

SEDIMENTOLOGICAL IMPLICATIONS OF GRAIN-SIZE CHARACTERISTICS ON PERIPHERAL DEPOSITION AND POST-IMPACT MODIFICATION OF LONAR CRATER LAKE, INDIA

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ABSTRACT

Lonar Crater, excavated within the Deccan Traps of central India, is one of the best-preserved terrestrial impact structures developed in basaltic terrain. Although impact-formed, its present morphology is strongly modified by post-impact geomorphic and sedimentary processes governed by tropical monsoonal climate. This study evaluates the influence of seasonal streams and marginal depositional processes through grain-size analysis of surface sediments collected along the lake periphery. Nine samples (S1–S9) were analyzed using Laser Particle Size Analysis (LPSA) to obtain high-resolution grain-size distributions, and statistical parameters were calculated following Folk and Ward. Cumulative frequency curves, bivariate plots, graphic standard deviation, and the Passega C–M diagram were applied to interpret transport and depositional mechanisms. Results indicate predominantly fine-grained, poorly to very poorly sorted, and positively skewed sediments, reflecting episodic sediment influx under fluctuating hydrodynamic conditions. The C–M plot suggests dominant graded and uniform suspension, characteristic of low-energy lacustrine marginal settings. Seasonal erosion of the crater rim supplies sediment to the margins, where rapid energy loss promotes deposition and progressive infilling. This marginal accumulation contributes to a gradual reduction in effective crater depth, highlighting ongoing post-impact evolution driven by climatic forcing.

Keywords: *Lonar Crater, grain-size analysis, peripheral lake sediments, seasonal streams, C–M plot, crater infilling*

INTRODUCTION

Meteorite impact craters represent unique geomorphic systems that undergo continuous modification through post-impact weathering, erosion, sediment transport, and deposition. Lonar Crater Lake, situated in Buldhana District, Maharashtra, India, is one of the world's rare terrestrial impact structures developed entirely within basaltic terrain of the Deccan Traps. Since its formation, the crater has evolved under tropical monsoonal climatic conditions, where seasonal runoff and surface drainage play a dominant role in redistributing rim-derived sediments into the crater basin.

Previous investigations at Lonar have primarily emphasized palaeoenvironmental reconstruction and lake geochemistry. Anoop et al. (2013) demonstrated that sedimentological and geochemical records from Lonar Lake preserve valuable palaeoclimatic information, reflecting fluctuations in hydrology and sediment influx over time. Limnological studies by Ghutke *et al.* (2018) further highlighted the alkaline nature of lake waters and stressed the ecological sensitivity of this closed basin system, emphasizing the need for integrated geomorphic and sedimentary assessments. More recently, Chikhalkar et al. (2026) quantified morphometric and hydrological changes in Lonar Crater using remote sensing and rainfall variability, documenting progressive shoreline modification and hydrologically driven morphological adjustments between 2019 and 2024.

Despite these advances, detailed sedimentological investigations focusing on lake-margin deposits and rim-derived material remain limited. In particular, the role of seasonal streams in transporting weathered basaltic sediments from the crater rim to the peripheral lake boundary has not been adequately quantified using

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grain-size statistical approaches. Marginal depositional zones act as important sediment traps, recording short-term hydrodynamic variability as well as long-term geomorphic evolution of the crater basin. Grain-size parameters provide critical insights into sediment transport mechanisms, depositional energy conditions, and post-impact landscape modification. Statistical measures such as mean size, sorting, skewness, and kurtosis, together with bivariate relationships and C–M plots, are widely employed to distinguish between tractional, suspension, and mixed transport processes in lacustrine and fluvial environments.

The present study aims to evaluate sedimentological controls on peripheral deposition in Lonar Crater Lake through detailed grain-size analysis of surface sediments collected along rim-to-basin transects at the lake margin. By integrating cumulative curves, bivariate plots, and Passega's C–M diagram, this work seeks to (i) characterize sediment texture and transport modes, (ii) assess the influence of seasonal streams on marginal sediment accumulation, and (iii) infer implications for progressive crater infilling and reduction in effective crater depth. This study provides new insights into climate-driven post-impact modification of Lonar Crater and complements earlier morphometric, limnological, and palaeoenvironmental investigations.

