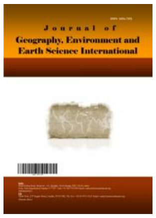

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# Facies Analysis of Eocene Sediment of Umuahia Area, Southeastern Nigeria

**A. C. Ezebunanwa[1*], J. I. Eronin[1], V. Okorie[1], E. C. Mbagwu[1] and Njoku Achu Uchenna[1]**

[1]*Department of Geology, Federal University of Technology, Owerri, Nigeria.*

***Authors' contributions***

*This work was carried out in collaboration among all authors. Author ACE designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors ECM and JIE managed the analyses of the study. Author JIE managed the literature searches. All authors read and approved the final manuscript.*

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## ABSTRACT

This research work is the detailed facies analysis of the depositional environments and paleogeographic setting of the Eocene sedimentary sequence (Ameki Formations) exposed in the Umuahia area and paleoclimate during that periods. The study area was mainly concentrated around Amaudara inUmuahia South and Ekeoha in Umuahia North. And the co-ordinate are as follows,location-1 0.5°30.80N, 0.7°26.93E, location-2 0.5°30.39N, 0.7°26.62E, location-3 0.5° 32.83N, 0.7°27.24 E and location-4 0.5°32.19 N, 0.7°26.13 E.

The aim of the study is to analyze the detailed sedimentary facies and describe the depositional environment in other to predict the depositional environment of the Eocene sediment (Ameki Formation) of the study area, which is underlain by rock unit of Ameki and predominately contains Laterite, mudstone, siltstone, claystone, sandstone and shale and Burrows were identified.

The rock sequence consist of reddish lateritic material, highly weathered mudstone capped with ripped bedded kaolinite clay unit, light grey claystone, cross-bedded sandstone with claystone, whitish sandstone, siltystone, fine-medium grained sandstone with pockets of mudclast capped with ferruginized ground and dark grey shale.

**Corresponding author: E-mail: anthonyeze00@gmail.com;*

On the basis of gross lithology, sand-silt-clay percentage, color, texture and assemblage of sedimentary structure, eight distinct lithofacies type were recognized, grey shale facie (Gs), clay stone facie (Cs), cross-bedded sandstone facie (Cbs), mudstone facie (Mf), lateritic facie (Lf), mudstone facie (Bms), ferruginized sandstone facie (Fsf), sandstone facie (Bsf) are recognized within the lithosuccesion.

From the analysis, the facies are grouped into two facie association on the basis of grain size. The Fine-grained facies association (FFA) which consist of Gs, Cbs, Cs, Mf and Fst and the Medium to Fine-grained facies association (MFA) which also consist of Bms, Bsf and Lf. It also shows medium grained sand, moderately sorted to well sorted sandstone, Skewness ranged from symmetrical to positive skewed and kurtosis showed leptokurtic.

Deduction from facies analysis and grain size analysis shows that Ameki Formation consist of foraminifera and Mollusca which indicate that Ameki Formation was deposited in the estuarine(Marine) environment.

*Keywords: Depositional; Markov; Ameki; facies; Amaudara; Ekeoha; lithofacies.*

## 1. INTRODUCTION

A sedimentary deposit is therefore that body of solid materials accumulated at or near the surface of the earth under low temperature and pressure.

Sedimentation particles are produce from pre-existing rocks, which undergo transportation and subsequent deposition to produce sedimentary rock. The sediment is generally but not always deposited from fluid in which it was contained either in a state of suspension or as bed load [1,2]. The deposits are traditionally largely the result of breakdown of pre-existing rocks, (weathering product) which have been re-distributed by wave and currents or precipitated chemically or biochemical from solutions.

Basically, any sedimentological study commences with a description of the physical properties of the deposit arising from sedimentary processes. It is interesting to note that by studying the physical and biological characteristics of modern environments, one can provide a key concept about the past [3,4]. Such studies include lithological, paleontological, granulomentric and structural analysis of sedimentary deposits.

The study of sedimentary structures is not only of interest in relation to environmental analysis but also as a guide to ascertaining the current systems prevailing during the accumulation of sediments. The paleocurrent system can thus be reconstructed by measuring and mapping primary current structure [5].

## 2. LOCATION AND ACCESIBILITY

The location is centered at Amaudara in Umuahia South and Ekeoha in Umuahia North. Location 1, 2 and 3 is located along Umuahia-Aba road with co-ordinate as follows location-1 0.5°30.80 N, 0.7°26.93E, location -20.5°30.39 N, 0.7°26.62 E, location-3 0.5°32.83 N, 0.7°27.24 E and location 4 is located along Ekeoha Ohuhu-Ihette-Uboma road, the elevation is 340ft above the mean sea level and it lies with latitude 0.5°35.19 N and longitude 0.7°26.13 E. The study area is bounded in the North by Umuahia North, Isiala Ngwa in the South, Ikwuano LGA in the east and the Imo River demarcates it with Imo state in the Western part.

## 3. PHYSIOGRAPHY

### 3.1 Climate

The area is characterized by high temperature of about 29° - 31°. The highest temperature occurs in February and March at the end of dry season. The lowest temperature occurs in July, August and September and these Months have the highest degree of cloudiness, and causes lowering of the day-time temperature.

Rainfall varies widely over short distance and from year to year. Mostly the rainy season starts in April or May and runs through September or October, making the mean annual rainfall between 1933 mm – 2329 mm of the mean 180 days of the rainy days, it has double maxima rainfall peaks in July and September.

The vegetation of the study area lies within the guinea savanna. The vegetation is grassy and scattered trees are common being the Shea butter tress, bamboo trees, mahogany. The forest is thick similar to those in Okigwe and some area in southeastern Nigeria. Vegetation is characterized by oil palm trees crops,fruits and grass lands.Visibility is fair and people can see and talk up to 200 m apart.

## 4. GEOLOGY OF THE STUDY AREA

The study area is Ameki formation it is a shallow marine sequence and tidal deposits. It contains Nanka sands which is coarse and loose, siltstone, claystones as well as shelly limestones sandy shales mudstones interbeds with basal sandstone that is is coarse and cross-bedded.It is divided into two lithologic units: lower and upper Ameki. The upper beds contain coarse sandstones while the lower beds consist of massive dark grey to brown sandy mudstone. The formation is about 300 m thick composed mainly of sands intercalated with calcareous shales. This formation is aquifereous, but not to the same extent as the coastal plain sands. Its transmissivity coefficient is lower because of the higher percentage of shale.

## 5. METHODOLOGY

Two methods were used for the study of the area.

### 5.1 Field Studies

An E-TREX Geographic Positioning System (GPS) was used to reference the outcrop location on the base map, each section was subdivided into litho-units which were later assessed based on textural, structural geometrical and paleontogical characteristics. Photographs of outcrop location/units were taken with a camera. The thickness of the unitswere measured with a Pogo stick, also bed orientation with respect to space were estimated with a Brunton compass. A field lithologic section was subsequently drawn to represent all observation pictorially. Samples were collected from each unit labeled and packaged for further studies in the laboratory.

### 5.2 Laboratory Analysis

The measurement of particles size is of the most useful techniques used for sediment analysis. It helps in the understanding of processes of transportation and deposition of sediments. The samples collected from the outcrops of the study area were subjected to sieving, and the procedure used for sieving in the laboratory is presented below.

#### 5.2.1 Procedure for sieve analysis

Sieving is a method of mass measurement used in evaluating the size frequency distribution of sedimentary particles in sand-size fraction -1 to 5 (0.062-2.00 mm). This was carried out at the Department of Geosciences, Federal University of Technology, Owerri. The equipment for this analysis includes a set of sieve, an automatic sieve shaker, and a sensitive beam balance.

Preparation of samples for analysis; unconsolidated sandstone sediments were dried then placed on a large sheet of glazed paper then crushed with the finger. Sandstone amenable to sieving are the loose and friable sandstones, poorly cemented calcareous.

Seven (7) sandstone samples were selected for the analysis and they were first sun dried 50-100g of each sample was shaken in a nest of sieves arranged in phi(Φ) interval with an automatic sieve shaker for 15 minutes. The sand fractions retained in each sieve is then weighed and the weight recorded in a sieve analysis data sheet. The weight percent and cumulative frequency curves are presented graphically as histograms and cumulative frequency curves. The cumulative frequency curve was presented on probability(log) scales for the percentile ordinate of Friedman and Sander [6]. Grain sizes of 0.875, 1.395, 1.477, 1.851, 1.668, 2.497 and 2.715 percentile were obtained and were used to calculate the graphic mean, standard deviation, inclusive graphic skewness and graphic kurtosis for each sample. This calculation were based on a formulae by Folk and Ward [7].

#### 5.2.2 Methods for lithofacies analysis

At first in field, a detailed investigation was carried out in order to have information about distinguishable rock units based on gross lithology, internal homogeneity of sedimentary texture and sedimentary structures for the preparation of lithologs. The outcrops were selected on the basis of bed attitude, lithology, minor and major structures. At each exposure, various data were acquired and noted; such as attitude of the rock exposure, gross lithology, sedimentary structure etc and to serve these purposes, clinometer, pocket lenses as well as HCl acid were used. Seven (7) samples were collected from the outcrops for the study of sedimentary characteristics. Thickness of the sequence and bedding planes are measured accordingly. Photographs were also taken at each outcrop during the investigation. Every centimeter of the exposed sediments were closely examined to identify lithology, texture, internal sedimentary structures, boundary conditions and also to identify the individual lithofacies with its depth and thickness. Lithofacies are coded according to lithofacies coding schemes of Miall [8].

