Grain-size Analysis and Depositional Environment of Lameta Sediments Exposed at Salbardi and Belkher, Amravati District, Maharashtra and Betul District, Madhya Pradesh

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Abstract: Grain-size analysis of sixteen sandstone samples from two exposures of Lameta sediments (Upper Cretaceous) laying at Salbardi (lat. 21°25’15” N; long.78°00’00”E) and Belkher area (lat. 21°21’48” N; long.77°31’23”E) has been carried out to measure the textural and statistical parameters. The sandstones of both the successions are mainly medium to fine-grained, moderately-sorted, near-symmetrical to fine-skewed and mesokurtic in nature. Inter-relationships of various parameters show unimodal to bimodal nature of the sediment, of which, the medium-sand size grains are the principal mode. Based on the granulometric analysis, the environment of deposition is adjudged to be fluviatile for sandy units.

Keywords: Lameta, Granulometric analysis, Depositional environment, Salbardi, Belkher.

INTRODUCTION

The Lameta lithounits are exposed as isolated patches at three near-by places viz., Salbardi (lat. 21°25’15” N; long.78°00’00”E), Bairam (lat. 21°22’25” N; long.77°37’23”E) and Belkher area (lat. 21°21’48” N; long.77°31’23”E), close to the boundary of Madhya Pradesh and Maharashtra (Fig. 1). The sediments are mainly represented by greenish, brownish and yellowish clay; friable to hard, reddish-brown, brownish to greenish, medium-grained sandstones; and, siliceous, brecciated and nodular limestones constituting 34m, 39m and 47m thick lithocolumns, respectively, at above-mentioned localities. However, at Bairam area, the sandy unit is not well developed. So far, all the three lithounits are never subjected to detailed sedimentological investigation and bear only casual reports about their occurrences with minor details (Srivastava et al., 1995, 1996, 1999, 2001, 2003; Saxena, 1987; Ravishankar et al., 1991; Gawande 2003; Rawale, 2004).

In the present study, the sandstones of Salbardi and Belkher areas are considered for detailed grain-size analysis apart from establishing detailed sedimentological log. Various parameters viz., mean, standard deviation, skewness and kurtosis and, their inter-relationships have been worked out to decipher the nature of sediments and environment of deposition. As, the data is generated from the sandy units only, therefore, interpretations are also limited to the same.

GEOLOGY AND STRATIGRAPHY OF THE AREA

The Lameta successions along with the uppermost Gondwana are exposed due to roughly E-W trending Satpura Fault, which is locally known as the Salbardi Fault, in Salbardi area (Ravi Shankar et al., 1991). The Salbardi area lies at about 60 km east of Bairam-Belkher area. Both the sedimentary lithounits are still very less explored for their sedimentological and palaeobiological details, however, the underlying Gondwana has been referred to in a few earlier works (Pascoe, 1959; Adyalkar, 1975; Bhusari, 1979), which reflect a controversy about the age and stratigraphic position of these sediments. Recently, the Gondwana succession of Bairam-Belkher area has been assigned an Early Cretaceous age on the basis of rich and diversified megafloral assemblage including *Pilophyllum*, *Taeniopetis*, *Elatoicladius*, *Pagiophyllum*, *Brachyphyllum*, *Araucarites* etc. (Srivastava et al., 1995, 1999, 2001, 2003 and Gawande, 2003). The same age has also been assigned to the Gondwana succession of Salbardi area, mainly on the basis of its similarity in lithological set-up including pebbly horizons in topmost part of the successions and facies architecture with those of the Bairam-Belkher area (Srivastava and Mankar, 2008).

Stratigraphically, the Lameta overlies the Gondwana with a disconformable contact. The Deccan Trap overlies the succession forming a regional exposure of vesicular
Fig.1. Generalized geological map of Bairam, Belkher and Salbardi area, (modified from district resource maps of Amravati and Betul, GSI, 2001, 2002).

Table 1. General stratigraphy of Salbardi and Belkher area. At Belkher, Achaean not exposed.