2. Study Area

Lonar Crater lies at approximately 19°58'N latitude and 76°31'E longitude (as shown in fig 1) with a diameter of ~1.8 km and a rim-to-floor depth of ~130–150 m. The crater rim rises prominently above the surrounding Deccan basaltic plateau and is dissected by several seasonal drainage channels. Lonar Lake, occupying the crater floor, is a closed basin with no surface outflow.

The regional climate is characterized by hot summers and a distinct southwest monsoon season, during which intense rainfall generates short-lived streams that transport sediments from the crater rim toward the lake margin. These seasonal inflows strongly influence sedimentation patterns along the lake's peripheral boundary, making it an ideal setting to study crater modification through sedimentary processes.

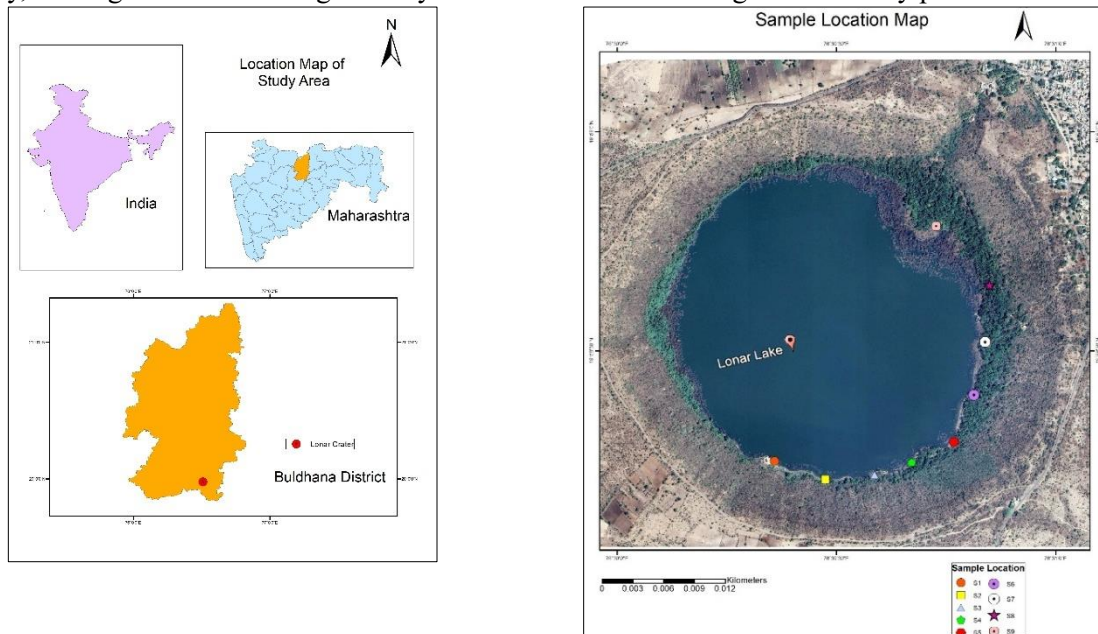


Figure 1: Map of Lonar Crater showing location of sampling sites (Source: Google Earth. (2025, May 13). *Lonar Crater Lake, Maharashtra, India* [Satellite image]. Google. <https://earth.google.com/>)

MATERIALS AND METHODS

3.1 Field Sampling Strategy

Surface sediment samples in post monsoon (S1–S9) were collected exclusively from the peripheral boundary of Lonar Crater Lake, focusing on marginal depositional zones influenced by seasonal stream

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inflow. Sampling locations were selected at different points along the lake margin to capture spatial variability. Approximately 300–500 g of sediment was collected from the upper 5–10 cm layer at gently sloping shoreline segments and relatively stable lake-margin surfaces. All samples were air-dried, homogenized, and stored in labelled polyethylene bags prior to analysis.

3.2 Laser Diffraction Particle Size Analysis (LPSA)

Grain-size distributions were measured using a Laser Diffraction Particle Size Analyzer (LPSA). Samples were oven-dried at 60 °C, disaggregated, treated with dilute H₂O₂ to remove organic matter, dispersed with sodium hexametaphosphate, and ultrasonicated to ensure complete particle separation. Measurements were conducted over a size range of 0.5–500 µm, with repeated runs to ensure reproducibility.