First-order Embedded Markov Chain method has been applied to formulate transitional matrix of the Eocene sedimentary sequence of the study area. This method has been used to count transition matrix and analyze to facilitate tabulation of transitions from one facies to another. All the results are tabulated and presented accordingly.

**a) Tally matrix:** The numerical observed numbers of transitions are tabulated and has put into a tally matrix. The boundary type between facies is indicated by the coded sequence.The numbers to the right of the matrix indicate the total number of transitions in each row and the number below the matrix indicate the total number of transitions in each column. Row and column totals for a given facies may be different from each other.

**b) Transition probability matrix:** Second matrix, the transitional probability matrix is constructed by converting the observed transition numbers where each number of transitions in each cell has been divided by the total number of transitions for the row containing the cell (row total) in the tally matrix.

**c) Independent trials probability matrix:** Based on the assumption that all facies transitions are random; it has constructed an independent trials probability matrix. The independent trial probability matrix or transitional probability for random sequence matrix is calculated by using following formula,

$$Rij=SCj/ (T-SCi)$$

Where,

Rij = Random probability of transition from facies i to j.
SCj = The random number of occurrence of facies j (column total of facie j).
T = Total number of transition for all facies.
SCi = Number of occurrences I (column total of facies i).

One of the characteristics features of the embedded Markov Chain is its diagonally empty cells that mean all values are zero.

**d) Difference matrix:** Difference matrix has been constructed by the observed minus the random probabilities. The range of values is +1.0 to –1.0. Positive values means transition occurs more frequently than random whereas negative values indicate transitions occur less frequently than random.

**e) Facies relationship diagram:** A simplified facies relationship diagram using transitions with ‘high’ positive values has to be drawn. Transitions with lower positive values may be added using different symbols, (e.g. light solid lines or dashed lines). In the diagram arrows indicate gradational versus sharp contacts.

### 5.3 Markov Chain Analysis

A Markov process may be defined as a process in which the probability of the process being a given state at a particular time may be deduced from the knowledge of the immediately preceding state [9]. This model demonstrates growing interest in application of probabilistic mechanisms in stratigraphy, sedimentation, paleontology, geomorphology, petrology and other aspects of earth sciences. First-order Markov Chain is the simplest model. The basic structure of this model is that the nature of an event is dependent to some degree on the nature of the preceding event, but independent of all events previous. First-order Embedded Markov Chain model has been used to count transition matrix and analyze these to facilitate tabulation of transitions from one facies to another. The observed numbers of transitions are tabulated and put into a tally matrix. Type of boundaries between facies (sharp or gradational) is indicated in the coded sequence. Then second matrix, the transitional probability matrix is constructed by converting the observed transition numbers where each number of transitions in each cell has been divided by the total number of transitions for the row containing the cell (row total) in the tally matrix. The independent trial probability matrix or transitional probability for random sequence matrix is calculated using formula. Difference matrix is determined by subtracting the random probabilities from the observed probabilities. Individual values in each cell in the random probability matrix are subtracted from the values in each cell in the observed transition probability matrix. The positive values indicate transitions that occur more frequently than would be the case if the facies were arranged randomly. From this difference matrix facies relationship diagram has been constructed and from this a summery sequence or facies sequence model has been reconstructed for paleoenvironmental interpretation. Facies relationship is the relationship between epositional environments in space and the resulting stratigraphic sequence developed through the time as a result of ransgression and regression as well as allocyclic and autocyclic migration of environmental settings [6,10].

To construct facies relationship diagram of the sequence and to identify the cyclical characteristics of the lithofacies first-order embedded Markov model is use during construction of this diagram vertical transition from one lithofacies to another and their boundary condition are taken into consideration. Tally matrix of the sequence from both the flanks was counted and constructed (Table 5). From tally matrix, transition probability matrix, independent trial probability matrix and difference matrix have been calculated and tabulated accordingly (Tables 6,7,8,). Finally from the difference facies relation diagrams (Figs. 6-9) and facies sequence models (Fig. 10 facie model) have been constructed. Facie relationship diagram shows that the stable relationship which is indicated by bold line exist between the lithofacies, Gs, Cs, Cbs, Mf and Fst for the Eocene sequence of the study area (Fig. 7). The most abundant facies are Gs and Cbs and the facies transition indicate that Eocene sedimentary sequence forms a fining upward sequence which indicates the gradual decrease in velocity of current. The stable relationship exist between the lithofacies Gs, Cbs, Cs, Mf and Fsf for the Eocene sequence of the study area (Fig. 7). Overall lithofacies relationship shows a fining upward cyclicity. Maximum occurance present in facies Gs, Cbs, Mf, and Fsf and minor lithofacies are Lf, Bms and Bsf.

## 6. RESULTS

### 6.1 Presentation of Litholog

#### 6.1.1 Lithostratigraphic description of location-1 of the study area

The location is situated at Latitude N0.5°30' and Longitude E07°26'. The location is a mining site (burrow pit) were they produce kaolinite. Seven units were described (Fig.1). Unit one is a light to dark grey shale, plastic and well indurated, about 0.85 m thick overlain by 1m thick claystone with some lenses of whitish sandstone. See Fig.1. While Location 2 is situated along Umuahia Aba road, Latitude N5°30' and Longitude E07°26'.

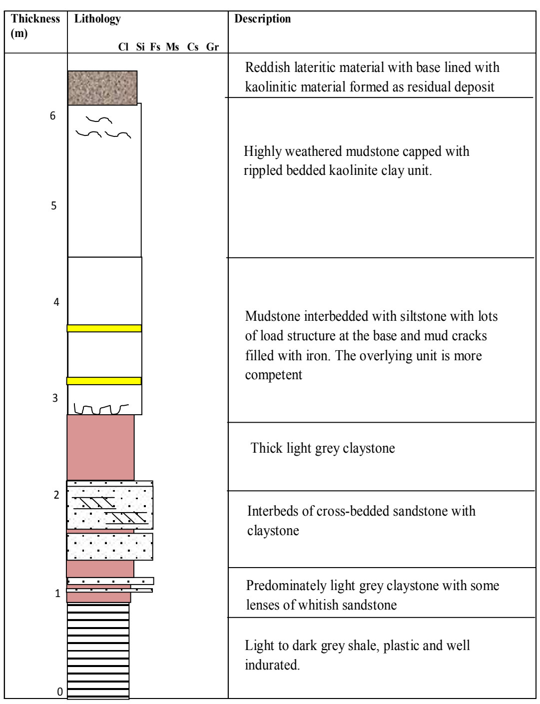



**Fig. 1. Lithostratigraphic description of location-1**

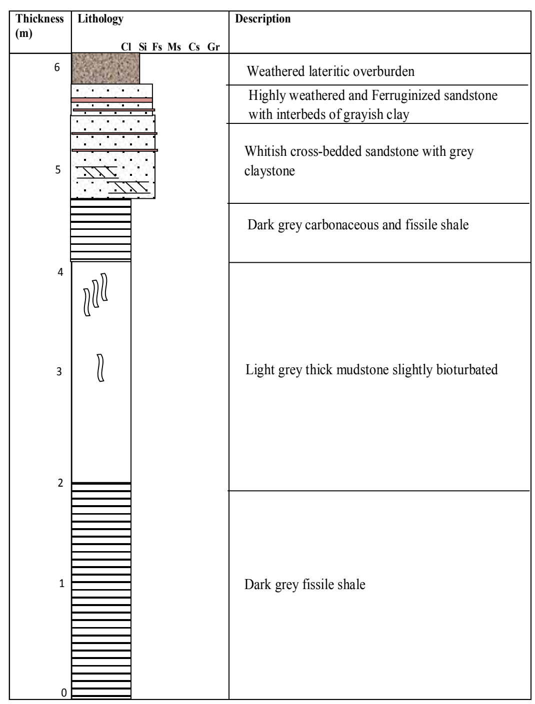



**Fig. 2. Lithostratigraphic description of location-2**

The location is quarry site, Six unitswere described (Fig. 2). The lowermost unit shows a dark grey fissile shale with a thickness of about 1 m and this unit is overlain by 1.50 m thick bioturbated mudstone and a weathered lateritic overburden at the top.

### 6.1.2 Lithostratigraphic description of location-3

The location is situated along Umuahia Aba road, Latitude N5°32' and Longitude E07°27'. The location is road cut exposing part of the outcrops, it has a strike value of 310 NW and dip 14°, the elevation is about 366 ft. (Fig. 3). The lowermost unit shows a very coarse,cross-laminated,internally graded sandstone slightly biotutbated, with a thickness of about 2 m and this unit is overlain by 0.5 m thick fine-medium grained sandstone with pockets of mudclasts and capped with ferruginized ground, and a thick silty claystone with thin bands of siltstone at the top, with a thickness of 1.5 m.

