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Variations in Water Level of Dewar Lake, Chamoli, Central Lesser Himalaya, in the last 30 ka: Preliminary Results

Bahadur Singh Kotlia* and Kamini Bisht

CAS in Geology, Kumaun University, Nainital (Uttarakhand), India

✉ bahadur.kotlia@gmail.com

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Abstract: A continuous 3.6 m thick core from the water logged Dewar Lake at Chamoli (Uttarakhand) was retrieved to study its depositional history. The base of the sediment core is dated as ca. 30 ka BP. Based on the variation in the grain-size percentage, the core is dominated by silt over clay and sand. With a mean grain size of 5.38ф, the sediment shows very poor sorting, finely to symmetrically skewed and mesokurtic to leptokurtic kurtosis. Variation in the textural parameters throughout the core suggests climatically influenced deposition, hence five major litho-facies are reflected in the sediment core. During the phase 1, the lake water column was perhaps decreased gradually incorporating more silt to the lake through the presence of finer silt laminations indicating required energy conditions. The phase 2 is represented by somewhat raised water level compared to the phase 1. The minimum depth achieved by the lake is exposed in facies 1. The phase 3 shows fluctuating energy conditions, whereas, phase 4 reveals stable and high energy conditions. The litho-facies 5 shows the change in climatic conditions from humid to arid.

Keywords: Dewar lake; Grain-size; Lake water fluctuations; Climatic conditions.

Introduction

Studies of different proxies used in climatic study gives detailed insights on the high resolution climate variability in the past (Cook et al., 1995; Lamoureux and Bradley, 1996; Overpeck et al., 1997; Evans et al., 1998). A number of palaeoclimatic studies using lakes have provided detailed insights on the high resolution climatic changes in the past. Lakes are restricted water bodies distributed throughout the geographical region known to be the sentinels of climate change (Adrian et al., 2009). Considering their sensitivity to climate, they have potential to record small scale heterogeneity in the climatic conditions. The uninterrupted sequence of sediment and vast distribution of lakes in the terrestrial landscapes have enhanced their usefulness in the field of climatic change (Willett, 1999; Stolar et al., 2007; Pham et al., 2008; Adrian et al., 2009; Whittaker, 2012).

Several modern and ancient lake sediments have been studied all along the Himalayan region for obtaining high resolution climatic variability (Chauhan et al., 1997; Bhattacharya, 1989; Kotlia et al., 1997a,b; 2000, 2008, 2010; Ghosh et al., 2003; Basavaiah et al., 2004; Juyal et al., 2004; Pant et al., 2006; Bhattacharya et al., 2006; Trivedi et al., 2009; Juyal et al., 2009; Wünnemann et al., 2010; Kotlia and Joshi, 2013; Sanwal et al., 2019; Joshi et al., 2019). Most of the palaeolakes in Central Himalaya were formed by damming of perennial rivers/streams due to neotectonic movements along the Quaternary thrusts/faults (Kotlia et al., 1997a, 2000, 2008, 2010; Valdiya and Kotlia, 2001; Ghosh et al., 2003; Pant et al., 2006; Sundriyal et

*Corresponding Author

al., 2007; Joshi and Kotlia, 2015; Kothyari et al., 2017; Taloor et al., 2017).

The sedimentological attributes over other useful proxies in lakes are mostly overlooked but seem important to decipher the depositional environment and hydrodynamic conditions prevailing in the lake, in turn a replica to the climatic variability (Deba et al., 2016). Each sedimentary environment differs from each other in their energy condition that is reflected from its grain size distribution (Passega, 1957; Mason and Folk, 1958; Freidman, 1961, 1967; Klova, 1966; Folk, 1966; Vischer, 1969; Solohub and Klovan, 1969; Kotlia and Rawat, 2004; Rana et al., 2013). The present work deals with the grain size variability of the Dewar lake sediment profile to understand the energy conditions and its depositional history in addition to the past water level fluctuations and facies variability, resulting in the climatic phases.

Study Area

Dewar lake area (30°25′31.5″; 79°20′50″; Figure 1a) lies near the Main Central Thrust (MCT) zone which is considered as tectonically very active. The lake (Figure 1b) is fed by subterranean water and small streams and is water logged open swampy land (Chauhan and Sharma, 2000) and dries up in the summers. A number of geomorphologic features (e.g., triangular facets, fault scarps, waterfalls, rock falls, deep gorges etc. (see Figure 2), all are considered to represent active tectonics. Most of the annual precipitation received by the study area (1300 mm) is contributed by the Indian Summer Monsoon (ISM) with much more rainier summers than the winters.

