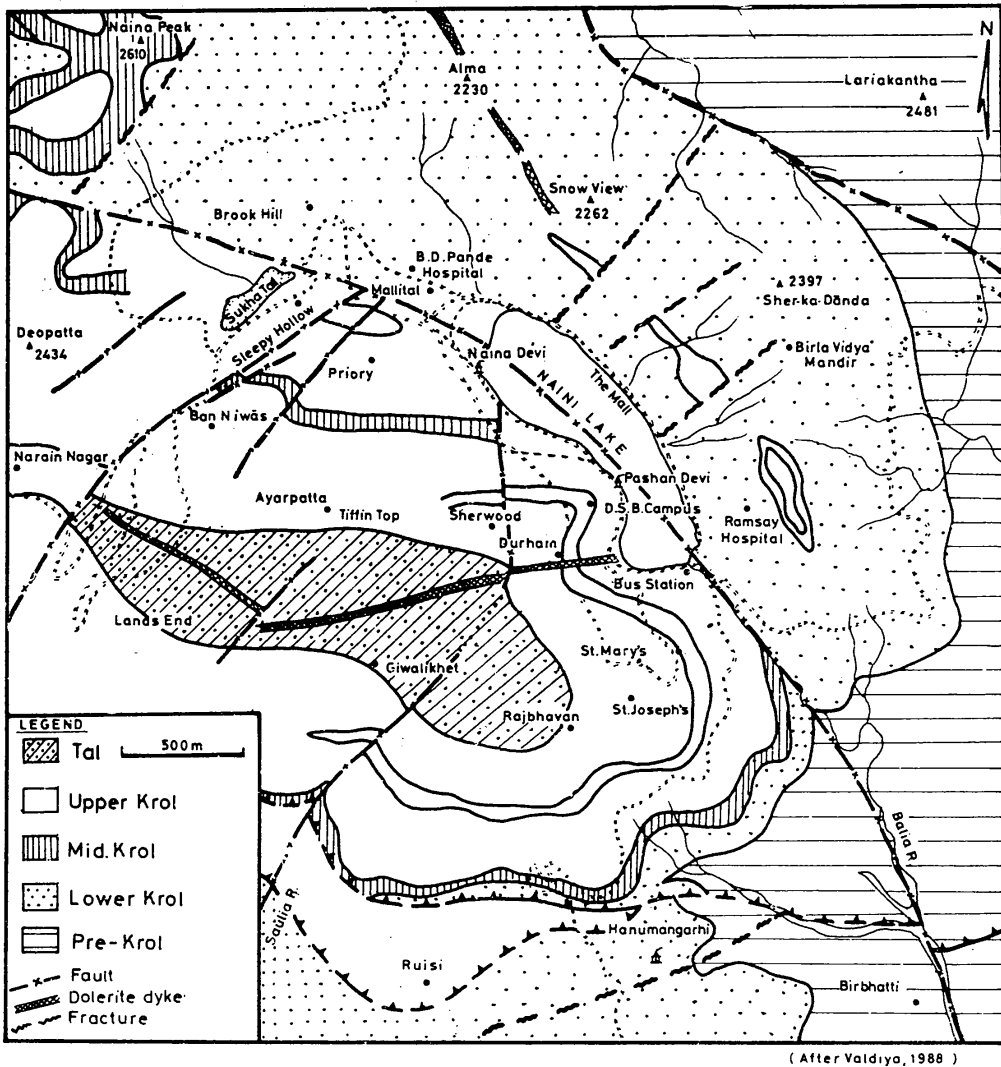


Fig. 2 Simplified geological map of the Naini basin brings out its much faulted nature (After Valdiya, 1988)

follows the valley of the Balia and through the lake basin. Quite after the establishment of the drainage of the mature Balia Nala, subrecent movements of the order of 20 m to 80 m within the lake basin caused the uplift of the north-eastern SherkaDanda Range relative to the Ayarpatta Ridge. The rotational movements was responsible for the blockade of the stream in its upper reaches, resulting in the formation of the lake (Valdiya, 1988). Then there are other active faults which, likewise, gave rise to

many lakelets, now completely filled up with sediments.

The Nainital massif was uplifted *en bloc* as a consequence of movement on the Main Boundary Thrust (MBT), triggering extensive mass-movements and gravity gliding on over-steepened slopes. The lake of the Nainital district (Khurpa, Naini, Bhim, Naukuchia and Sat "tals") are likewise related to neotectonic movements on the MBT and the genetically related faults (Valdiya, 1988).

## GEOMORPHOLOGICAL LAYOUT

Morphological analysis of the Naini basin has been carried out by Hukku *et al.* (1974), Sharma (1981) and Khanka and Jalal (1984). The 21- km<sup>2</sup> basin of the Naini lake (Figure 3) is surrounded by hillslopes having the mean slope of 19°, the larger part being confined to the slope group of 20° to 25° and the maximum value reaching 47° to 49° (Rawat, 1987). The mean value of the Snow View - SherkaDanda Ridge slopes is 5° to 35° (mean 18°). In many places the slopes exhibit convex bulges resulting from continuing creep movement. The slopes are locally broken by scarps and fringed at the base by a succession of debris cones and fans.