Particle-size data were converted to cumulative percentages and phi (Φ) units. Graphic mean (Mz), inclusive graphic standard deviation (σI), skewness (SkI), and kurtosis (KG) were calculated following Folk and Ward (1957) to characterize sediment texture and infer depositional processes.

3.3 Statistical and Graphical Interpretation

Cumulative grain-size percentage (as shown in table 1) has been calculated, and curves were constructed to examine sediment population characteristics. Bivariate relationships between mean grain size, sorting, skewness, and kurtosis were explored using standard plots (mean–sorting, mean–skewness, mean–kurtosis, and skewness–sorting). Inclusive graphic kurtosis and skewness diagrams were used to assess distribution symmetry and peakedness.

Passega’s C–M diagram was applied to infer sediment transport mechanisms using first percentile (C) and median grain size (M) values. These graphical analyses facilitated interpretation of hydrodynamic conditions and depositional processes operating along the lake margin under seasonal monsoonal influence.

Table No 1 Cumulative weight percentage of the sediment samples

S. No.	Size (µm)	Phi (Φ)	Cum Wt % S1	Cum Wt % S2	Cum Wt % S3	Cum Wt % S4	Cum Wt % S5	Cum Wt % S6	Cum Wt % S7	Cum Wt % S8	Cum Wt % S9
1	493.633	1.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	339.916	1.56	1.79	1.40	0.01	0.02	0.00	0.00	0.00	0.00	0.00
3	234.066	2.1	11.36	6.29	1.37	1.39	0.43	0.00	0.00	0.00	0.00
4	176.935	2.5	29.79	12.94	9.71	8.66	7.31	0.26	0.15	0.38	0.99
5	121.837	3.04	44.01	19.84	18.68	17.14	15.37	3.32	2.17	4.47	6.06
6	92.0988	3.44	59.10	32.66	34.12	32.00	28.70	11.38	8.64	13.53	17.96
7	63.4192	3.98	64.64	39.69	42.32	40.15	36.19	16.38	13.42	18.71	25.86
8	52.6264	4.25	71.49	50.43	54.22	52.61	47.54	25.91	23.46	28.25	39.10
9	39.7813	4.65	77.21	60.47	64.60	63.79	58.44	37.47	36.70	39.66	52.57
10	30.0714	5.06	81.87	68.97	72.87	72.59	67.81	49.16	50.26	51.41	64.38
11	22.7315	5.46	86.35	77.29	80.37	80.35	76.70	61.84	64.08	64.08	73.74
12	15.6529	6	88.79	81.77	84.17	84.26	81.37	69.18	71.44	70.96	77.92
13	11.8323	6.4	91.56	86.66	88.31	88.43	86.38	77.55	79.32	78.35	82.97
14	8.14773	6.94	93.34	89.71	90.91	91.01	89.47	82.88	84.19	82.99	86.55
15	6.15902	7.34	94.83	92.22	93.06	93.14	92.00	87.29	88.19	86.91	89.70
16	4.65572	7.75	96.37	94.72	95.24	95.30	94.54	91.73	92.21	91.10	93.02
17	3.20592	8.29	97.68	96.76	97.04	97.12	96.64	95.27	95.49	94.79	95.77
18	2.011	8.96	99.05	98.72	98.82	98.90	98.71	98.31	98.39	98.21	98.34
19	0.953552	10.03	99.77	99.69	99.71	99.74	99.69	99.60	99.62	99.59	99.59
20	0.544872	10.84	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

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4. RESULTS

4.1 Grain-Size Distribution

Cumulative grain-size curves (as shown in fig 2) display smooth sigmoidal patterns, indicating mixed sediment populations derived from multiple transport processes. Samples S1–S3 show relatively coarser grain fractions, whereas samples S6–S9 are dominated by fine silt-sized particles, reflecting a clear fining trend across the marginal depositional settings.