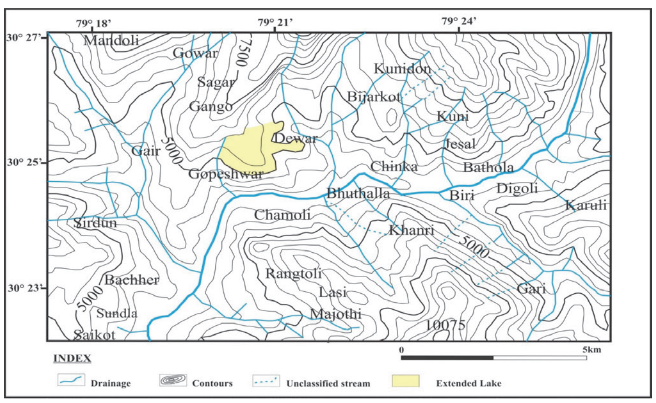

Figure 1a: Location map of Dewar Lake (maximum extent of lake is highlighted with yellow colour).

Figure 1b: Modern Dewar lake which becomes a marshy land in summers.

Figure 2: Geomorphological characteristics indicating neotectonic activity around Dewar lake: (a) V shaped valley, (b) Triangular fault facets, (c) Deposition of boulders and debris, responsible for formation of lake, and (d) Huge waterfall.

Methoology

The lake was selected by means of topographic sheet and Google earth image. A 3.6 m long core (Figure 3) from the deepest part of the lake was retrieved in July, 2018 using a piston corer when there was considerable amount of water. To obtain the maximum core, three overlapping cores were collected from the same location. After acquiring the core, it was successfully transported to the laboratory and was split into two halves along its length and photographed. Different lithological observations, e.g., colour, texture and lithology were made and was prepared along the core length for the stratigraphic study. The core was properly sub sampled at 1 cm interval and the samples dried overnight at 50°C. On the basis of variations in sedimentary characteristics, 60 samples were selected for grain size analysis, for which 1-2 gm sample was soaked for 12 hours in H_2O_2 solution to remove carbonate material and diluted with distilled water. The samples were analyzed using a Malvern Mastersizer 2000, based on

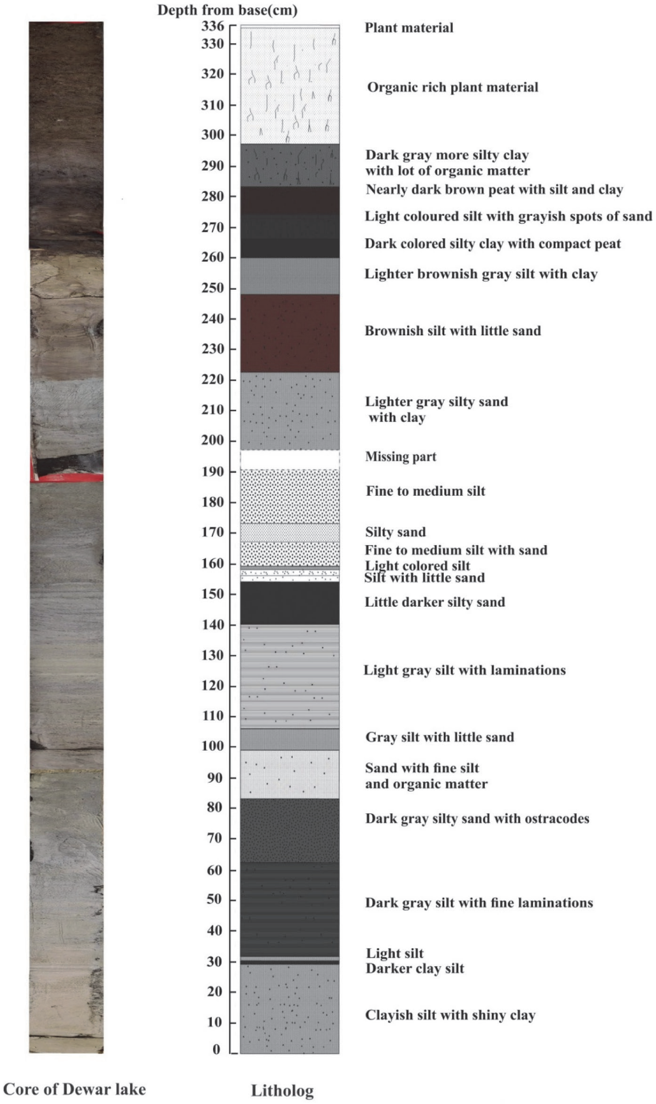

Figure 3: Core photograph with the lithological details.

a principle of Mie scattering (occurs when the particle diameter is larger than the wavelength of the radiation) using distilled water as dispersing medium. It gives high resolution across broad range of sizes and provides the results in the form of the volume percentage which gives a size range of 0.02-2.0 micron and a grain-size resolution of 0.166 U in interval.