## 6.2 Seive Analysis Results

The results of the grain size statistical parameter evaluated and their interpretation was based on Folk, (1974).

The obtained values were used to calculate the individual and cumulative weight percent of the various samples, from which histograms and cumulative frequency curves were, plotted.

Thereafter, different quantitative values for various percentiles ranging from Φ0 to Φ100 were derived directly from the plotted cumulative curves.

The obtained values were used to evaluate statistical textural parameters such as Graphic Mean (Mz), Inclusive Graphic Standard Deviation (Gsdφ), Inclusive Graphic Skewness (Gsk) and Graphic Kurtosis (Gk) for each sample, using the formulas proposed by Folk and Ward [7] for univariate values and it is useful in inferring depositional processes and hence aid in the interpretation of depositional environments.

The overall grain size interpretation shows that sediments from the study area are medium grained (with the average grain size of 1.783), moderately sorted (with average sorting of 0.714), coarse skewed (with the average skewness of -0.127) and leptokurtic (with the average kurtosis of 1.315) respectively.

The Histogram plots of the individual weight percent against the phi scale show that the sandstones in the study area are majorly unimodal.

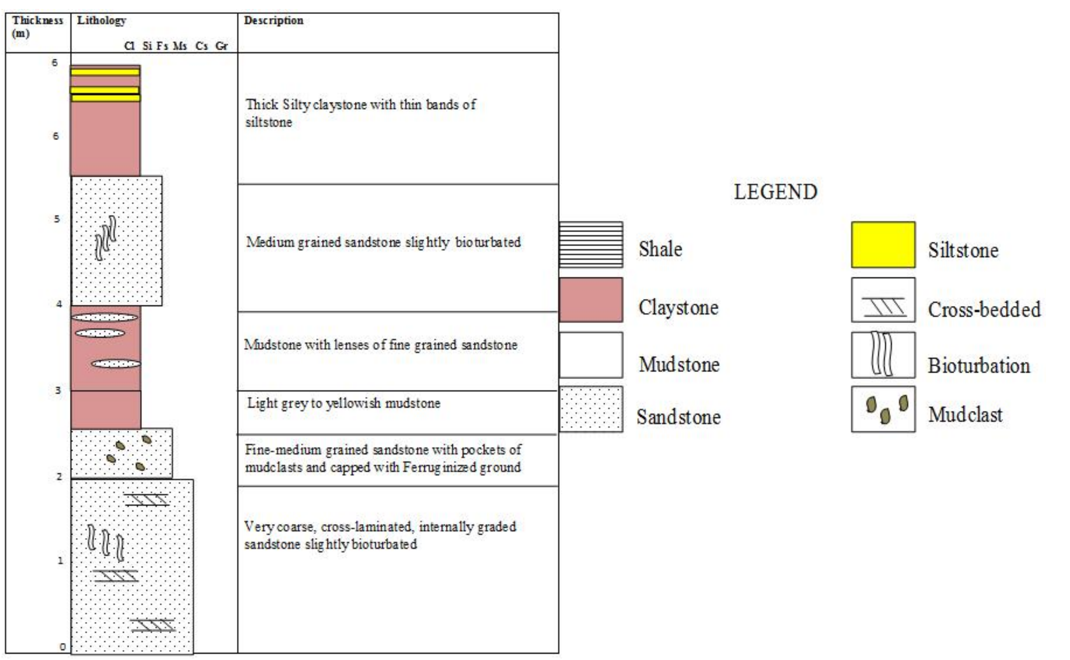



**Fig. 3. Lithostratigraphic description of location-3**

**Sieve Result**

**Table 1. The results sieve analyses of different samples**

| Sample ID | | L1U2 | | | | |
|---|---|---|---|---|---|---|
| | | Starting wt (g) = 78.20 | | | | |
| Mm | phi (Φ) | Weight retained (g) | Corrected Weight retained (g) | % Weight retained | Cum. weight retained (%) | % Pass |
| 2.0 | -1.0 | 0.10 | 0.10 | 0.13 | 0.13 | 99.87 |
| 1.0 | 0.0 | 1.40 | 1.40 | 1.79 | 1.92 | 98.08 |
| 0.5 | 1.0 | 0.20 | 0.20 | 0.26 | 2.17 | 97.83 |
| 0.25 | 2.0 | 6.00 | 6.00 | 7.67 | 9.85 | 90.15 |
| 0.125 | 3.0 | 68.60 | 68.60 | 87.72 | 97.57 | 2.43 |
| 0.063 | 4.0 | 1.80 | 1.80 | 2.30 | 99.87 | 0.13 |
| Pan | | 0.10 | 0.10 | 0.13 | 100.00 | 0.00 |
| Total weight (g) | | 78.2 | 78.20 | | | |
| Sieve loss/Gain (g) | | 0.00 | | | | |

**Table 2.**

| Sample ID | | L1U4B | | | | |
|---|---|---|---|---|---|---|
| | | Starting wt (g) = 50.70 | | | | |
| Mm | phi (Φ) | Weight retained (g) | Corrected weight retained (g) | % Weight retained | Cum. weight retained (%) | % Pass |
| 2.0 | -1.0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 |
| 1.0 | 0.0 | 0.40 | 0.40 | 0.79 | 0.79 | 99.21 |
| 0.5 | 1.0 | 0.80 | 0.80 | 1.58 | 2.37 | 97.63 |
| 0.25 | 2.0 | 8.40 | 8.40 | 16.57 | 18.93 | 81.07 |
| 0.125 | 3.0 | 40.60 | 40.60 | 80.08 | 99.01 | 0.99 |
| 0.063 | 4.0 | 0.30 | 0.30 | 0.59 | 99.61 | 0.39 |
| Pan | | 0.20 | 0.20 | 0.39 | 100.00 | 0.00 |
| Total weight (g) | | 50.7 | 50.70 | | | |
| Sieve loss/Gain (g) | | 0.00 | | | | |

**Table 3.**

| Sample ID | | L2U5 | | | | |
|---|---|---|---|---|---|---|
| | | Starting wt (g) = 183.10 | | | | |
| Mm | phi (Φ) | Weight retained (g) | Corrected weight retained (g) | % Weight retained | Cum. weight retained (%) | % Pass |
| 2.0 | -1.0 | 0.40 | 0.40 | 0.22 | 0.22 | 99.78 |
| 1.0 | 0.0 | 1.70 | 1.70 | 0.93 | 1.15 | 98.85 |
| 0.5 | 1.0 | 45.40 | 45.40 | 24.80 | 25.95 | 74.05 |
| 0.25 | 2.0 | 117.50 | 117.50 | 64.18 | 90.13 | 9.87 |
| 0.125 | 3.0 | 17.30 | 17.30 | 9.45 | 99.58 | 0.42 |
| 0.063 | 4.0 | 0.40 | 0.40 | 0.22 | 99.80 | 0.20 |
| Pan | | 0.37 | 0.37 | 0.20 | 100.00 | 0.00 |
| Total Weight (g) | | 183.07 | 183.07 | | | |
| Sieve Loss/Gain (g) | | 0.03 | | | | |

**Table 4.**

| Sample ID | | L2U6 | | | | |
|---|---|---|---|---|---|---|
| | | Starting wt (g) = 110.60 | | | | |
| **Mm** | **phi (Φ)** | **Weight retained (g)** | **Corrected weight retained (g)** | **% Weight retained** | **Cum. weight retained (%)** | **% Pass** |
| 2.0 | -1.0 | 0.00 | 0.00 | 0.00 | 0.00 | 100.00 |
| 1.0 | 0.0 | 3.80 | 3.80 | 3.44 | 3.44 | 96.56 |
| 0.5 | 1.0 | 45.90 | 45.90 | 41.50 | 44.94 | 55.06 |
| 0.25 | 2.0 | 44.90 | 44.90 | 40.60 | 85.53 | 14.47 |
| 0.125 | 3.0 | 7.50 | 7.50 | 6.78 | 92.31 | 7.69 |
| 0.063 | 4.0 | 2.20 | 2.20 | 1.99 | 94.30 | 5.70 |
| Pan | | 6.30 | 6.30 | 5.70 | 100.00 | 0.00 |
| Total Weight (g) | | 110.6 | 110.60 | | | |
| Sieve Loss/Gain (g) | | 0.00 | | | | |

**Table 5.**

| Sample ID | | L3U2 | | | | |
|---|---|---|---|---|---|---|
| | | Starting wt (g) = 51.80 | | | | |
| **Mm** | **phi (Φ)** | **Weight retained (g)** | **Corrected weight retained (g)** | **% Weight retained** | **Cum. weight retained (%)** | **% Pass** |
| 2.0 | -1.0 | 0.20 | 0.20 | 0.39 | 0.39 | 99.61 |
| 1.0 | 0.0 | 1.60 | 1.60 | 3.09 | 3.47 | 96.53 |
| 0.5 | 1.0 | 12.60 | 12.60 | 24.32 | 27.80 | 72.20 |
| 0.25 | 2.0 | 28.00 | 28.00 | 54.05 | 81.85 | 18.15 |
| 0.125 | 3.0 | 8.10 | 8.10 | 15.64 | 97.49 | 2.51 |
| 0.063 | 4.0 | 1.20 | 1.20 | 2.32 | 99.81 | 0.19 |
| Pan | | 0.10 | 0.10 | 0.19 | 100.00 | 0.00 |
| Total Weight (g) | | 51.8 | 51.80 | | | |
| Sieve Loss/Gain (g) | | 0.00 | | | | |