The average precipitation in the lake basin in the period 1965-1980 was 207 cm/year (Sharma, 1981). Emanating from the debris fans at the foot of the Naina Peak, the feeder stream Bara Nala derives the larger part of its discharge from the "Parada" spring, pouring out water at the rate varying from 574 to 141 gallons/minute (Sharma, 1981). Some of the transverse gullies also derive their discharge from springs.

## UNDERWATER TOPOGRAPHY

### Previous Attempts

Reconstruction of bathymetry of the Naini Lake was attempted by Rawat (1987) on the basis of measurements of depth along many traverses across the lake (Figure 4). Prepared from the depth data for the years 1895, 1969 and 1979, these maps revealed the existence of a 100 m long transverse ridge at the mean depth of 18.55 m, subdividing the lake into two parts, and of the presence of knolls (possibly fallen blocks). Comparison of the maps indicated progressive reduction in the lake capacity due to accumulation of sediments — 5500 m<sup>3</sup> in 80 years at the rate of 67 m<sup>3</sup>/year in the interval 1895-1969 and 78 m<sup>3</sup>/year during 1969-1979 (Rawat, 1987). According to Sharma (1981), the data for the period 1960-1977 showed accumulation of 0.377 million m<sup>3</sup> of sediments

in just 17 years at the rate of 0.022 million m<sup>3</sup>/year. It is quite evident that the lake is being filled up at a brisk rate. This is also evident from the growing fronts of 23 deltas identified (Valdiya, 1988).

### Present Bathymetric Study : Methodology

The bathymetric and shallow acoustic data were collected in November 1989 along nearly equi-spaced (10-15 m) E-W and N-S transects having aggregate length of 45 km. Using the main sounding line in the east-west direction - practically normal to the configuration of the lake shore - the bottom topography was studied. The positions of the survey boat carrying echosounder, sub-bottom profiler and side-scan sonar were continually fixed with the help of earlier installed Motorola Miniranger III having repeatable accuracy of ± 3m. The Atlas Deso - 10 (dual -frequency channel of 30 and 210 KHz) echosounder recorded the depth and the ORE sub-bottom profiler (3.5 KHz frequency) penetrated the bottom of the sedimentary accumulation. In the laboratory on the basis of the position-data records a track map on the scale of 1:2000 was prepared, in order to construct the base-map for the lake. The datum base level of the soundings is that of the lake for the survey period in November 1989 i.e. 3.28 m above the bottom level of the sluice gate located at Tallital at the southern end. The echosounder records were digitized and plotted at the corresponding fix locations and presented in the form of the bathymetric map, with contour interval of one metre. Similarly, the records of the sub-bottom profiles of every transect were examined to identify underwater features.

### BATHYMETRY AND TOPOGRAPHY

Bathymetric mapping of the lake floor (Figure 5) has resulted in gaining a detailed topographic data-base of crucial import, both for tectonic interpretation and future comparison. Quite a few hitherto unknown relief forms have been located on the lake-floor. Since the soundings were spaced very closely, a topographic portrait at the 1-m contour interval has emerged (Figure 5).



Fig. 3 Naini lake is a result of rotational movement along the fault that follows the valley between the uplifted Naina Peak - SherkaDanda Range to the left (east) and relatively subsided Deopatta - Ayarpattia Ridge to the right (west). Note the convex bulges on the slope. View from northwest due southeast. (From Sharma, 1981).