GRADISTAT software (Blott and Pye, 2001) was used to determine the grain size parameters which provide both moment method and graphical representation of the data. Various parameters (see Figure 3), e.g., mean (Mz), mode (Ms), sorting (standard deviation), skewness (degree of lopsidedness), kurtosis (degree of peakedness) and a range of cumulative percentile values (grain size at which a specified percentage of the grains are coarser), namely D10, D50, D90, D90/D10, D90–D10, D75/D25 and D75–D25 were calculated arithmetically (based on a normal distribution with metric size values), geometrically (based on a log-normal distribution with metric size values) and logarithmically (based on a log-normal distribution with phi size values) using both moment and folk and ward graphical method (Folk and Ward, 1957). Here, we opted for the Gradistat values as the difference between the values obtained by two methods (Gradistat and manually done moment method in excel) were negligible. The values were transferred to excel to prepare a temporal to perceive the variability in different parameters with depth.

Chronology of the Lake Core

We obtained four radiocarbon dates from Poznań Radiocarbon Laboratory, Poland and these are 30,068 yr (basal most horizon), 20,036 yr (at 141 cm), 11,257 yr (249 cm) and 2,356 yr (at 296 cm level). Assuming an uniform accumulation rate, we have assigned age of 30,245 yr (at the base), 20,075 yr (141 cm level), 11,280 yr (249 cm) and 2,340 yr (296 cm) (see Figure 4).

Proxies Used and Their Significance

Deposition of coarser and finer grain size depends on the energy conditions that are prevailing in a lake and mean grain size defines the average grain size of the sediment, whereas, standard deviation is an index for sorting which is environmentally sensitive and is defined by the spread of the distribution from the mean (see Freidman, 1961). The sorting has an inverse relationship with the standard deviation and both parameters characterize the kinetic energy of depositing agent. Kurtosis (KG) and Skewness (SK) are used to discriminate between different environments (Friedman, 1961a, b). Kurtosis (KZ) is measured by the peakedness of the curve, whereas, skewness (SK) defines the symmetry of curve and its tendency to shift from its symmetrical form. Mixing of varying proportions of two normal populations result in skewness and kurtosis (Folk and Ward, 1957; Tanner, 1960) but sign of skewness is more environmentally sensitive (Mason and Folk, 1958) as compared to kurtosis. Silt is the key component and due to the changes in intensity of wind and hydrodynamic conditions, addition of the silt creates drastic change in the values of skewness changing its sign to either positive or negative (Spencer, 1963; Duane, 1964; Thomas et al., 1972, 1973; Sly et al., 1983). Different signs of skewness result due to position of the distribution tail. Positive and negative results occur when median and mode both lie right and left of the