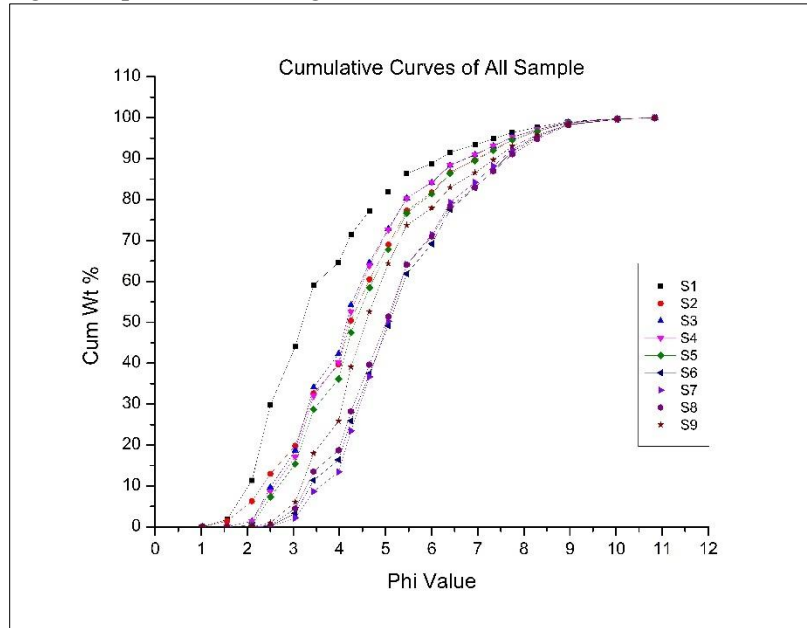


Figure 2 - Cumulative curve showing trends of all samples.

The table showing graphic measure and statistical parameter is given below (table- 2). The graphic measure and statistical parameters are calculated by using different formulas.

Table 2 – Graphic measures and Statistical parameters of samples

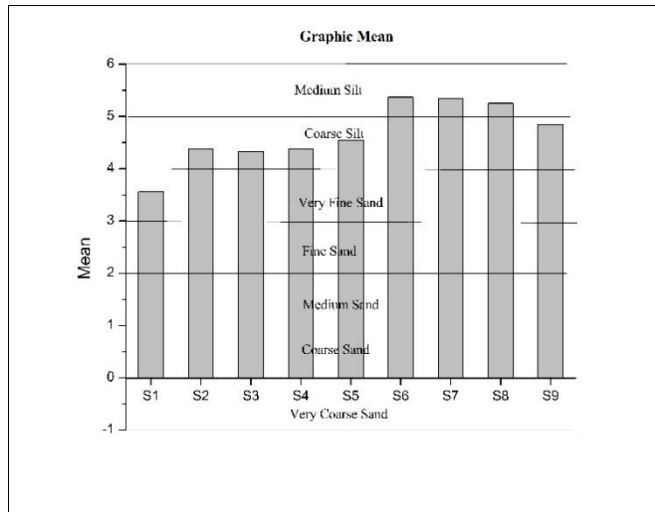
Sampl es/ Phi value	Φ95	Φ84	Φ75	Φ50	Φ25	Φ16	Φ5	Φ1	Mz	σI	Sk ₁	K _G	C in micr on	M in micr on
Sample 1	7.36 63	5.25 21	4.52 43	3.20 72	2.44 47	2.20 21	1.78 62	1.26 63	3.55 38	1.60 80	0.41 58	1.09 97	416	85
Sample 2	7.86 22	6.19 86	5.36 68	4.22 30	3.18 32	2.72 73	1.99 95	1.44 50	4.38 30	1.75 61	0.18 99	1.10 04	367	48
Sample 3	7.75 29	5.98 53	5.18 81	4.14 84	3.21 26	2.86 60	2.27 68	2.06 88	4.33 32	1.60 95	0.24 71	1.13 61	238	50
Sample 4	7.71 82	5.98 53	5.20 68	4.17 77	3.24 19	2.96 46	2.30 61	2.09 82	4.37 59	1.57 52	0.25 26	1.12 88	234	48
Sample 5	7.96 08	6.22 89	5.41 47	4.35 10	3.34 59	3.06 86	2.37 54	2.13 28	4.54 95	1.63 63	0.24 05	1.10 65	228	43
Sample 6	8.30 74	7.05 97	6.28 12	5.07 88	4.21 23	3.96 97	3.13 79	2.72 20	5.36 94	1.55 58	0.26 56	1.02 40	152	24
Sample 7	8.27 28	6.95 97	6.17 72	5.04 42	4.28 17	4.03 91	3.20 72	2.82 60	5.34 77	1.49 77	0.29 32	1.09 53	141	25
Sample 8	8.41 14	7.05 97	6.24 66	5.00 95	4.14 30	3.69 25	3.06 86	2.61 80	5.25 39	1.65 13	0.24 56	1.04 09	163	26
Sample 9	8.16 88	6.60 91	5.65 74	4.55 89	3.93 51	3.38 05	2.93 00	2.54 87	4.84 95	1.60 09	0.32 41	1.24 66	171	35