**Table 6.**

| Sample ID | | L3U1 | | | | |
|---|---|---|---|---|---|---|
| | | Starting wt (g) = 70.60 | | | | |
| **Mm** | **phi (Φ)** | **Weight retained (g)** | **Corrected weight retained (g)** | **% Weight retained** | **Cum. weight retained (%)** | **% Pass** |
| 2.0 | -1.0 | 0.30 | 0.30 | 0.42 | 0.42 | 99.58 |
| 1.0 | 0.0 | 12.30 | 12.30 | 17.42 | 17.85 | 82.15 |
| 0.5 | 1.0 | 34.30 | 34.30 | 48.58 | 66.43 | 33.57 |
| 0.25 | 2.0 | 17.74 | 17.74 | 25.13 | 91.56 | 8.44 |
| 0.125 | 3.0 | 4.80 | 4.80 | 6.80 | 98.36 | 1.64 |
| 0.063 | 4.0 | 1.08 | 1.08 | 1.53 | 99.89 | 0.11 |
| Pan | | 0.08 | 0.08 | 0.11 | 100.00 | 0.00 |
| Total Weight (g) | | 70.6 | 70.60 | | | |
| Sieve Loss/Gain (g) | | 0.00 | | | | |

## 6.3 Sandstone Classification

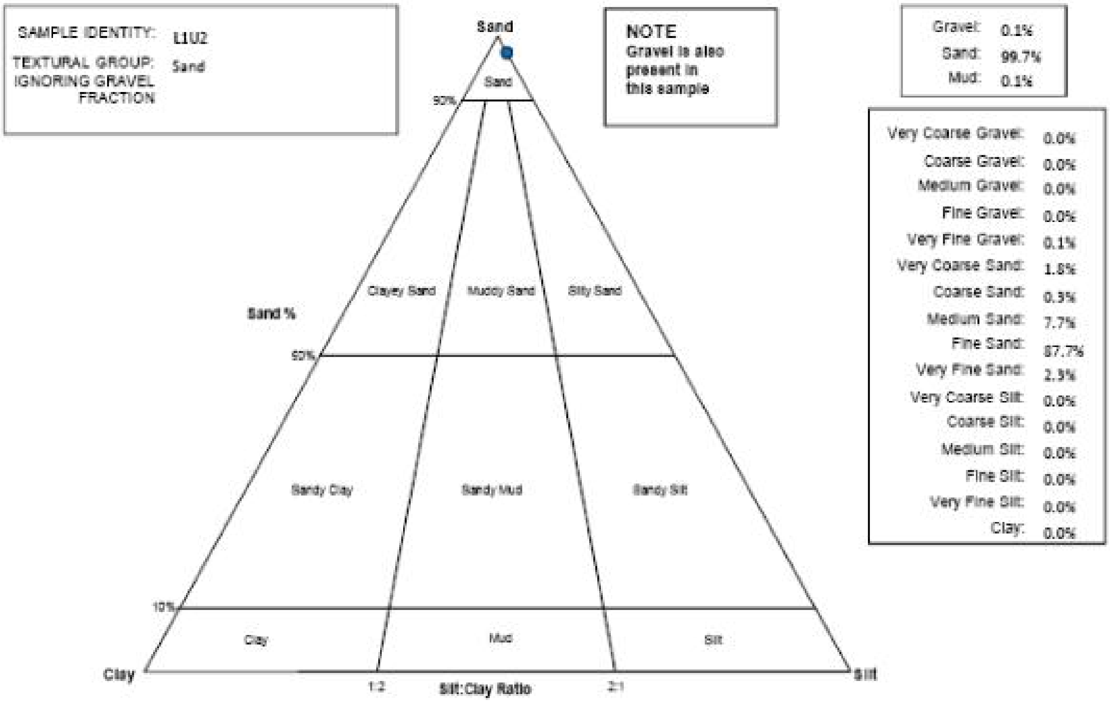



**Fig. 4.**

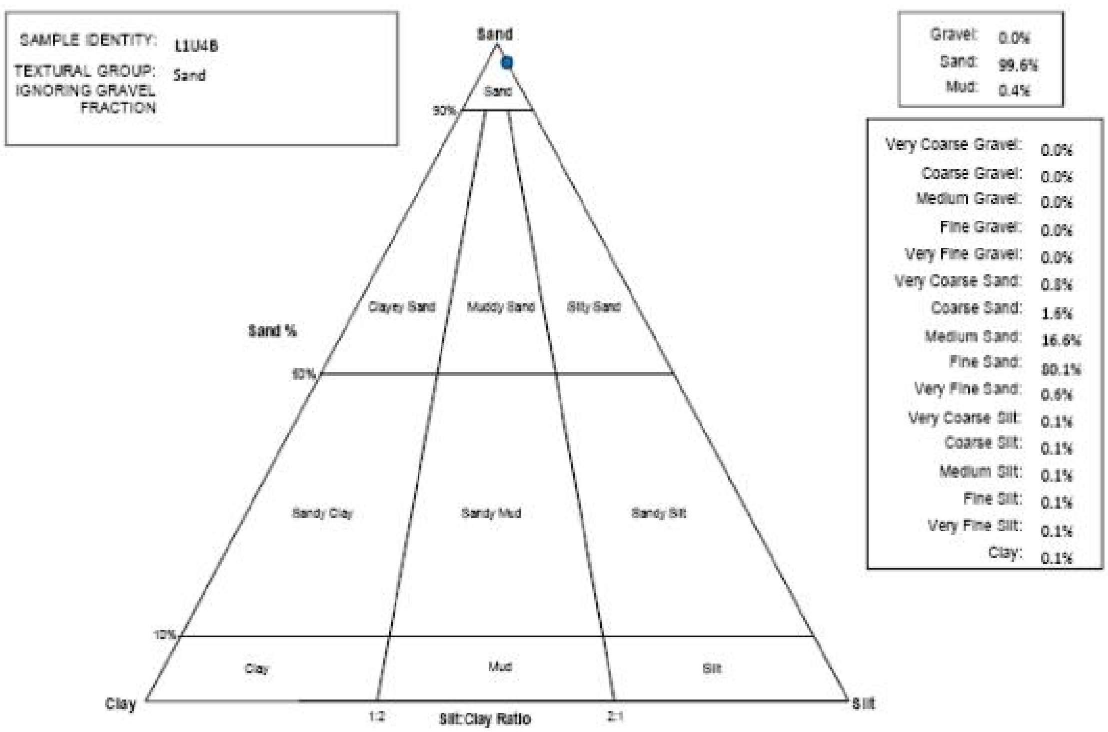
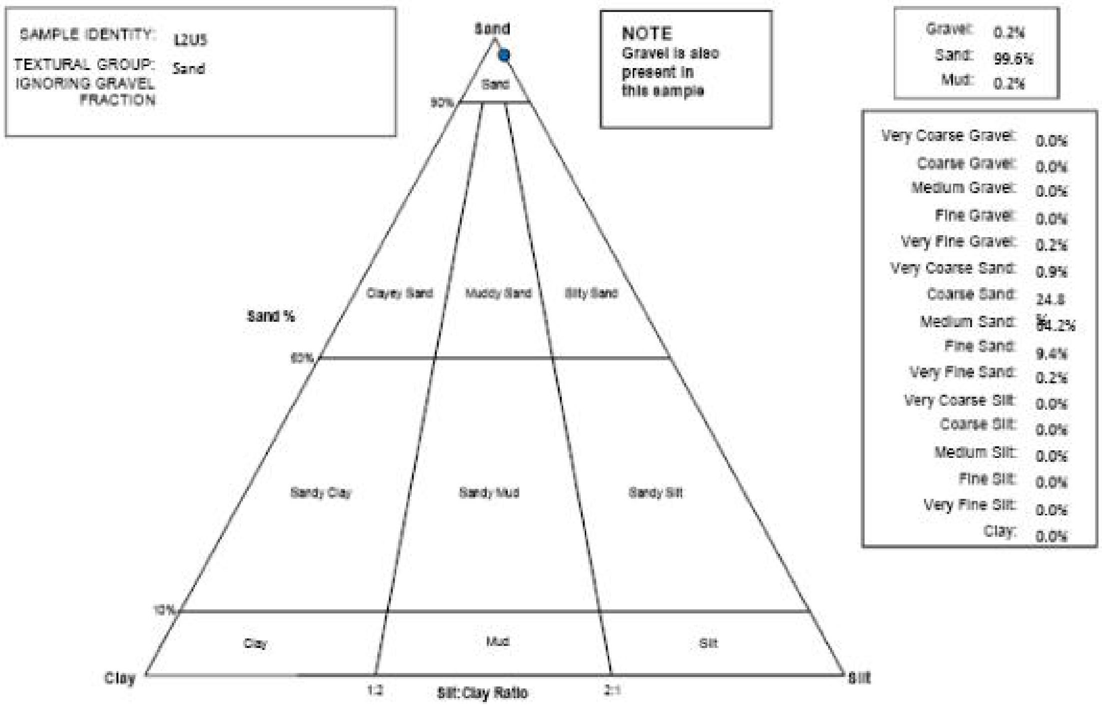
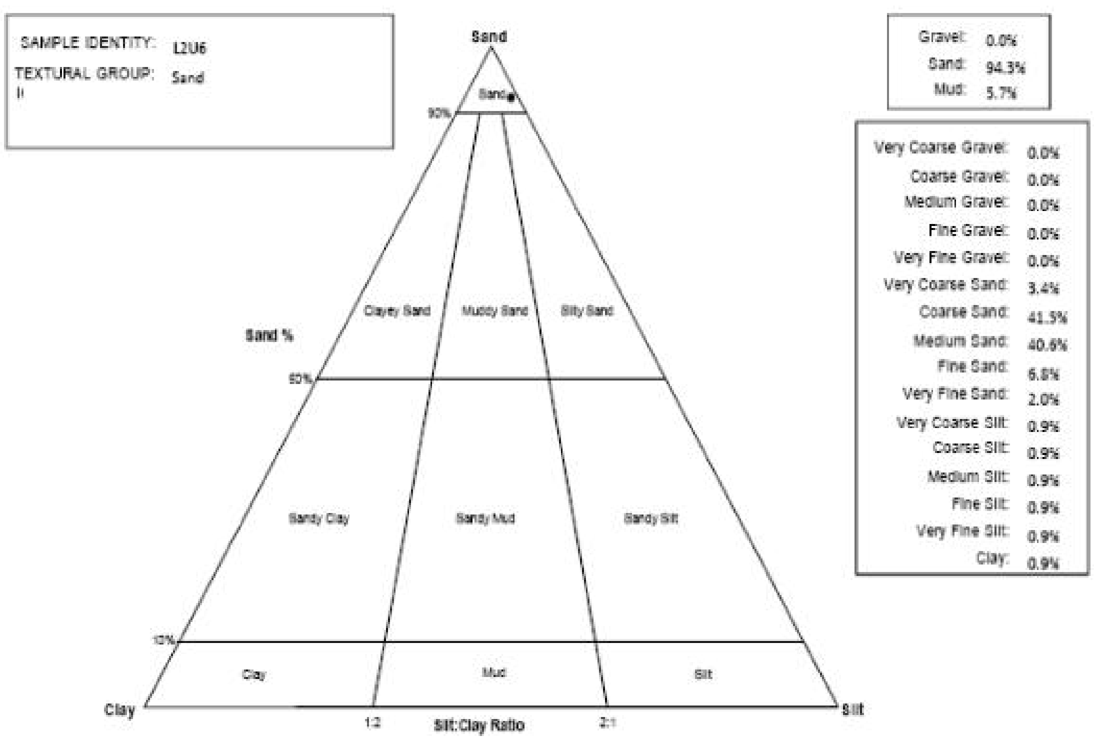