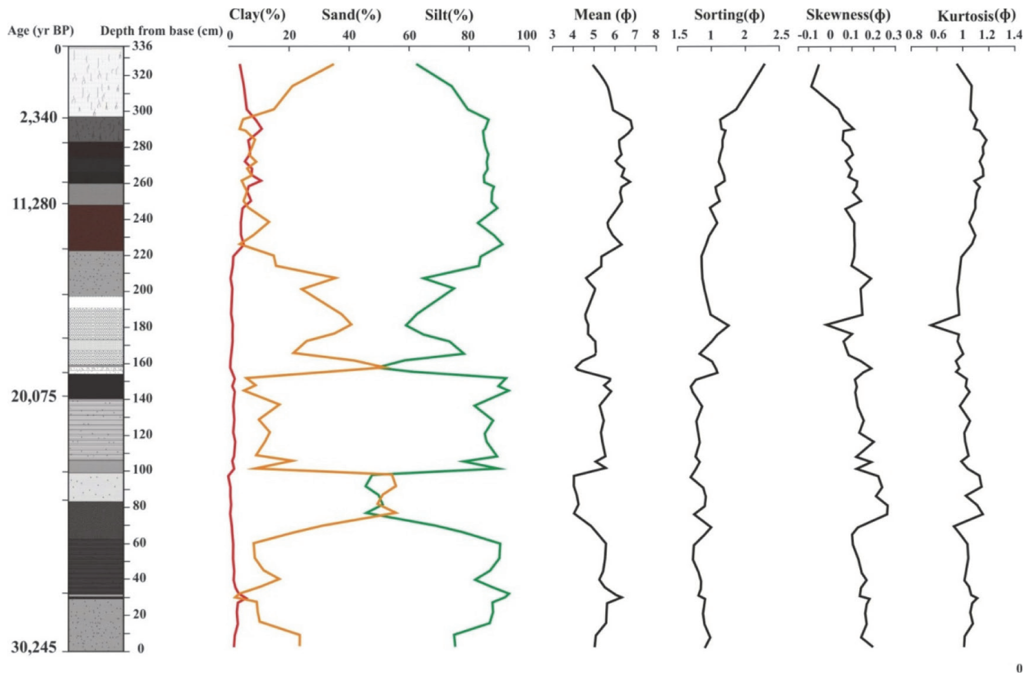

Figure 4: Temporal correlation showing variability in the Clay%, Sand%, Silt%, Mean, Sorting, Skewness and Kurtosis with depth.

mean (e.g., Friedman, 1962), whereas, overlapping of median and mode results in symmetrical distribution.

Results

The lake core comprises silt, sand and clay. Overall, it shows dominance of silt with little variation in its grain size from very coarse to medium silt. On the basis of grain size percentage classification (Folk, 1954) and lithological characteristics, the core can be divided into three major litho-facies, namely, sandy-silt, silt and silty-sand (Figures 4-5). Each litho-facies shows an increase in thickness towards the top.

The sandy-silt litho-facies (39-80 cm thick) is observed throughout the core but is dominant around 220 cm depth of the core. It comprises coarse to very coarse silt with little amount of sand and is light to dark grey coloured showing micro-laminations. The silt litho-facies (1-21 cm in thickness), dominant in the top 103 cm, comprises medium to coarse silt and is rich in peat and organic matter, and also exhibits variation in colour ranging from light to dark grey to brown. The silty-sand horizon (17 cm thick) contains very coarse grained silt and differs from sandy-silt in having organic matter.

Facies Analysis

The lake sediments confirm a polymodal mixture of different grain sizes. All the identified litho-facies show variation in their granulometric parameters (Figures 4-5). Major litho-facies are briefly described as below.

Silty-sand litho-facies: This is exposed only at a depth of 83 cm of the core having a small amount of organic matter (see Figure 4). It is 17 cm thick with a mean grain size of 4.11ϕ. The sand averages 52% (49.7-53.8%), silt as 47.6% (45.5-49.6%) and clay as 0.5% (0-0.7%), showing sand as major component. It is overlain by grey clayish silt and underlain by dark grey silt rich in ostracods. The sediments are very poorly sorted (1.19-1.42), finely skewed (0.21-0.24) and Kurtosis being mesokurtic to leptokurtic in nature (1.02-1.15). This litho-facies may have been accumulated due to decrease in water level of the lake with organic matter generally low, as the content of organic matter suggests helps in interpreting the depth of water column (e.g., Wetzel, 2001; Vijayaraj and Achyuthan, 2016). Very poor sorting of the sediments indicates unstable energy conditions and multiple source of the sediments (e.g., Visher, 1969).

Sandy-silt litho-facies: It dominates the entire section of the lake with silt as 86.2%, sand 5.9% and clay as 7.9%. The thickness of the beds ranges from 10-90 cm with light to dark grey colour (see Figures 4-5). Depending upon the percentage of sand, silt, clay and sedimentary structures this litho-facies is further classified into following sub-facies.

Laminated sandy-silt sub-facies: About 30-34 cm thick horizons of laminated sandy-silt are restricted and

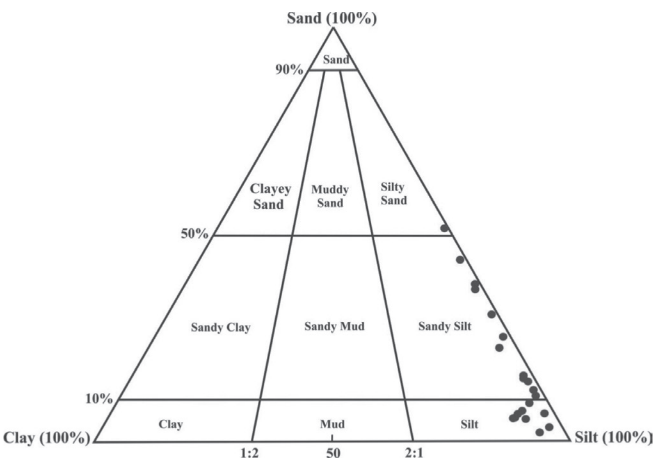

Figure 5: Ternary diagram showing classification of sand, silt and clay percentage (see Folk and Ward, 1957).