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4.2 Mean Grain Size

Graphic mean (M_z) values range from 3.55Φ in Sample S1 to 5.37Φ in Sample S6. Samples S1–S5 exhibit comparatively coarser mean sizes corresponding to fine sand to coarse silt, whereas Samples S6–S9 show finer mean values indicative of silt-dominated sediments (as shown in Fig. 3). This progressive fining reflects spatial variations in depositional energy along the lake-margin environments, likely controlled by localized sediment input and reworking processes within the marginal zones.

Figure 3 - Graphic Mean values of all samples



4.3 Sorting (Inclusive Graphic Standard Deviation)

Sorting values (σ_I) vary between 1.49Φ (S7) and 1.76Φ (S2), classifying all samples as poorly to very poorly sorted (as shown in fig 4). Such poor sorting suggests rapid deposition from sediment-laden flows with limited hydraulic sorting, consistent with episodic sediment input during seasonal runoff.

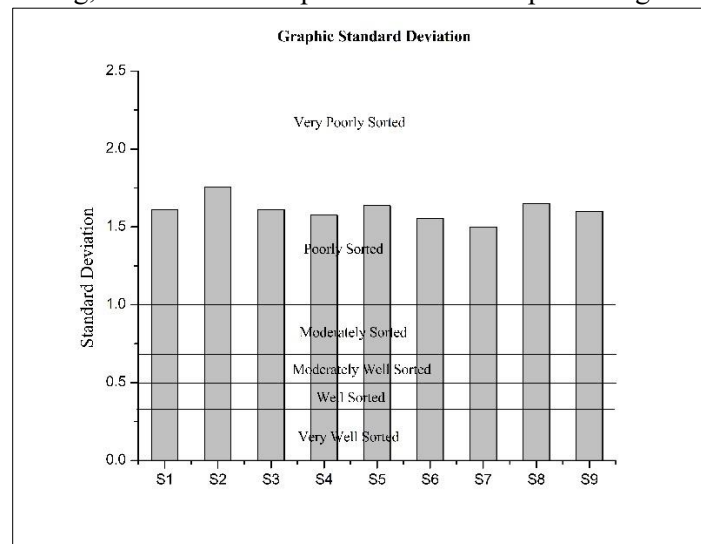


Figure 4 – Graphic Standard Deviation values of samples

4.4 Skewness

Inclusive graphic skewness (Sk_I) values range from 0.18 (S2) to 0.42 (S1), indicating predominantly fine-skewed distributions (as shown in fig 5). The enrichment of fine material implies dominance of suspension settling under low-energy lacustrine marginal conditions.

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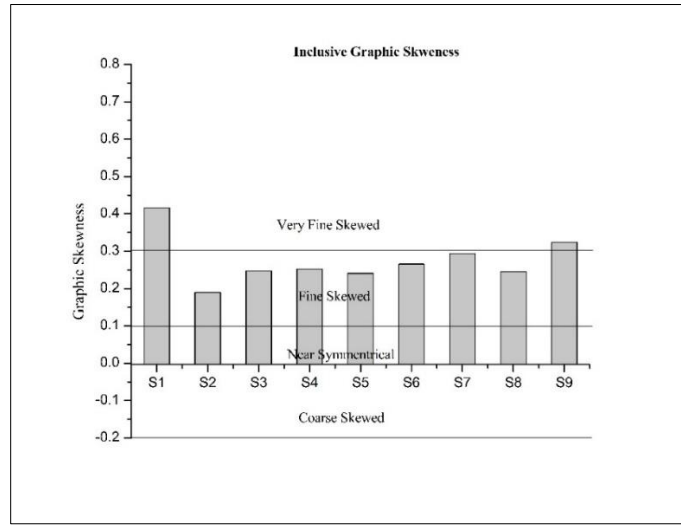


Figure 5- Inclusive Graphic Skewness values of all samples

4.5 Kurtosis

Graphic kurtosis (KG) values range from 1.02 (S6) to 1.25 (S9), falling within mesokurtic to moderately leptokurtic categories (as shown in fig 6). These values suggest intermittent sediment supply with moderate concentration around the mean grain size, reflecting fluctuating depositional regimes.