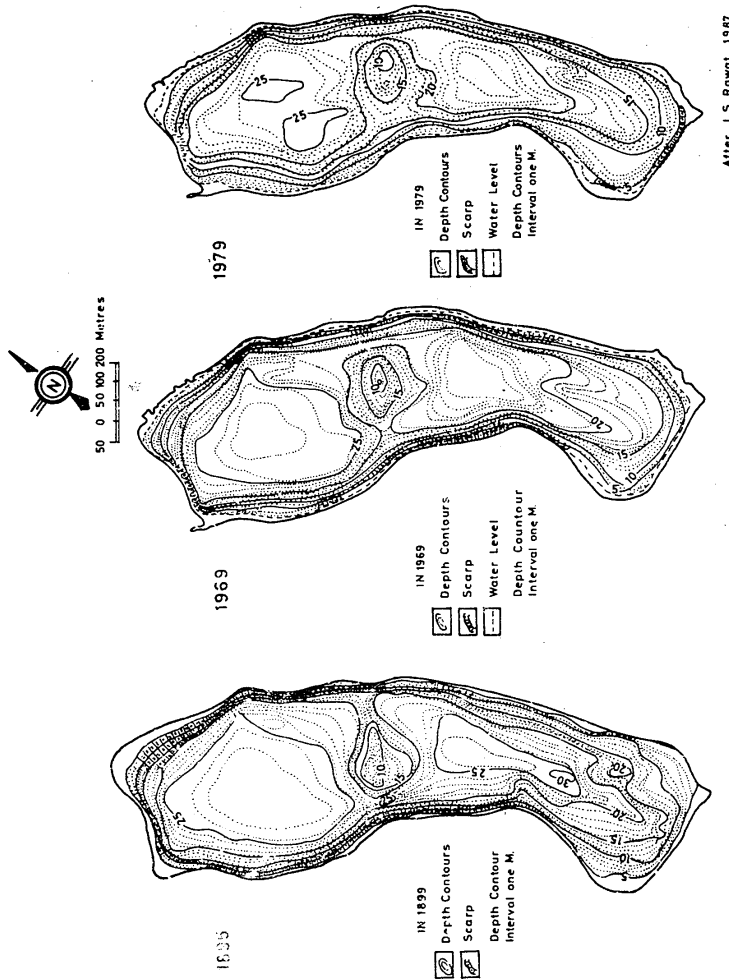


Fig. 4 Previous attempts at gaining insight into the underwater topography of the lake were based on the depth data for the years 1895, 1969 and 1979 (From Valdiya, 1988, modified after Rawat, 1987).

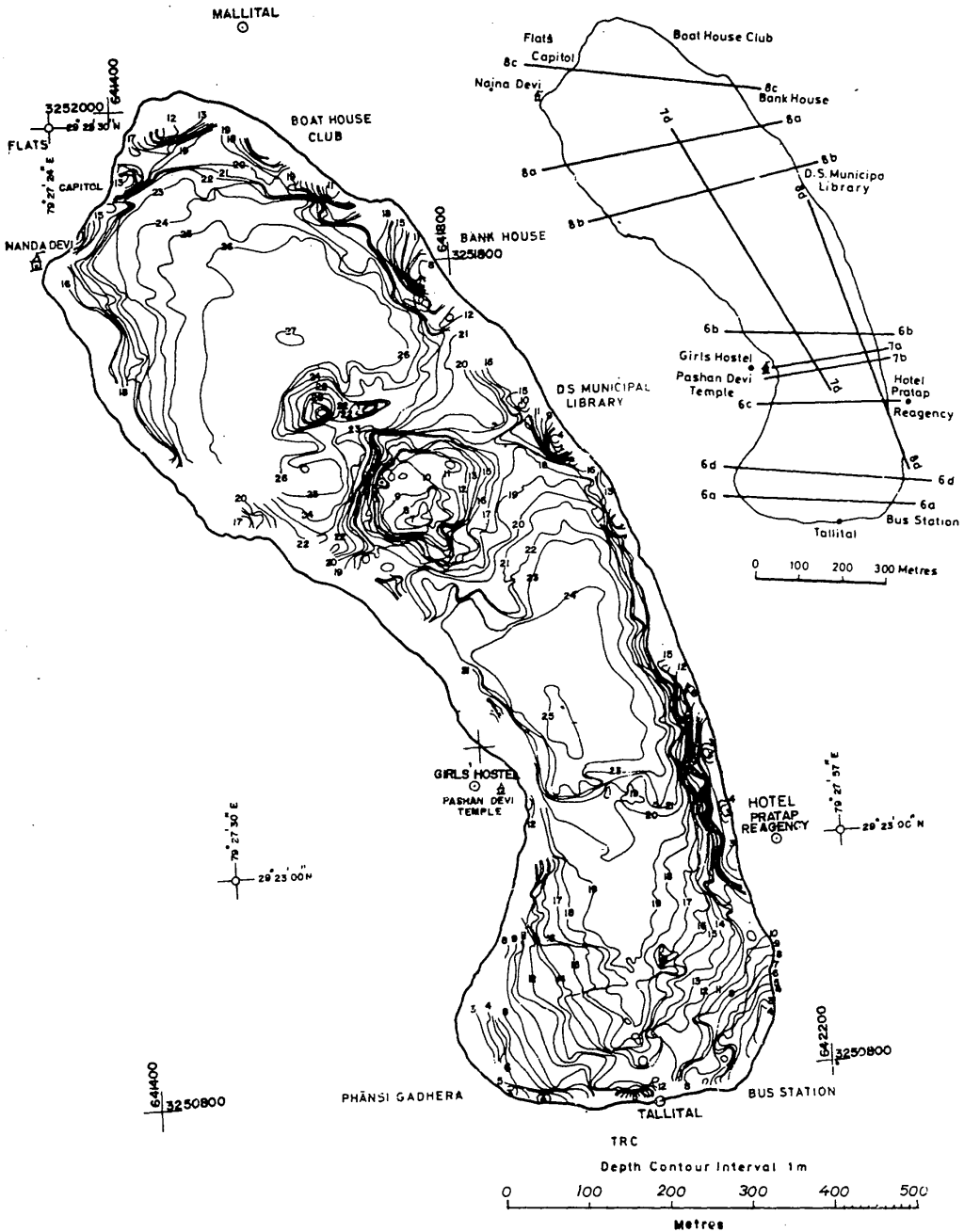


Fig. 5 Bathymetric map of the Naini lake prepared from the present survey, using sophisticated echosounder, sub-bottom profiler, side-scan sonar with position fixing Motorola Miniranger.