**Fig. 5.**



SAMPLE IDENTITY: L2U5
TEXTURAL GROUP: Sand
IGNORING GRAVEL FRACTION
NOTE
Gravel is also present in this sample
Gravel: 0.2%
Sand: 99.6%
Mud: 0.2%
Very Coarse Gravel: 0.0%
Coarse Gravel: 0.0%
Medium Gravel: 0.0%
Fine Gravel: 0.0%
Very Fine Gravel: 0.2%
Very Coarse Sand: 0.9%
Coarse Sand: 24.8 %
Medium Sand: 64.2%
Fine Sand: 9.4%
Very Fine Sand: 0.2%
Very Coarse Silt: 0.0%
Coarse Silt: 0.0%
Medium Silt: 0.0%
Fine Silt: 0.0%
Very Fine Silt: 0.0%
Clay: 0.0%
Sand
90%
Clayey Sand
Muddy Sand
Silty Sand
Sand %
50%
Sandy Clay
Sandy Mud
Sandy Silt
10%
Clay
Mud
Silt
Clay
1:2
Silt:Clay Ratio
2:1
Silt


**Fig. 6.**



SAMPLE IDENTITY: L2U6
TEXTURAL GROUP: Sand
Gravel: 0.0%
Sand: 94.3%
Mud: 5.7%
Very Coarse Gravel: 0.0%
Coarse Gravel: 0.0%
Medium Gravel: 0.0%
Fine Gravel: 0.0%
Very Fine Gravel: 0.0%
Very Coarse Sand: 3.4%
Coarse Sand: 41.5%
Medium Sand: 40.6%
Fine Sand: 6.8%
Very Fine Sand: 2.0%
Very Coarse Silt: 0.9%
Coarse Silt: 0.9%
Medium Silt: 0.9%
Fine Silt: 0.9%
Very Fine Silt: 0.9%
Clay: 0.9%
Sand
90%
Clayey Sand
Muddy Sand
Silty Sand
Sand %
50%
Sandy Clay
Sandy Mud
Sandy Silt
10%
Clay
Mud
Silt
Clay
1:2
Silt:Clay Ratio
2:1
Silt


**Fig. 7.**

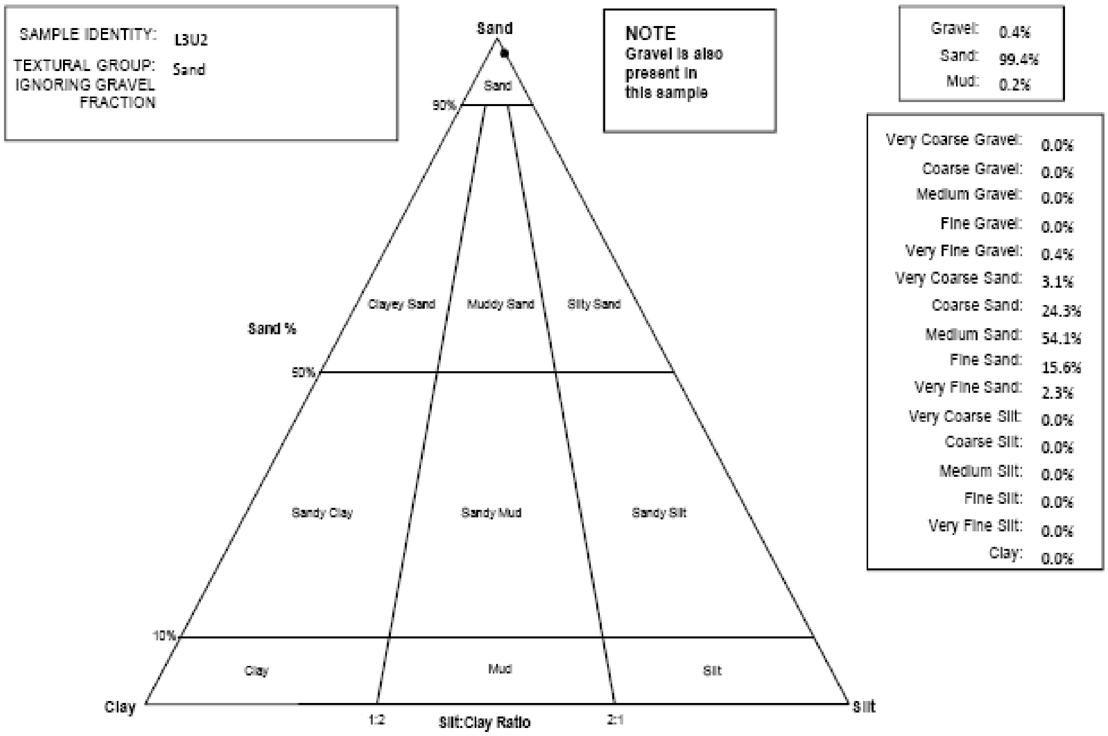

SAMPLE IDENTITY: L3U2
TEXTURAL GROUP: Sand
IGNORING GRAVEL FRACTION
NOTE
Gravel is also present in this sample
Gravel: 0.4%
Sand: 99.4%
Mud: 0.2%
Very Coarse Gravel: 0.0%
Coarse Gravel: 0.0%
Medium Gravel: 0.0%
Fine Gravel: 0.0%
Very Fine Gravel: 0.4%
Very Coarse Sand: 3.1%
Coarse Sand: 24.3%
Medium Sand: 54.1%
Fine Sand: 15.6%
Very Fine Sand: 2.3%
Very Coarse Silt: 0.0%
Coarse Silt: 0.0%
Medium Silt: 0.0%
Fine Silt: 0.0%
Very Fine Silt: 0.0%
Clay: 0.0%
Sand
90%
50%
10%
Sand %
Clayey Sand
Muddy Sand
Silty Sand
Sandy Clay
Sandy Mud
Sandy Silt
Clay
Mud
Silt
Clay
Silt
1:2
Silt:Clay Ratio
2:1