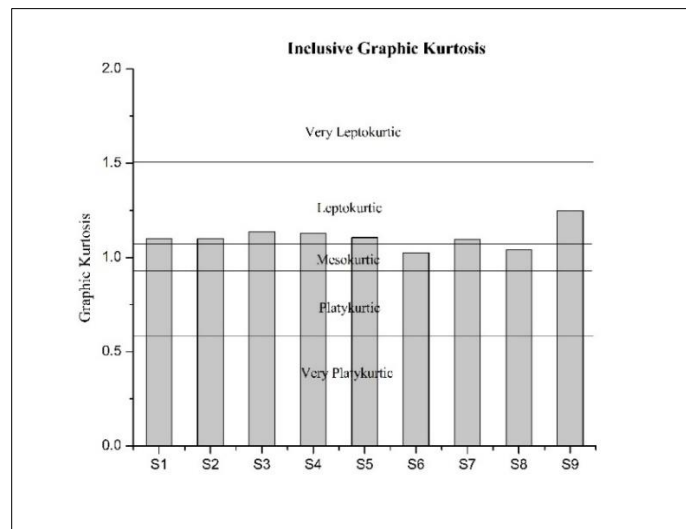


Figure 6- Graphic Kurtosis values of all samples

4.6 Bivariate Plots

The bivariate plots of Mean vs Standard Deviation (Fig 7), Mean vs Skewness (Fig 8), Mean vs Kurtosis (Fig 9), Skewness vs Standard Deviation (Fig 10), Standard Deviation vs Mean (Fig 11), and Standard Deviation vs Skewness (Fig 12) show tight clustering of samples within fine sand to coarse silt sizes and poorly sorted fields, indicating broadly uniform depositional conditions around the lake periphery. Mean–Standard Deviation relationships (as shown in fig 7) reflect consistently poor sorting, suggesting rapid deposition from fluctuating energy flows. Mean–Skewness and Skewness–Standard Deviation (as shown in fig 8 & 10) plots display dominant positive skewness, highlighting enrichment of fine particles through

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suspension settling. Mean–Kurtosis plots (as shown in fig 9) indicate mesokurtic to slightly leptokurtic distributions, implying episodic sediment input with moderate size concentration. Overall, these plots collectively demonstrate suspension-dominated transport with limited hydraulic reworking, driven by seasonal sediment influx at different peripheral locations.