<table>
<thead>
<tr>
<th>Age Quaternary</th>
<th>Lithounits</th>
<th>Roc types Soil and Alluvium</th>
</tr>
</thead>
<tbody>
<tr>
<td>U. Cretaceous to Eocene</td>
<td>Deccan Trap</td>
<td>Non-porphyritic and porphyritic basalt</td>
</tr>
<tr>
<td>U. Cretaceous</td>
<td>Lameta</td>
<td>Sandstone, shale and limestone</td>
</tr>
<tr>
<td>U. Cretaceous</td>
<td>Disconformity</td>
<td>Upper Gondwana Sandstone, siltstone, Conglomerate and clay</td>
</tr>
<tr>
<td>Archaean</td>
<td>Unconformity</td>
<td>Quartzo-feldspathic gneiss with dolerite intrusions</td>
</tr>
</tbody>
</table>

to non-vesicular basalts. The trap is overlain by soil and alluvium of Quaternary and Recent age, which forms the top most horizons. The basement to Gondwana is of quartzo-feldspathic gneiss of Archaean age, which is exposed at Salbardi area (Deshpande, 1998) (Table 1).

LAMETA SUCCESSIONS OF THE AREA

The Lameta of Belkher and Salbardi area is almost similar, represented by limestone, calc-marl and arenaceous units (Figs. 2 & 3), however, the succession of Belkher area is comparatively well developed. At Belkher, it constitutes ca. 47m thick lithocolumn, of which, the lower part shows preservation of thinly-bedded, brownish to reddish, medium to fine-grained, loose to compact sandstones (Figs. 2, 4A & 4B). Bioturbated zones are also recorded. The upper part of succession is dominantly calcareous represented by nodular, brecciated and chertified limestones. At Salbardi, the lower sandy horizons is represented by only 12m thick unit, whereas, the upper calcareous part is similar to Belkher area, making a lithocolumn of ca. 34m thickness (Figs. 3, 4C & D). The Bairam area shows good development of only calc-marl unit. The arenaceous unit, though present, but less developed.

SAMPLING AND METHODOLOGY

A total of sixteen sandstone samples have been analyzed, of which, eleven belong to Belkher area and rest of five to Salbardi area. The samples are collected at close intervals, depending on bedding geometry, grain-size and colour variations.

Sievng technique as proposed by Ingram (1971) is applied to separate grains of various size-classes from the sediment admixture. Initially, 100gm of sample is prepared by removing carbonates and organic matters by treating it with 10% dilute hydrochloric acid and 6% hydrogen peroxide, respectively. The samples, completely free from carbonate and organic matter are subjected to sieve analysis. The sample was placed in the BSS sieves arranged at half phi (φ) interval, starting from 8 mesh (1.25 φ), 12 mesh (0.75 φ), 16 mesh (2.5 φ),
Fig. 2. Detailed sedimentological-log of Lameta succession exposed at Belkher area.

0.25 \phi, 22 mesh (0.35 \phi), 30 mesh (0.75 \phi), 45 mesh (1.50 \phi), 60 mesh (2.00 \phi), 85 mesh (2.60 \phi), 120 mesh (3.0 \phi), 170 mesh (3.50 \phi), 240 mesh (4.10 \phi) and -240 mesh (4.25 \phi), and was shaken for thirty minutes in sieve-shaker. The retained fractions on each sieve i.e., weight percentage, served as the basic data for the reconstruction of the cumulative curves, which are further applied to generate various statistical parameters as proposed by Folk (1980), Reinick and Singh (1980), Pettijohn (1984), Lindholm (1987) and Sengupta (1996). Various graphical and statistical parameters of the sediments of both the successions are given in Table 2.

RESULTS AND DISCUSSION

Cumulative weight percentage frequency curves

The cumulative weight percentage frequency curves of the sediments belonging to both Belkher and Salbardi exposures show the dominance of medium to fine-grained sediments, and exhibit almost similar trend i.e., little sorting of grains and dominance of medium sand-size fraction (Fig. 5).