The survey shows that the NW-SE oriented crescent-shaped lake is divided by a ridge into two sedimentary subbasins, a feature recognised in 1979 as well. In terms of topography and general gradient, the lake-floor may be described under four parts or segments i.e. (i) southeastern or Tallital subbasin, (ii) the northwestern or Mallital subbasin (iii) the Central Ridge, and (iv) the deltaic deposits along the shores.

### **Southeastern or Tallital Segment**

The lake floor is characterized by a narrow valley with steep slopes and very irregular bottom. The isobaths run parallel to the shore and trend commonly in the N-S direction up to the Pashan Devi Temple and then change to the NW-SE direction. The convergence of bathymetric contours towards the southeastern end along the shore (Figure 5) establishes the steepness of the slopes at the bottom. The echograms suggest presence of blocks of rocks of varying heights on the floor. It is evident from these profiles that the topography is irregular and dominated by highs and lows. Presence of a distinct V-shaped valley with steep sides ( $60^\circ$  in east and  $80^\circ$  west) is recognised. This valley must have served as a channel for swift-flowing currents before it was dammed, giving rise to the lake. It is now covered with a thin layer of sediments (Figure 6a). The width-depth ratio of this valley decreases rapidly downstream.

The northern part of this depression (channel) broadens funnel-like on the meander "plain", towards the dividing Central Ridge. This part has been filled thickly with the sediment brought by the tributary streams so that a flat-top sedimentary fill has formed. The depth of the depression varies from 11m at the southeastern (Tallital) end to 35m in the proximity of the Central Ridge. Furthermore, the echograms show sliding and slumping of the sediments on steeper ( $75^\circ$ ) irregular slopes (Figure 6b). Prominent scarps with gentler base are indicated on the echograms in this segment (Figure 6a). Significantly, the shape

of these scarps are by and large very similar. The sub-bottom extension of the scarps are revealed in the shallow acoustic records (Figure 7d).

It is inferred that the bathymetry of the southeastern segment of the lake is structurally controlled. A number of step-like features are discernible on the echograms at various depths, more prominent at the depth of 16m (Figure 6c). These features or terraces are probably related to slumping of the cover layers or possibly due to recent step-faulting. Locally, blocks of rocks reaching above the general level of the lake bottom are suspected. These blocks are restricted to the western and northwestern shores of the Tallital part of the lake. Near the Pashan Devi Temple (Figures 7a & 7b) sharp pinnacles, seemingly protruding up from the lake-floor at depths of 24.6 m to 18.4 m, have partitioned the lake floor into two or three valleys. North of the Pashan Devi the "pinnacles" along with the lake floor are covered with a mantle of unconsolidated sediments (Figure 7). These "pinnacles" presumably represent uplifted slivers of sheared rocks adjacent to the active Nainital Fault, leading to the inference that the bathymetry of the southeastern segment of the lake is controlled by neotectonic movements.

### **Northwestern or Mallital Segment**

The Mallital segment of the lake-floor is wider than that in the Tallital side. The isobaths here run parallel to the shore-line, trending in the northwest-southeast direction (Figure 5). The topography resembles the shape of a bowl. More than 5m penetration achieved by the echosounder shows that the area is covered with unconsolidated clay sediments (Figures 8b & 8c). Blocks of rocks or debris dumps seem to be protruding through the sediments (Figure 8a), the slope of which is steeper than that of the western shore. Terrace-like features are developed almost continuously along the northeastern shore (Figure 8a). On the E-W transect south of the Boat House Club, presence of an escarpment is indicated (Figure 8b).