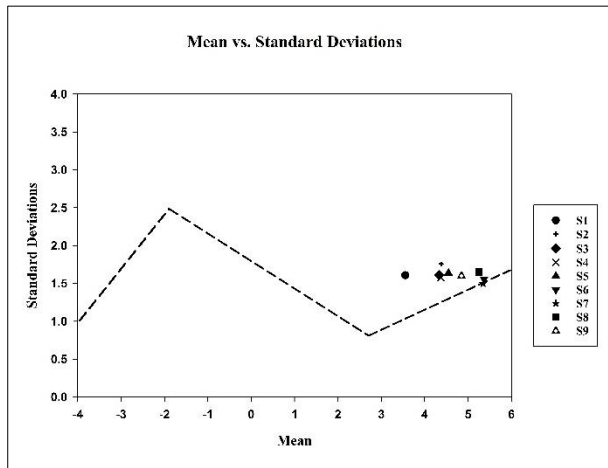


Figure 7 – Mean vs. Standard Deviations

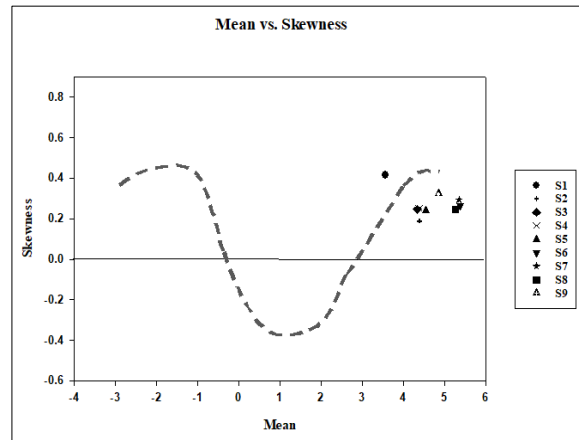


Figure 8 – Mean vs. Skewness

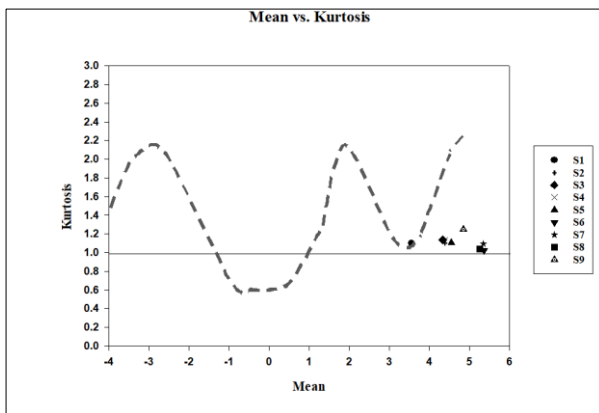


Figure 9– Mean vs. Kurtosis

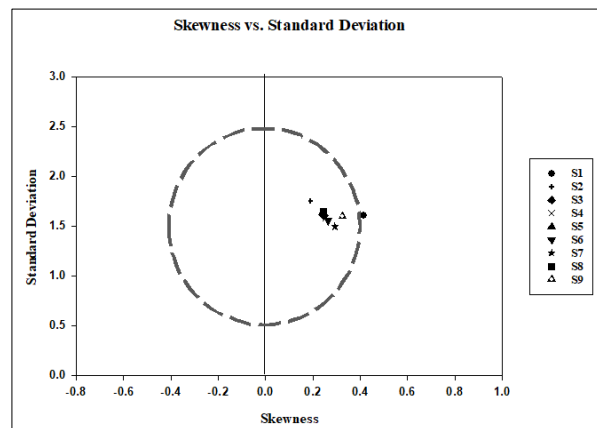


Figure 10–Skewness vs. Standard Deviation

4.7 C–M Plot

In the C–M diagram (as shown in Fig. 13), all samples plot within the graded suspension (CS) and uniform suspension (CU) fields, indicating that sediment transport is predominantly controlled by suspension processes. C values decrease from approximately 416 μm in Sample S1 to 152–171 μm in Samples S7–S9, while corresponding M values decline from $\sim 85 \mu\text{m}$ (S1) to $\sim 24\text{--}35 \mu\text{m}$ (S6–S8). This systematic reduction in both C and M reflects progressive fining and a general decrease in depositional energy across the lake-margin environments, consistent with sediment deposition under low-energy, suspension-dominated conditions influenced by localized inflow and reworking processes.

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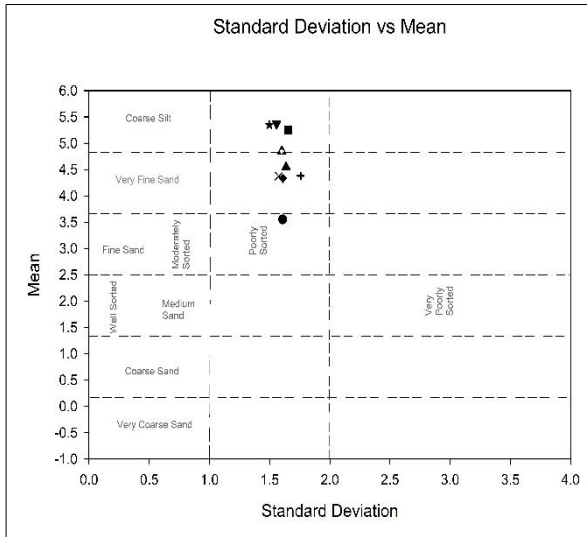