Statistical parameters

Inclusive Graphic Mean (Mz)

Graphic mean (Mz) is a measure of central tendency. The average mean value of Salbardi sediments is a little higher than that of the Belkher sediments i.e., 1.92\phi and 1.53\phi respectively, however, the general tendency is the dominance of medium sand-size sediments. Solitary sample (BLL-3) showing lower value i.e., 0.97\phi is because of comparatively higher fractions of coarse-grained sediments (Fig. 6A). It may be due to the temporary increase in the energy condition of depositional environment.
Fig. 3. Detailed sedimentological-log of Lameta succession exposed at Salbardi area.

Table 2. Graphical and statistical measures of the sediments belonging to Belkher and Salbardi area.
Fig. 4. Field photographs showing - A & B) thinly-bedded, medium-grained sandstone (Belkher area), C) thinly-bedded, fine-grained, friable sandstone (Salbardi area) and D) medium-grained, cross-bedded sandstone (Salbardi area).

Fig 5. Cumulative curves showing trend of all samples.
**Inclusive Graphic Standard Deviations (σ)**

The graphic standard deviation (σ) measures the sorting or uniformity of particle-size distribution. In general, the sediments show poor to moderate sorting with an average standard deviation of 1.03σ (Fig. 6B). The sediments of Salbardi area are poorly-sorted (av. 1.26σ) whereas, the Belkher sediments are poor to moderately-sorted with an average of 0.95σ.

**Inclusive Graphic Skewness (Sk)**

The graphic skewness (Sk) measures the asymmetry of distribution i.e., predominance of coarse or fine-sediments. The negative value denotes coarser-tail i.e., coarse-skewed, whereas, the positive value represents more fine material in the fine-tail i.e., fine-skewed.

The skewness values range from 0.01σ to 0.50σ for the Belkher sediments, whereas, 0.01σ to -0.25σ for Salbardi sediments, falling together between near-symmetrical to very fine-skewed categories (Fig. 6C). However, the complete assemblage shows the dominance of fine-skewed category, followed by near-symmetrical category shown by six and five samples, respectively. Very fine and coarse-skewed categories are represented by one and three samples, respectively.

**Inclusive Graphic Kurtosis (K)**

The graphic kurtosis (K) is the peakedness of the distribution. It measures the ratios between the sorting in the tails and central portion of the curve. If the tails are better sorted than the central portion, then it is termed as leptokurtic, whereas, it is platykurtic in opposite case, or mesokurtic if sorting is uniform both in tails and central portion. The values obtained from both the successions range widely between 0.56σ to 2.84σ (Fig. 6D). However, there is a dominance of very leptokurtic sediments represented by six samples, followed by leptokurtic to mesokurtic sediments represented by four samples each. The platykurtic condition is represented by only two samples. It shows that both coarse and fine fractions of most of the sediments are subjected for the sorting by the depositing medium to some extent.

![Fig 6. Comparative histograms of all samples showing trends of - A. mean, B. standard deviation, C. Skewness, and D. kurtosis values.](image)

**Bivariate plots**

The basic idea behind the inter-relationship analysis is the fact that changing patterns of the textural parameters of the sediments have an established relationship with environmental set-up (Folk and Ward, 1957; Friedman, 1961, 1967; Moiola and Weiser, 1968). Plots between certain parameters are also helpful to interpret the energy conditions, medium of transport, mode of deposition etc. (Passega, 1957; Vischer, 1969). In the present study, these plots are basically used to interpret the nature of sediments, environment of deposition and energy condition of the medium of transposition.

**i. Plots Showing Nature of Sediments**

The nature of sediment admixture is interpreted by inter-relationship plots of mean, standard deviation, skewness and kurtosis, as proposed by Folk and Ward (1957). The scatter between mean vs. standard deviation shows either ‘V’ or inverted ‘V’ trend, which denotes very smaller size-range (Folk and Ward, 1957). Accordingly, the present values show a very small size-
Fig. 7. Bivariate plots showing the placement of present samples in the model plot of Folk and Ward (1957) for- A) mean vs. standard deviation, B) mean vs. skewness, D) Skewness vs. standard deviation and E) standard deviation vs. kurtosis.