**Fig. 8.**

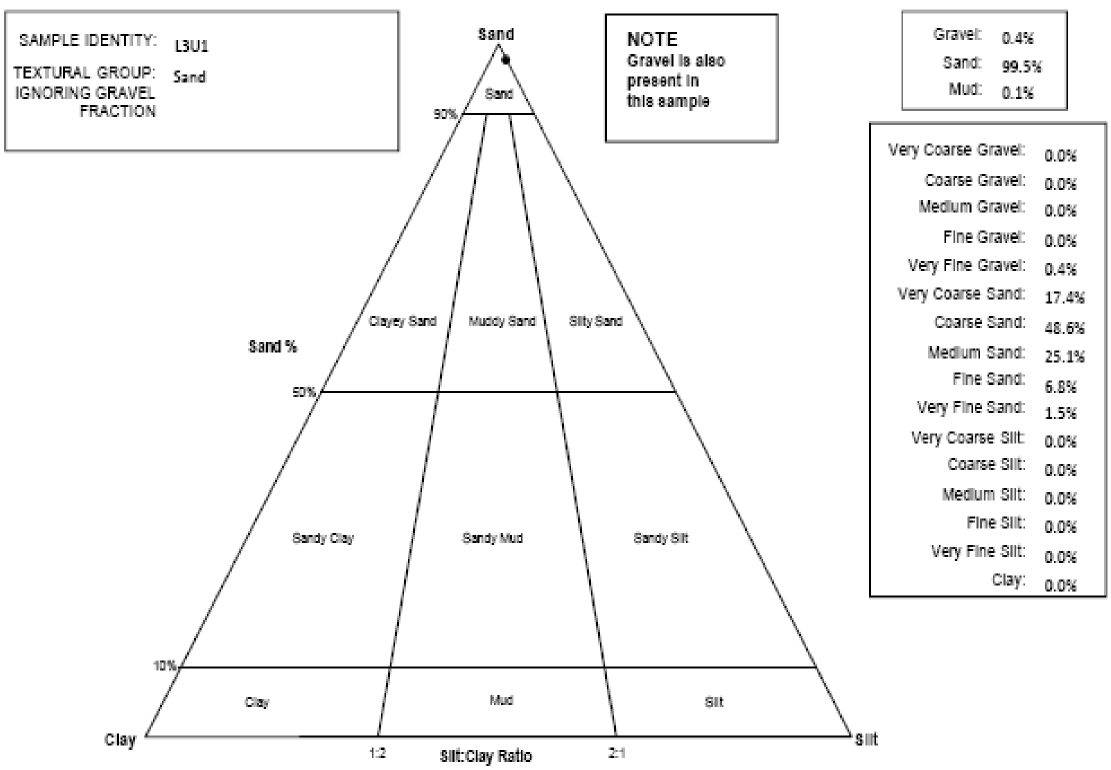

SAMPLE IDENTITY: L3U1
TEXTURAL GROUP: Sand
IGNORING GRAVEL FRACTION
NOTE
Gravel is also present in this sample
Gravel: 0.4%
Sand: 99.5%
Mud: 0.1%
Very Coarse Gravel: 0.0%
Coarse Gravel: 0.0%
Medium Gravel: 0.0%
Fine Gravel: 0.0%
Very Fine Gravel: 0.4%
Very Coarse Sand: 17.4%
Coarse Sand: 48.6%
Medium Sand: 25.1%
Fine Sand: 6.8%
Very Fine Sand: 1.5%
Very Coarse Silt: 0.0%
Coarse Silt: 0.0%
Medium Silt: 0.0%
Fine Silt: 0.0%
Very Fine Silt: 0.0%
Clay: 0.0%
Sand
90%
50%
10%
Sand %
Clayey Sand
Muddy Sand
Silty Sand
Sandy Clay
Sandy Mud
Sandy Silt
Clay
Mud
Silt
Clay
Silt
1:2
Silt:Clay Ratio
2:1

**Fig. 9.**

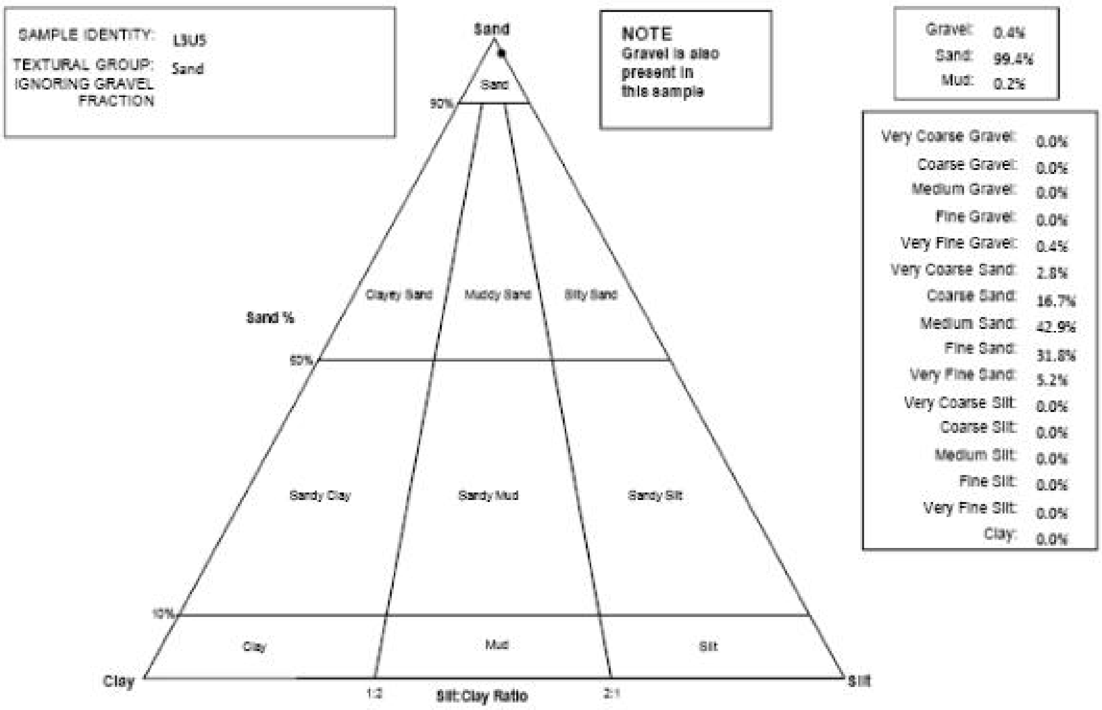



**Fig. 10.**

## Cumulative frequence curve for Tables 1-7

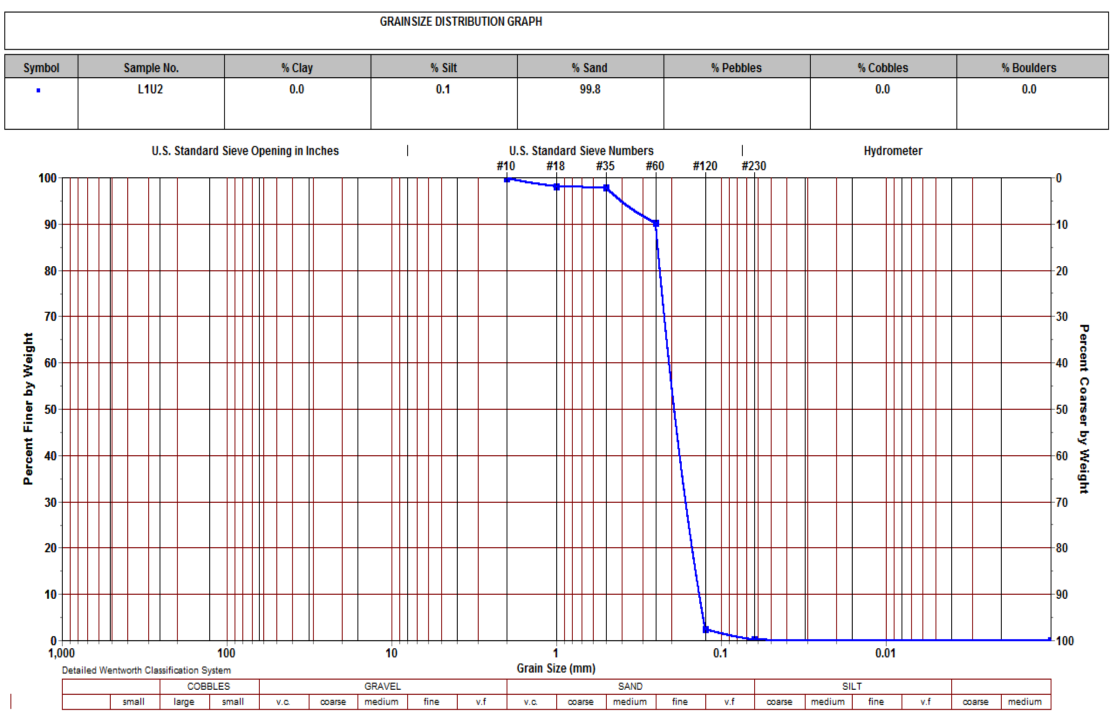



**Fig. 11.**

GRAINSIZE DISTRIBUTION GRAPH

| Symbol | Sample No. | % Clay | % Silt | % Sand | % Pebbles | % Cobbles | % Boulders |
|---|---|---|---|---|---|---|---|
| ▪ | L1U4B | 0.7 | 12.0 | 87.6 | | 0.0 | 0.0 |