The depth of these subbasins ranges from 4m



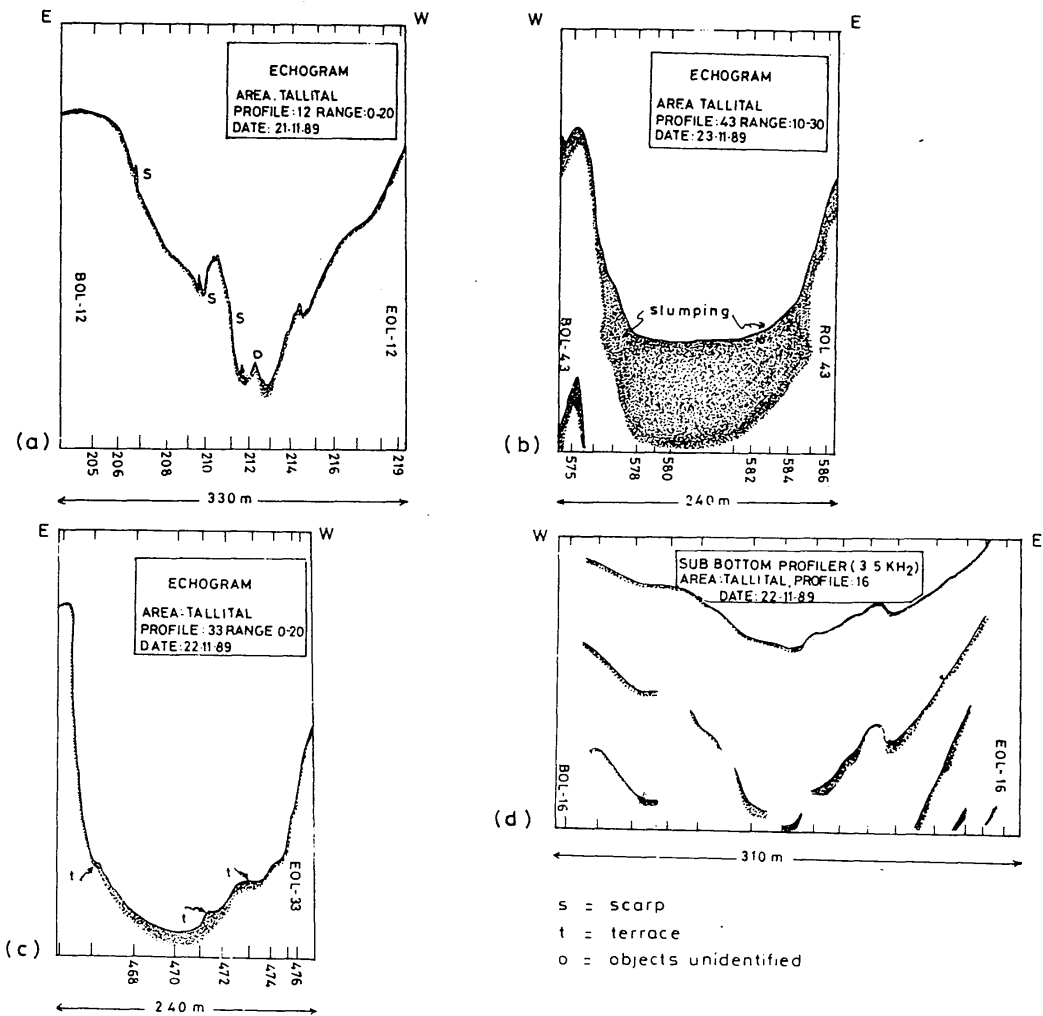


Fig. 6 Shape of the bottom of the southeastern part of the Naini lake portrayed in echograms drawn to scale.

- (a) Narrow V-shaped underwater valley profile showing steep slopes with local scarps.
- (b) Thick accumulation of soft sediments in the southeastern part of the lake, showing slumping on steeper slopes.
- (c) Step-like features (t) in the Tallital side of the lake floor.
- (d) Shallow seismic profile of the south eastern part of the lake delineating the bottom and sub-bottom multiples.

near the Naina Devi Temple to 27 m in the middle of the lake, west of the Bank House on the Mall. The depth of the floor off the Capitol Cinema is unusually great (19-20 m) (Figure 5). This is because the shallower part of the lake basin to the northwest was filled up completely with the enormous volume of debris of the 1880

landslide and converted into what is known as the Flat.

### Underwater Transverse Ridge

Off the Durga Sah Municipal Library, there is an elongate ridge measuring about 180 m in length on an average, 100m wide and