observed at around 140 cm and 62 cm of the core (see Figures 4-5). It comprises light to dark grey silt with average grain size of 5.46 ɸ and is composed of 86.7% silt (81.9-90.2%), 11.4% sand (8.3-16.5%) and 1.9% clay (1.6-2.4%) with micro-laminations. Thickness of this sub-facies decreases towards the bottom of the core with laminations even finer and colour from light grey to dark grey with organic matter. At 140 cm depth, it is overlain and underlain by light grey and dark grey sandy silt layers, whereas, at 62 cm it is overlain by ostracods rich non-laminated sandy silt layer and underlain by light coloured silt (see Figure 4). This sub-facies is finely skewed (0.10- 0.20), mesokurtic (0.98-1.05) and very poorly sorted (1.23-1.36). The dark grey colour of the sediments is likely to be a result of organic matter; as such laminations are generally formed by low energy conditions under insignificant bioturbation (e.g., Kemp, 1996; Verschuren et al., 1999).

Non-laminated sandy-silt sub-facies: This sub-facies (thickness 7-32 cm) dominates the entire core and is observed at different intervals (Figure 4). The average grain size is 5.20ɸ with very poor sorting (1.25- 2.29). The silt (72.1%, varying from 45.6-92.1%) dominates, with secondary presence of sand (25.9%, ranging from 2-53.7%) and very less clay (2.1%, between 0.9-6.1%). It is rich in fossil remains with little organic matter and shows varied colour, ranging from light to dark grey and blackish at places and is mostly overlain by silt litho-facies and is also devoid of sedimentary structures. The kurtosis ranges from 0.76-1.16, representing mesokurtic to leptokutic to platykurtic nature and is finely to symmetrically skewed (0.09-0.26). The dark grey sediments with abundant ostracods at 83 cm depth indicates a shallow, well-oxygenated, photic zone that may have been conducive to benthic organisms and plant growth (e.g, Galloway and Hobday, 1996). The sediment was probably accumulated in shallow water conditions (e.g., Henriksen, 2008).

Silt litho-facies: This dominates the top 103 cm of the core with thickness from 1-25 cm and varies from light grey to dark grey and brown with average grain size as 6.2ɸ and comprises medium silt. The percentage of the silt averages 87.7% (83-93.1%), dominating over 6.1% sand (2.0-12.9%) and 6.2% clay (1.3-11%). Throughout the core, this litho-facies is overlain and underlain by the sandy silt litho-facies. Enriched in peat and organic matter in the upper part and absence in the lower part can be noticed throughout. The thickness increases towards the top (Figures 4-5) and sedimentary structures are observed throughout the entire litho-facies. The sediments are mesokurtic to leptokurtic in nature (1-1.16), symmetrically to finely skewed (0.07-0.18) and very poorly sorted (1.2-1.69). Peaty material is an accumulation of disintegrated plant remnants which have been preserved under conditions of high water content and incomplete aeration (e.g., Huat, 2004). Presence of more silt-rich clay, grey colour with organic matter, plant rootlets and animal life marks the presence of thick horizon of palaeosol towards the top of the core.

The past lake level can be inferred from the grain size of core, associated with the change in the intensity of precipitation (Peng et al., 2000; Zhang et al., 2003; Chen et al., 2006; Conroy et al., 2008). The grain size distribution depends on the prevailing hydrodynamic conditions and various successive efforts have been made to interpret the environment on the basis of statistical measures of grain size distribution (Folk and Ward, 1957, 1958, 1966; Freidman, 1961, 1967; Spencer, 1963; Lewis and Sly, 1971).

Overall, Dewar lake sediment core shows a mean grain size of 5.38ɸ (Table 1) with mean vs. standard deviation (Figures 5-6) of 1.69 to 2.09 (poor sorting). The standard deviation increases from sand to silt size and further decreases in the clay size range. Table 1 depicts increase in standard deviation with decrease in grain size although the maximum value is attained by the medium silt. The lake sediments comprise the polymodal sediment, the lake itself being inefficiently incapable of sorting. The poor sorted sediment has attained its character from its source area which itself was not a high energy environment. Mean vs. Skewness bivariate plot (Figure 5b) reveals skewness value varying from finely to symmetrically skewed (–0.03 to +0.22). Symmetrically skewed nature may have been due to presence of pure silt as a dominating