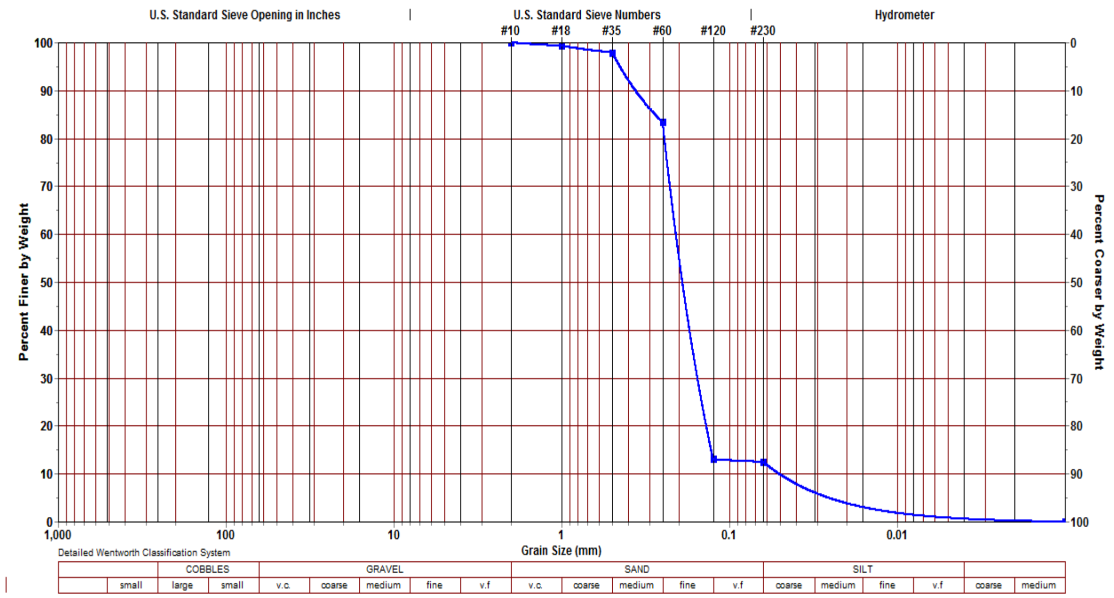



**Fig. 12.**

GRAINSIZE DISTRIBUTION GRAPH

| Symbol | Sample No. | % Clay | % Silt | % Sand | % Pebbles | % Cobbles | % Boulders |
|---|---|---|---|---|---|---|---|
| ▪ | L2U5 | 0.0 | 0.2 | 99.7 | | 0.0 | 0.0 |

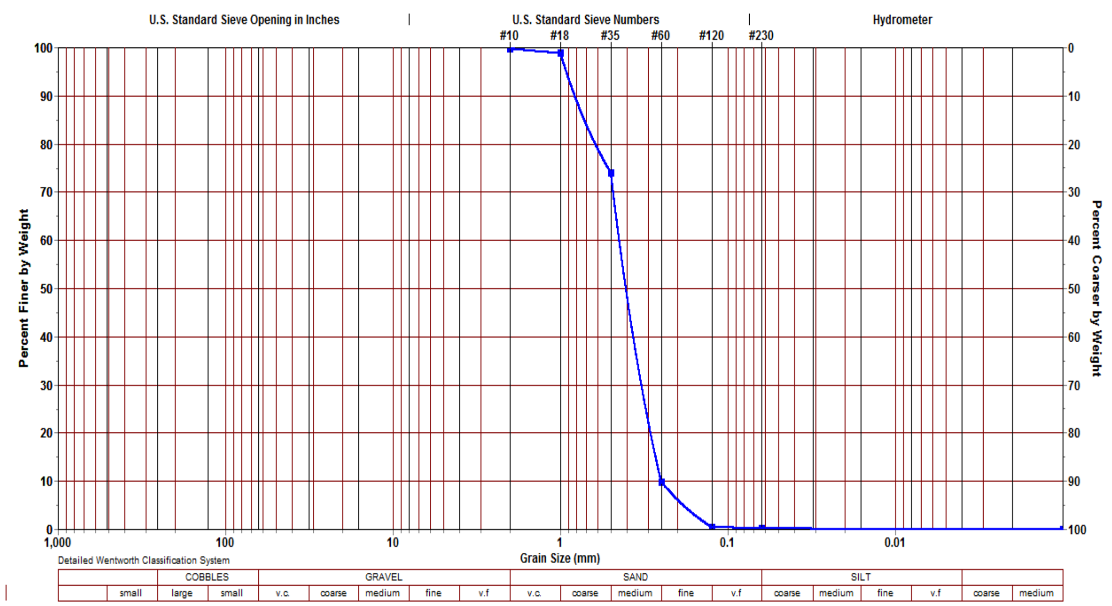



**Fig. 13.**

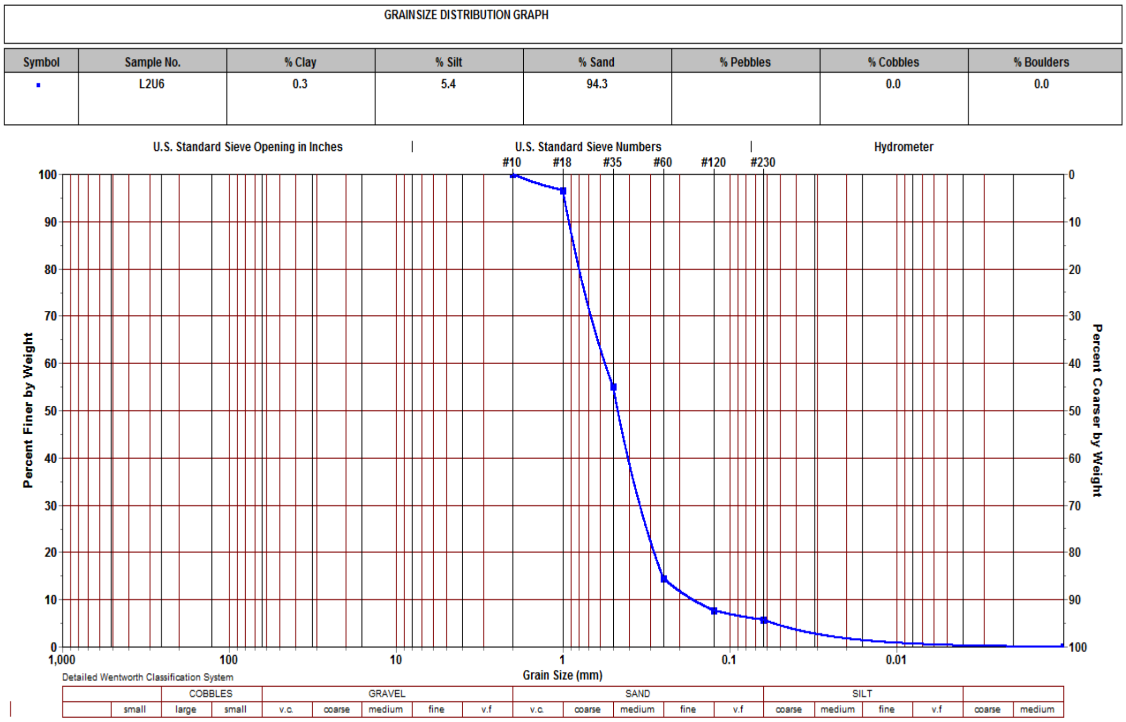

GRAINSIZE DISTRIBUTION GRAPH
Symbol
Sample No.
% Clay
% Silt
% Sand
% Pebbles
% Cobbles
% Boulders
L2U6
0.3
5.4
94.3
0.0
0.0
U.S. Standard Sieve Opening in Inches
U.S. Standard Sieve Numbers
Hydrometer
#10
#18
#35
#60
#120
#230
Percent Finer by Weight
Percent Coarser by Weight
Grain Size (mm)
Detailed Wentworth Classification System
COBBLES
GRAVEL
SAND
SILT