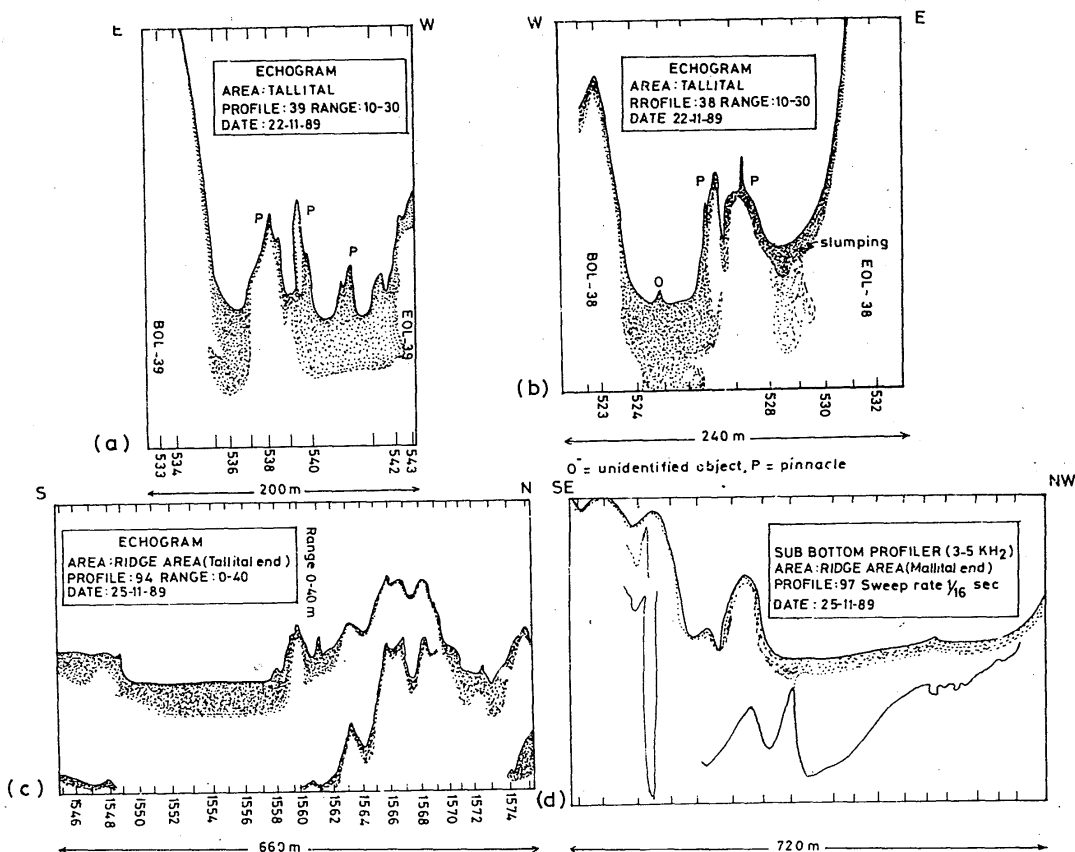


Fig. 7 Profiles of the bottom of the southeastern and central parts of the Naini lake.

- (a) Main channel in the southeastern part is filled with unconsolidated sediments. Note the sharp pinnacles (p) truncating or "resting upon" the sediments.
- (b) "Pinnacles" (p) truncating the soft sediments filling the channel. There are unidentified objects/features (o) on the bottom.
- (c) North-south profiles of a transverse underwater ridge, which divides the Naini lake into two unequal parts. Note the thick sediments abutting against the ridge to the left.
- (d) Good acoustic penetration through thick unconsolidated sediments in the northwestern part (sub-basin) of the lake.

rising from the depth of 20m to 6.8 m (Figure 5). The ESE-WNW oriented Ridge embraces a number of peaks whose height increases towards the centre. Its flanks gradually merge with the adjoining lake floor (Figure 7c). The topographic continuity and shape indicate that the Ridge is a natural feature which has divided the lake basin into two parts. Comparing Figures 2 and 5, one is struck by the fact that in the line of the underwater ridge to the east, the Sherka-

Danda slope is cut by two faults/fractures. It is tempting to relate the origin of this Ridge to movements on these faults.

The Ridge serves as a barrier to the flow of the sediments from the northwestern to southeastern subbasins. On either sides of the Ridge there are deep channels, through which bottom currents flow from one subbasin to the other. The origin of the deep channel perhaps can be attributed to the fault zone in the particular segment of the Ridge.