Table 1: Statistical values of grain size parameters

Depth from bottom (cm)	*Lithofacies*	*Mean size*			*Standard Deviation*			*Skewness*			*Kurtosis*		
		Min	*Max*	*Aver.*	*Min*	*Max*	*Aver.*	*Min*	*Max*	*Aver.*	*Min*	*Max*	*Aver.*
297-336	Sandy silt	4.97	5.94	5.53	1.87	2.29	2.08	0.09	0.04	-0.03	0.95	1.07	1.03
283-297	Silt	6.24	6.86	6.66	1.63	1.71	1.66	0.06	0.11	0.07	1.09	1.18	1.13
273-283	Silt	6.27	6.34	6.31	1.63	1.66	1.65	0.09	0.1.	0.10	1.15	1.16	1.16
266-273	Silt	6.10	6.46	6.28	1.61	1.65	1.63	0.07	0.10	0.08	1.13	1.16	1.14
260-266	silt	6.38	6.76	6.57	1.69	1.70	1.69	0.08	0.12	0.10	1.09	1.16	1.13
248-260	Silt	6.29	6.36	6.34	1.56	1.62	1.56	0.11	0.14	0.12	1.10	1.13	1.12
233-248	Silt	5.70	6.16	5.93	1.48	1.59	1.53	0.07	0.11	0.09	1.05	1.10	1.08
197-233	Sandy silt	5.06	6.33	5.5	1.35	1.47	1.4	0.10	0.14	0 1	0.96	1.10	1.0
173-191	Sandy silt	4.63	4.75	4.7	1.48	1.75	1.6	0.02	0.15	0.1	0.76	0.97	0.9
167-173	Sandy silt			5.07			1.51			0.06			0.96
159-167	Sandy silt	4.49	5.09	4.79	1.33	1.50	1.42	0.08	0.14	0.11	0.95	1.00	0.98
158-159													
154-158	Sandy silt	4.18	4.63	4.41	1.56	1.58	1.57	0.15	0.19	0.17	0.95	0.98	0.96
140-154	Silt	5.50	5.84	5.7	1.20	1.27	1.2	0.11	0.12	0.10	1.02	1.06	1.00
106-140	Lami. sandy silt	5.30	5.58	5.44	1.27	1.36	1.31	0.12	0.20	0.15	0.98	1.05	1.02
99-106	Sandy silt	5.10	5.60	5.35	1.27	1.33	1.30	0.12	0.19	0.15	0.99	1.04	1.02
83-99	Silty sand	4.06	4.19	4.11	1.19	1.42	1.33	0.21	0.24	0.22	1.02	1.15	1.10
62-83	Sandy silt	4.07	5.17	4.60	1.25	1.49	1.39	0.10	0.26	0.19	0.93	1.16	1.04
32-62	Lam. sandy silt	5.28	5.60	5.49	1.23	1.35	1.29	0.10	0.17	0.14	1.01	1.05	1.03
30-32	Silt			6.07			1.31			0.14			1.07
29-30	Silt			6.36			1.40			0.18			1.11
0-29	Sandy silt	5.06	5.67	5.42	1.38	1.49	1.41	0.14	0.17	0.17	1.01	1.08	1.05

litho-facies, whereas, finely skewed may have resulted due to addition of silt to sand component. The Mean vs. Kurtosis plot (Figure 5c) shows that majority of the sediments are of mesokurtic nature. Most of the medium silt is leptokurtic, resulted from the mixture containing one predominant and one very subordinate population. Based on lithology and grain size parameters (mean grain size, standard deviation, skewness and kurtosis), our study reveals five different phases of energy conditions in the Dewar lake (Figure 7).

Phase 1 (0-99 cm) is represented by the basal part of the core. The litho-facies present are medium silt at the bottom, followed by laminated coarse silt and very coarse silt towards the top. Sand percentage increases gradually (2%-52%), whereas, both silt (92.1-47.6%) and clay (5.9-0.5%) decrease in the upper part. The change in energy conditions is reflected in sediment types. From bottom to top of this phase, water column of the lake was perhaps decreased gradually incorporating more silt to the lake though the presence of finer silt laminations and absence of bioturbation indicates calm and low energy environment.

Phase 2 (99-159 cm) reveals the variation from ca. 23 to 19 yr BP. Somewhat enhanced humid conditions may have been responsible for little increased water level in the lake, followed by calm energy conditions, depositing finer laminations towards the top. The coarser silt mean grain size with decreasing sand towards the top and increasing silt and clay depict somewhat raised water level compared to the phase 1.