range, as the points are concentrated near the extreme end of the right limb of inverted V-shaped established trend of Folk and Ward (1957) (Fig. 7A). It is also supported by the average graphic mean value, which also confirms the dominance of medium sand-size sediments. A close observation of the mean vs. skewness plot (Fig. 7B) shows that the present data correspond to the established sinusoidal curve of Folk and Ward (1957). This established sinusoidal curve (Folk and Ward, 1957) is based on the proportion of two size-classes in the admixture of the sediment e.g., gravel and sand, which may produce either positive or negative skewness depending upon the proportions of size-classes in the admixture, otherwise, symmetrical in case of equal fractions. The present plot shows that the points are mostly clustered near normal graph in the range of near-symmetrical category of skewness, however, a few negative as well as positive-skewed samples are also represented, falling in the mean-size range of 1.0 to 2.09. Overall, the assemblage shows two categories of samples i.e., one having large number of samples shows unimodal nature of sediments whereas, second with less samples is bimodal. The medium-sand is the principal mode which looses the symmetrical distribution because of the addition of coarse or fine-sediments in the admixture, resulting in bimodal nature of the sediments.

The mean-size vs. kurtosis is also an important criterion to differentiate the mode of size-classes in an admixture of the sediments (Folk and Ward, 1957). It depicts the mixing of two or more size-classes and is a determining factor of the sorting in peak and tails i.e., index of kurtosis. The scattering of points give rise to an inverted ‘V’ shape trend, which depends on the proportion of two modes in the mixture. The scatters of present values indicate the dominance of mesokurtic (0.90 to 1.11) condition, whereas, sorting in peak as well as in tails is almost equal (Fig. 7C). But, in certain samples, mixing of the finer mode in varying proportions is clearly visible, as the points above the normal curve goes up to 2.49 value, i.e., very leptokurtic condition. Similarly, sediment admixture with coarser material is also represented, but very less.

Both, skewness vs. standard deviation and standard deviation vs. kurtosis are also used to interpret the presence of various size-modes in the sample (Folk and Ward, 1957). The skewness and standard deviation bear a mathematical relationship because both are the
functions of mean-size. The plot of these two variables produce nearly circular ring in the case of either unimodal samples with good sorting, or, equal mixture of two modes (Folk and Ward, 1957). In the present plot, most of the points are within the circular ring, concentrating in lower half, almost equally distributed on both sides of the normal curve, in the range of moderate to poorly-sorted category (Fig. 7D). It denotes that the samples, though, dominantly unimodal but, subordinate mode is also well represented in a few samples, hence, bimodal. The same is also supported by standard deviation vs. kurtosis plot (Fig. 7E).

ii. Plots Showing Depositional Environment

The depositional environment is interpreted as per the criteria proposed by Friedman (1967) and Moiola and Weiser (1968). The inter-relationship between mean vs. standard deviation and standard deviation (horizontal axis) vs. skewness (vertical axis) are considered to be significant tools to differentiate between beach and river environments (Friedman, 1967; Moiola and Weiser, 1968). Accordingly, both the plots show that the deposition of Lameta sediments took place under river influence, as all the points are falling in river-sediment sector of both the plots (Figs. 8A, B). Similarly, Friedman (1967) proposed the plot between SOS = \( \frac{1}{2} (\phi_{50} - \phi_{0}) \) and SKS = \( (\phi_{50} + \phi_{0}) - 2 \phi_{50} \) to differentiate between beach and river environments. This criteria also confirms fluvial environment of deposition, as all the points in the present cross-plot of both the successions are restricted in the river sector of the standard plot as proposed by Friedman (1967) (Fig. 8C).