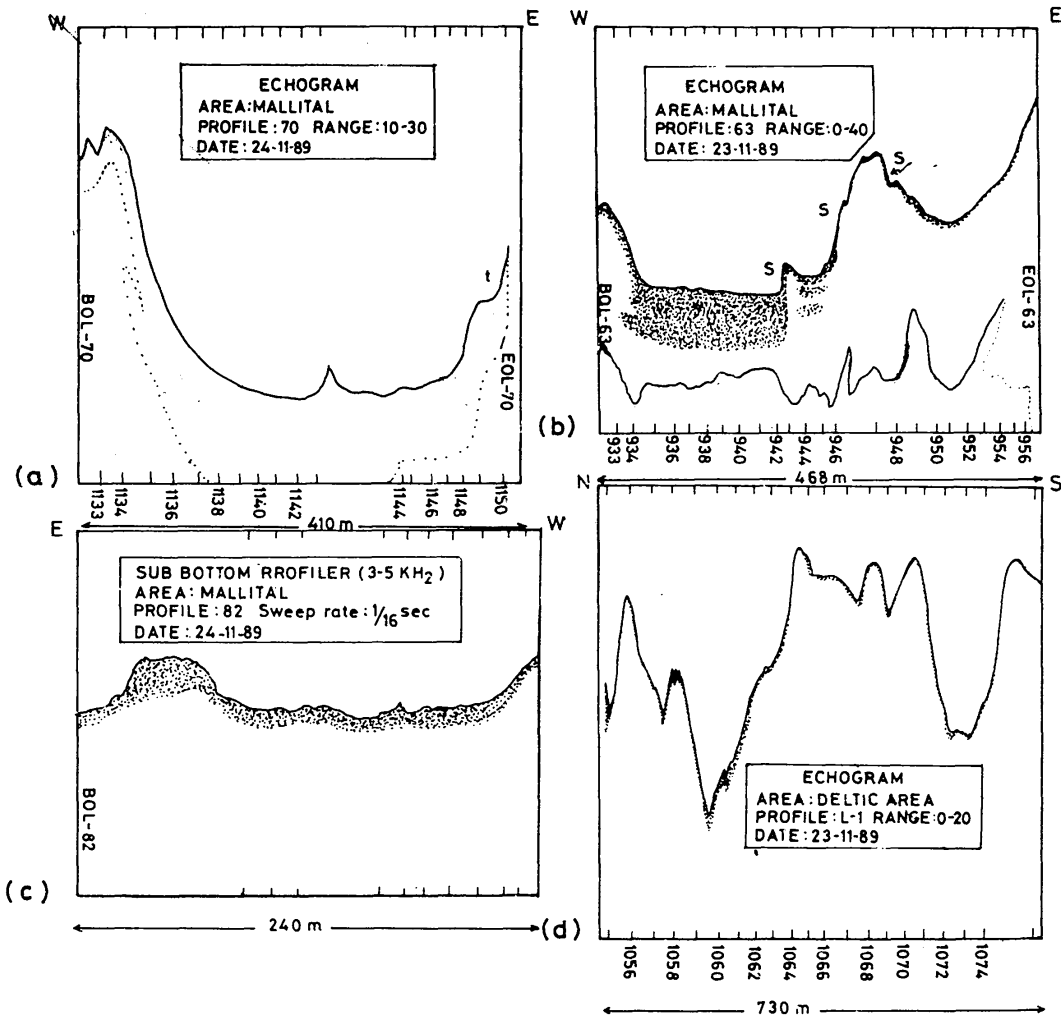


Fig. 8 Underwater topography characteristics of the Naini lake  
 (a) Profile of the wider part of the lake filled thickly with soft sediments. Note the terrace-like features (t) on the western side.  
 (b) The northwestern part of the lake also is characterized by scarps and slumping of sediments on slopes.  
 (c) Semi-consolidated sedimentary layer in the northwestern part of the lake basin exhibits deformation and displacement.  
 (d) Deltaic features are characteristic on the northeastern shore of the lake.

The southern flank of the Ridge is a gently sloping terrace, while the northern flank is steeply sloping. The echogram reflector indicates that the ridgetop is devoid of sediments. Lower down the slope, there are pockets (depressions) filled with unconsolidated sediments (Figures 7b, 7c).

**Deltas on Shores**

A number of small deltas have formed at the points of streams/gullies discharging into the lake (Figure 5). The strong reflections on the echograms of the 30 KHz echosounder indicates significantly hard bottom at these places (Figure 8d).

### Comparison of the Present and Previous Bathymetric Studies

The bathymetric profiles by Rawat (1987) were constructed from the depth data for the years 1895, 1969 and 1979 in order to quantify the sediments which accumulated in the lake basin. Mutual comparison of these profiles indicate progressive reduction of the lake capacity (Valdiya, 1988). Interestingly, the isobaths of the survey conducted in 1890 (Rawat, 1987; Valdiya, 1988) are similar in shape and configuration to that of present studies (Figure 9). However, in the absence of a common scale and of the vertical datum-line for the previous bathymetric results, it is not possible at present to quantify deposition of the sediments. Interestingly, the echograms show that there are some areas which do not have any trace of sediment accumulation.

The sonographs also confirm the deduction regarding the lake bottom relief and features, such as rock-blocks, and sediment-mantle on the lake floor.

### SUB-BOTTOM PROFILES

Shallow seismic profiling was carried out simultaneously. Barring some parts of the two sub-basins and a few pockets, there is little penetration of bottom reflectors. The only arrivals recorded are those of the sub-bottom multiples (Figure 6d). It seems that either the sedimentary layers are absent or the veneer of the sediments is very thin. However, several parts did indeed register excellent acoustic penetration, indicating a maximum sediment thickness of 15 m (Figure 7d). A few channels on the flanks of the Central Ridge and in the periphery of the lake exhibit good acoustic penetration (Figure 7d) implying that the channels are filled with sediments.

In the southern end of the Mallital sub-basin at a depth of 13 m there is a 8m high structure. There are two generations of sedimentary accumulation — the older one deposited in the depression on the northern side of the terrace and later on the wider area, including this structure. The contact between areas with no acoustic penetration (terrace-like structure) and the areas with excellent acoustic penetration north of terrace, is quite sharp (Figure 7d). The contrast in the acoustic reflectivity on the side of the terrace is due to change in its lithology. This is identified as a palaeo-structure which extends northwards into the deeper areas of the Mallital subbasin. A similar zone of acoustic penetration is discernible in the Tallital subbasin also where the acoustic bottom reaches to the depth of 15 m. These flat-bottom depressions are separated by the Ridge as already explained. The sub-bottom records of the Ridge confirms the absence of sediment on its summit. The shallow seismic records corroborate the shape, size, location and configuration of the Ridge as deduced from the bathymetric studies. Acoustic reflections show existence of buried blocks/rock debris and rock outcrops in the central part of the lake, just off the Pashan Devi Temple (Figure 5) in the northern part of the Mallital sub-basin, and in the western side of the lake.