Phase 3 (159-211 cm) shows alternating coarse grain size varying from coarse silt to very coarse silt (Figure 6). Variation in the sand, silt and clay percentage shows little fluctuations in the energy conditions prevailing in

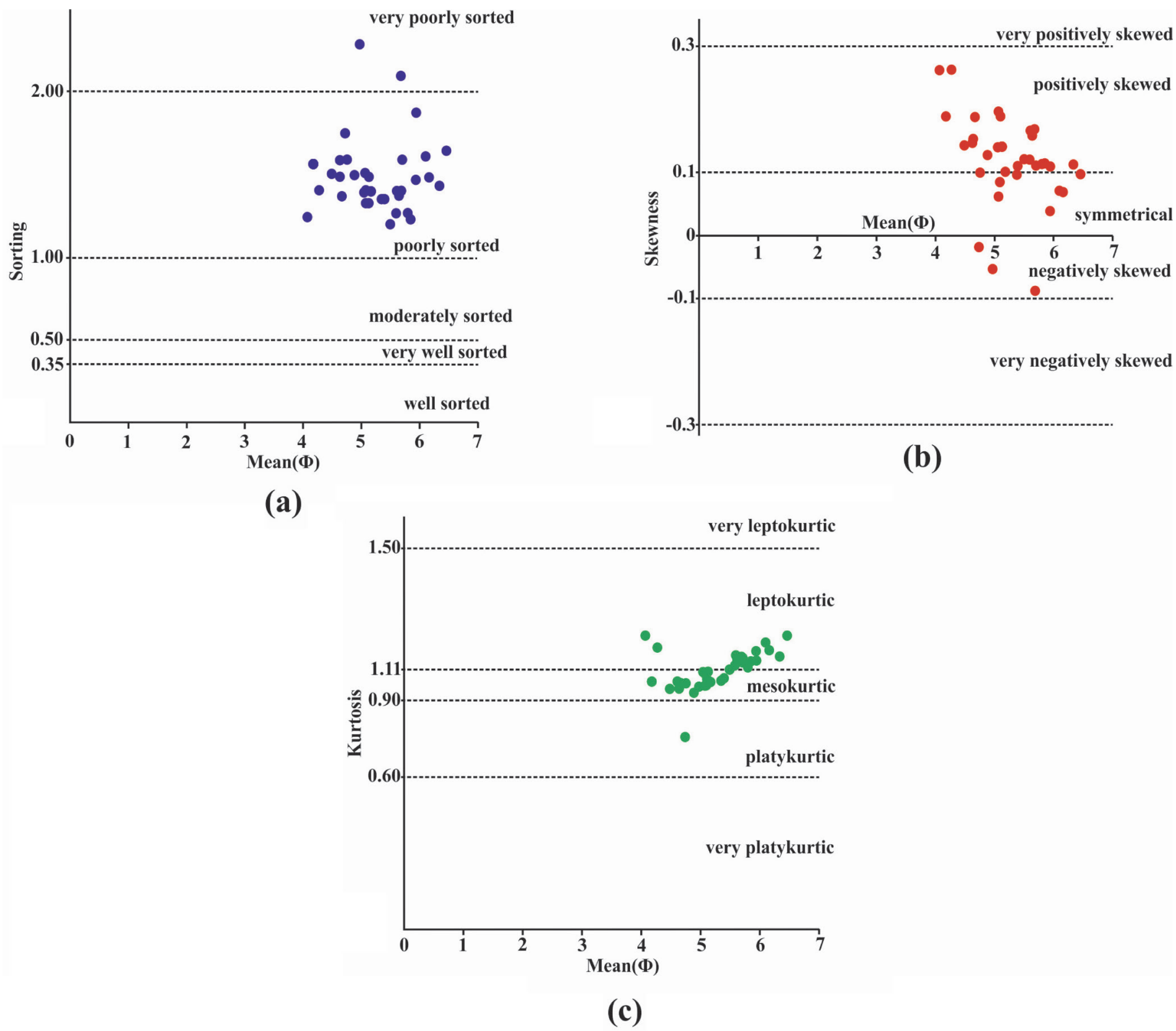

Figure 6: Bivariate plots showing (a) Standard deviation vs. Mean, (b) Skewness vs. Mean and (c) Kurtosis vs. Mean.

the lake. Here the water level remained at lower level for a longer period depositing the coarser sediment to the lake.

Phase 4 (211-297 cm) shows inverse relationship between sand, silt and clay. Presence of peat with abundant clay indicates highest water level (see Huat, 2004) at a depth of 297-283 cm (Figure 7). Little variation in the grain size points to less fluctuations in the lake water level.

Phase 5 (297-336 cm) is represented by higher sand and silt content, reflecting decreased water budget of the lake.