Based on the above-mentioned plots, it is concluded that the sandstone units of both the successions are a product of fluvial environment. This interpretation is specific to the sandstone units only, as the overlying and underlying lithounits of different composition may shows different environmental set-up. The lower part of both the successions show preservation of greenish-brownish-yellowish clay, which is lithologically correlatable with lacustrine facies of Nand-Dongangaon, (Mohabey and Samant, 2005). Similarly, the chertified, brecciated carbonate unit (Raiverman, 1995; Kumar et al., 1999; Tandon and Andrews, 2001), calcite horizons and bioturbated unit with long, slender, branched burrows in the upper part are also correlatable with the lithological architecture of Lametas in the type area of Jabalpur (Kumar and Tandon, 1978, 1979).

iii. Plots Showing Energy Condition

The C-M scatter, C- coarser one percentile value in micron, and M- median value in micron, plotted on log-probability scale, as proposed by Passega (1957) is an important tool to evaluate the hydrodynamic forces working during the deposition of the sediments. The present interpretation is based on Passega (1957, 1964) and Passega and Byramjee (1969). The plot shows that most of the samples fall in N-O and O-P regions of sector I, which indicates dominantly rolled sediments, followed by a few suspension sediments, representing their deposition through traction currents (Fig. 9). The C-value, in general, is more than one millimeter. A few samples, falling in II and IV sectors, show mainly rolled and suspension categories, which may be due to comparatively more percentage of coarse or fine-grained material respectively, in the admixture.

Visher (1969) proposed log-probability curves, which provide an idea about the relationship of grain-

![Fig.8. Bivariate plots showing environment of deposition - A) standard deviation vs. mean, B) standard deviation vs. Skewness, and C) simple sorting measure (SOS) vs. simple skewness measure (SKS).](image-url)
Fig. 9. C-M plot showing concentration of grains in upper right corner.

Fig. 10. Arithmetic probability curves (A to F) showing the trends of traction, saltation and suspension sub-populations of all samples.
size distribution and sediment transport. The plot is basically the representation of cumulative grain-size distribution on the probability (ordinate) paper with a view to construct straight line sectors, known as sub-populations. The dimensions and inter-relationships of the sub-populations i.e., length, slope and intersection points provide an important information about mode of transporting i.e., traction, saltation and suspension. The log-probability plots of all the samples, in general, show that the major sub-population is of suspension followed by saltation, which is mainly due to the fine-grained nature of the sediments. The traction sub-population, though represented, but, constitutes a very less proportion (Figs. 10A, B, C, D & E). It is because of variable proportions of medium-grain sediments in a few samples. Most of the intersection points between traction and saltation sub-populations are close to 0.35<sub>0</sub> value, whereas, it is closer to 1.0<sub>0</sub> for saltation and suspension, wherever, the saltation is clearly demarcated by suspension. The general dominance of medium-grained sediments in a few samples are exhibited by a straight line graph which may show one traction point depending upon the content of fine-grained constituents in the admixture (Figs. 10F).

The dominance of suspension and saltation populations is comparable with established trend of modern and ancient fluvial deposits as proposed by Visher (1969).

CONCLUSIONS

Grain-size analysis of a total of sixteen sandstone samples belonging to calc-marl-arenaceous Lameta successions exposed at Belkher and Salbardi areas have been carried out. The sandstone units are restricted to the lower part of both the successions, however, thickness is comparatively more in Belkher area as compared to Salbardi area. The important conclusions drawn on the basis of granulometric analysis are as follows:

i. The frequency curves indicate a medium to fine-grained nature of the sediments, of which, medium-grained sand dominates. The same is also evident from the average mean-size value of the sediments.

ii. In general, the sediments are moderately sorted, near-symmetrically skewed and very leptokurtic in nature. However, skewness and kurtosis exhibits a wide range because of low to medium sorting of the sediments.

iii. The inter-relationship plots between mean, skewness, kurtosis and standard deviation as proposed by Folk and Ward (1957) indicate a unimodal to bimodal nature of the sediments. The principle mode is medium sand which is mixed with coarse and fine-grained sands or silts.

iv. The plots between standard deviation vs. mean and standard deviation vs. skewness as proposed by Friedman (1967) and Moiola and Weiser (1968) indicate a fluvial environment of deposition. The same is also the outcome of SOS vs. SKS plot (Friedman, 1967).

v. The C-M pattern shows that the sediments are mostly rolled having little suspension, and deposited mainly by traction currents.

vi. The log-probability curves are also indicative of fluvial environment of deposition.

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