A very significant observation is the existence of displaced and deformed acoustic reflectors (Figure 8c) in the transects across the active Nainital Fault, in the northwestern and southeastern parts of the lake.

The shallow acoustic profiles also reveal the existence of uncovered irregularities and unfilled cavities or depressions. These features indicate that despite a high rate of sedimentation (Sharma, 1981; Rawat 1987) some parts of the lake remain without sedimentary cover. It is confessed that the age determination of the reflectors has not been done so far due to the absence of borehole data.

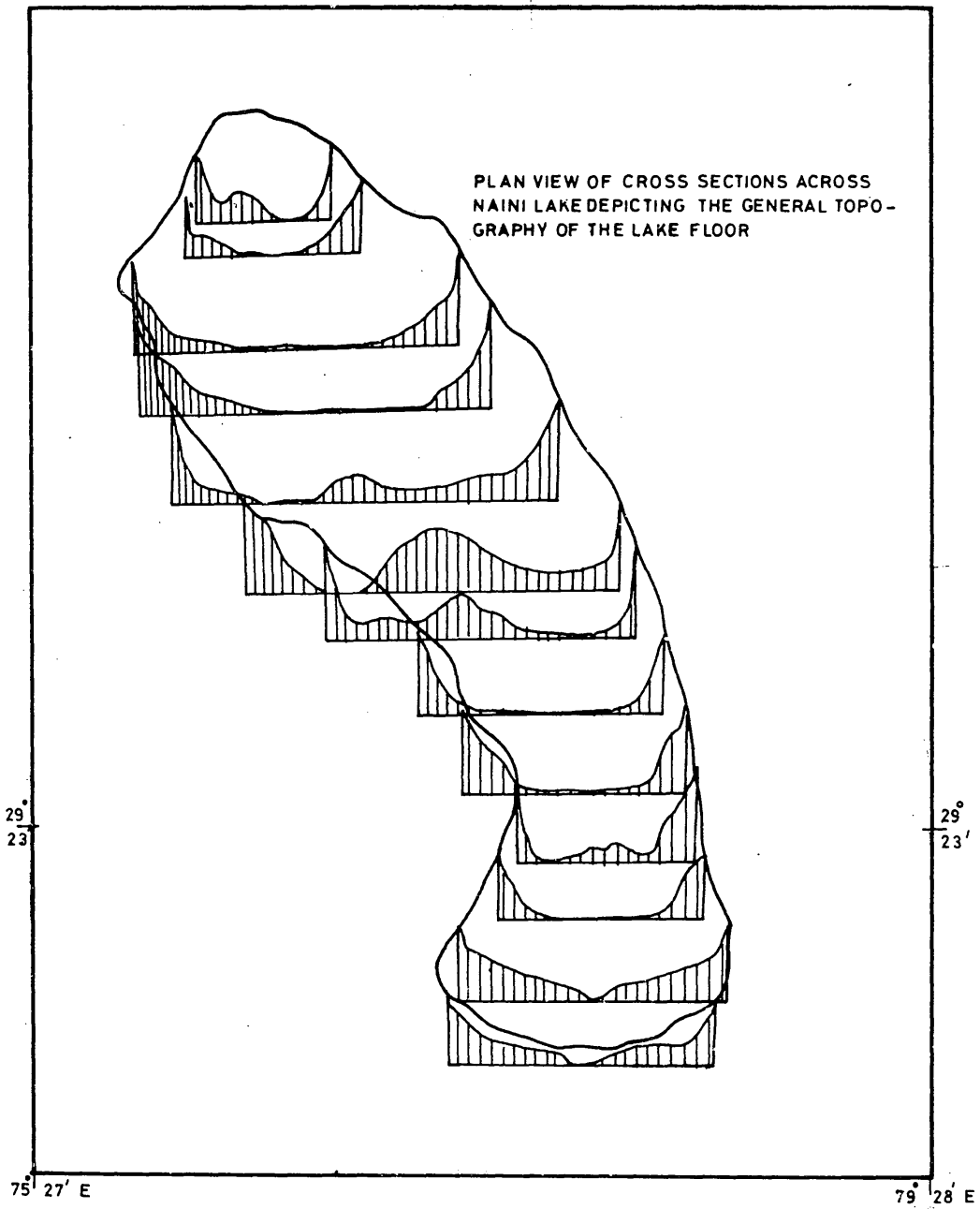


Fig. 9 Plan view of cross sections across the Naini lake, depicting the general topography of the lake floor (present work).

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