Conclusion

Dewar lake was formed about 30 ka BP due to neotectonically triggered huge landslide mass and now is an open swampy lake, bounded by steep fault scarps, triangular fault facets and deep gorges all around. Small streams and subterranean water contributes little to the lake but majority of the water storage is dependent on the precipitation resulting due to climatic variations. Based on the detailed grain size analysis of the Dewar lake core, the study reveals that the lake sediments are an admixture of sand, silt and clay, defined by their differential degree of mixing. Our preliminary interpretations suggest that the lake core shows five major phases of different climatic phases. Phase 1 and Phase 2 reveal shallowing of the lake, correlated with high evaporation rate influenced by the weakening of the monsoon. Phases 3 and 4 show fluctuating conditions, resulted from a number of frequent changes in lake water level, whereas, phase 5 indicates the lake condition approaching towards drier condition.

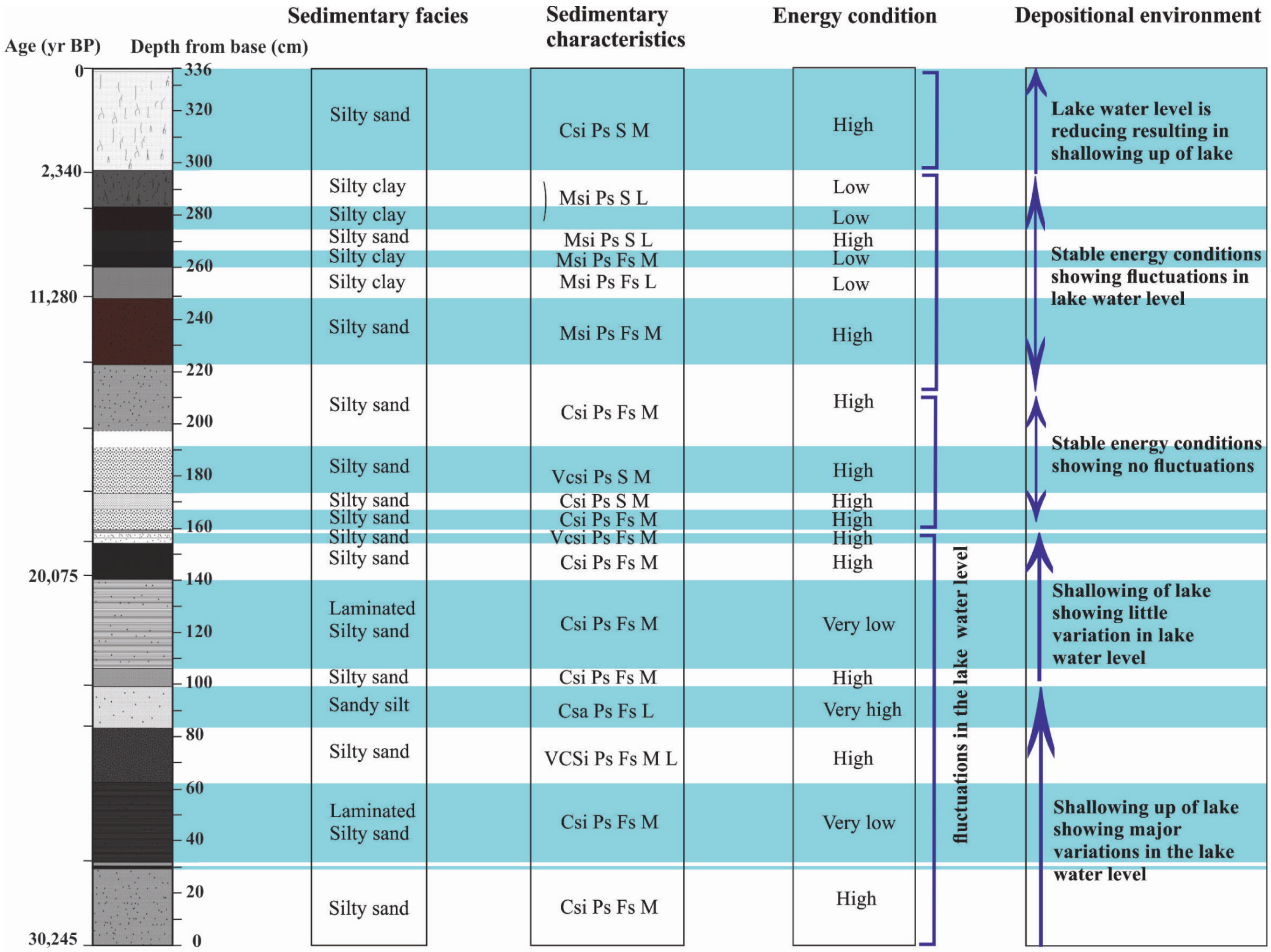

Figure 7: Lithology showing various litho-facies with depth in terms of sedimentary facies, sedimentary characteristics, energy conditions and sedimentary environment.

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