Figure 11–Standard Deviation vs. Mean

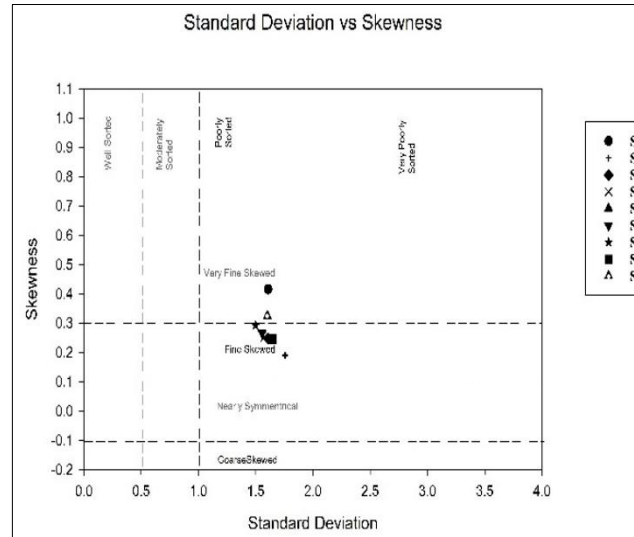


Figure 12 –Standard Deviation vs. Skewness

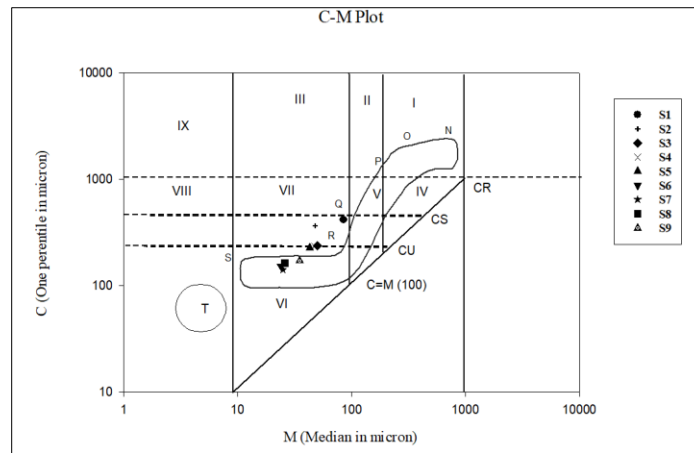


Figure 13 - C-M Plot

5. DISCUSSION

5.1 Role of Seasonal Streams

Seasonal streams draining the crater rim act as the primary agents of sediment supply to Lonar Lake. During monsoonal rainfall, these streams erode weathered basaltic material and transport sediments toward the crater interior. Upon reaching the lake margin, flow velocity decreases abruptly, promoting deposition of fine-grained material along the peripheral boundary.

5.2 Marginal Depositional Processes

The poor sorting and fine-skewed grain-size distributions indicate rapid deposition from fluctuating energy flows rather than prolonged reworking by waves or currents. Repeated monsoonal sediment pulses result in progressive marginal aggradation, gradually extending lake-margin deposits basinward.

5.3 Implications for Crater Depth and Evolution

Although the samples were collected only from the lake periphery, their sedimentological characteristics provide indirect evidence of ongoing rim erosion and sediment redistribution. Continuous marginal and basinward sediment accumulation contributes to long-term infilling of the crater floor, leading to a gradual

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reduction in effective crater depth. These processes represent an important phase of post-impact crater modification under tropical climatic conditions.

6. Conclusion

The grain-size analysis of sediments collected along the peripheral boundary of Lonar Lake reveals that seasonal monsoonal inflows play a crucial role in redistributing rim-derived material within the crater. The dominance of poorly sorted, fine-skewed sediments deposited primarily through suspension indicates low-energy lacustrine marginal conditions punctuated by episodic high-energy inflow events. Progressive sediment accumulation along the lake margin contributes to gradual crater infilling and reduction of effective crater depth. The study underscores the importance of climate-driven sedimentary processes in controlling the post-impact geomorphic evolution of Lonar Crater.

Declaration of Competing Interests

The authors declare that they have no financial interests, non-financial interests, or competing relationships that could have influenced the research presented in this manuscript.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions

P.N. Chikhalkar was responsible for the conception, fieldwork, data collection, analysis, interpretation, and drafting of the manuscript. M.M. Kasdekar contributed to the preparation and arrangement of figures. Dr. Y.K. Mawale assisted in data interpretation and provided critical revision of the manuscript for intellectual content. All authors reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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