**Fig. 14.**

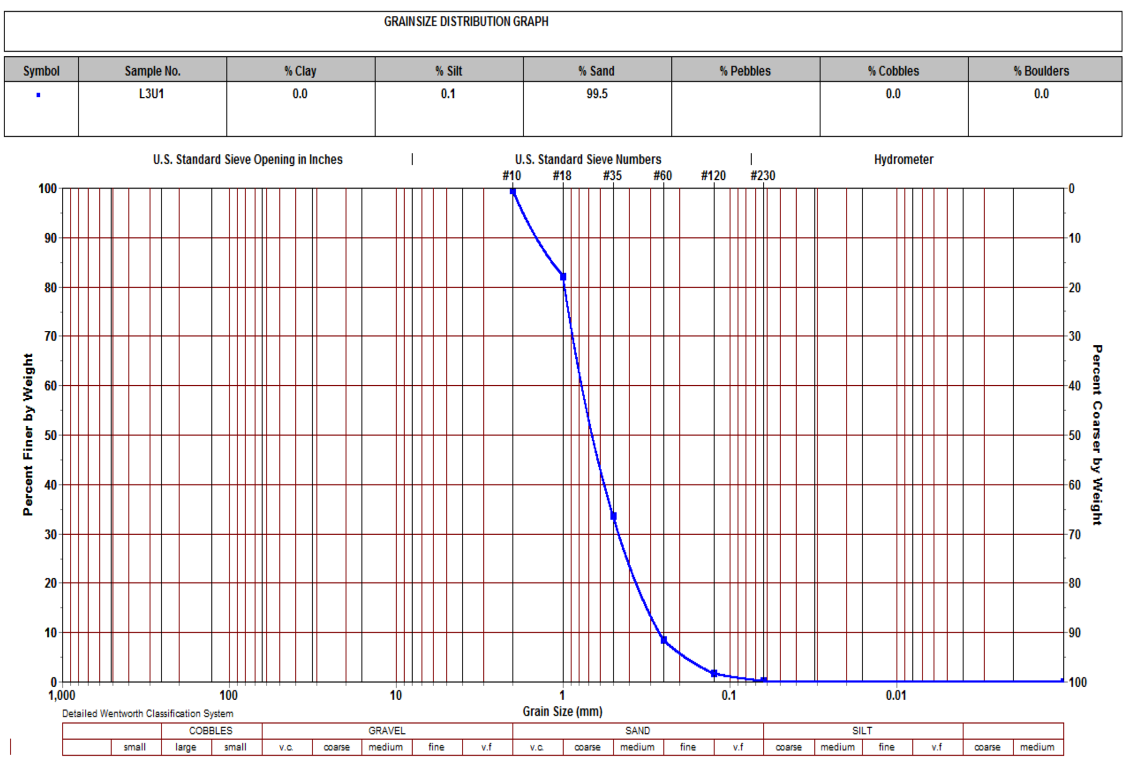

GRAINSIZE DISTRIBUTION GRAPH
Symbol
Sample No.
% Clay
% Silt
% Sand
% Pebbles
% Cobbles
% Boulders
L3U1
0.0
0.1
99.5
0.0
0.0
U.S. Standard Sieve Opening in Inches
U.S. Standard Sieve Numbers
Hydrometer
#10
#18
#35
#60
#120
#230
Percent Finer by Weight
Percent Coarser by Weight
Grain Size (mm)
Detailed Wentworth Classification System
COBBLES
GRAVEL
SAND
SILT

**Fig. 15.**

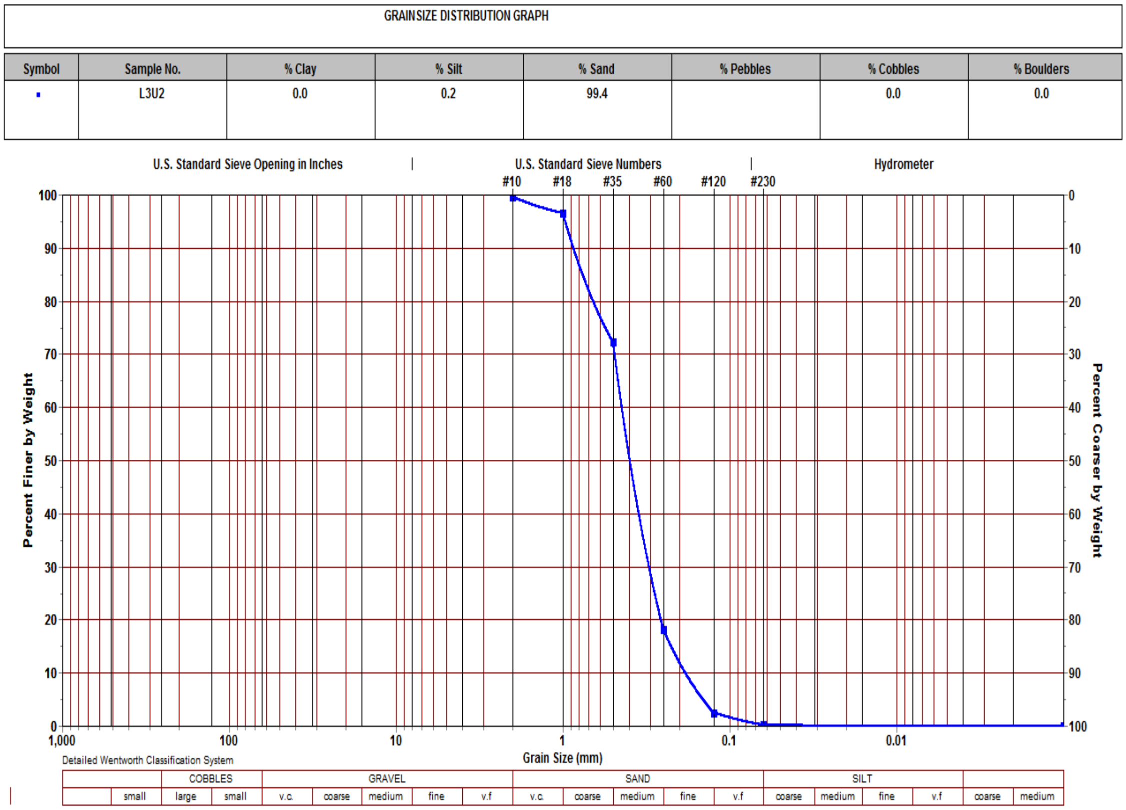

GRAINSIZE DISTRIBUTION GRAPH
Symbol | Sample No. | % Clay | % Silt | % Sand | % Pebbles | % Cobbles | % Boulders
L3U2 | 0.0 | 0.2 | 99.4 | 0.0 | 0.0
U.S. Standard Sieve Opening in Inches
U.S. Standard Sieve Numbers
Hydrometer
#10 #18 #35 #60 #120 #230
Percent Finer by Weight
Percent Coarser by Weight
Grain Size (mm)
Detailed Wentworth Classification System
COBBLES GRAVEL SAND SILT

**Fig. 16.**

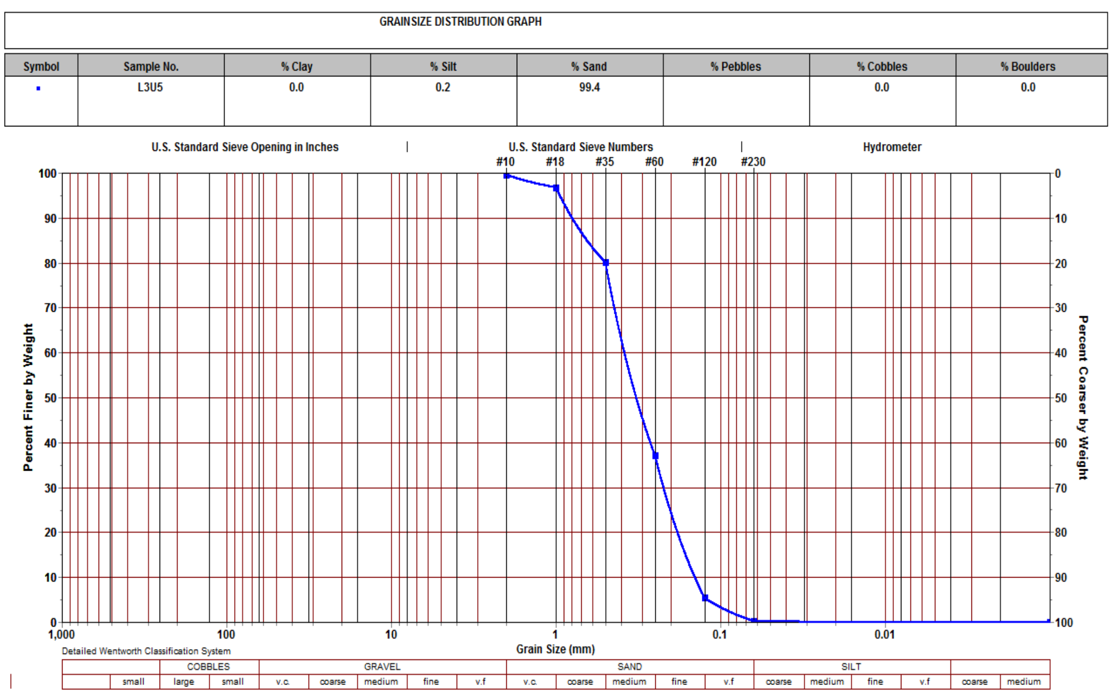

GRAINSIZE DISTRIBUTION GRAPH
Symbol | Sample No. | % Clay | % Silt | % Sand | % Pebbles | % Cobbles | % Boulders
L3U5 | 0.0 | 0.2 | 99.4 | 0.0 | 0.0
U.S. Standard Sieve Opening in Inches
U.S. Standard Sieve Numbers
Hydrometer
#10 #18 #35 #60 #120 #230
Percent Finer by Weight
Percent Coarser by Weight
Grain Size (mm)
Detailed Wentworth Classification System
COBBLES GRAVEL SAND SILT

**Fig. 17.**

**Grainsize distribution histogram for Tables 1-7**

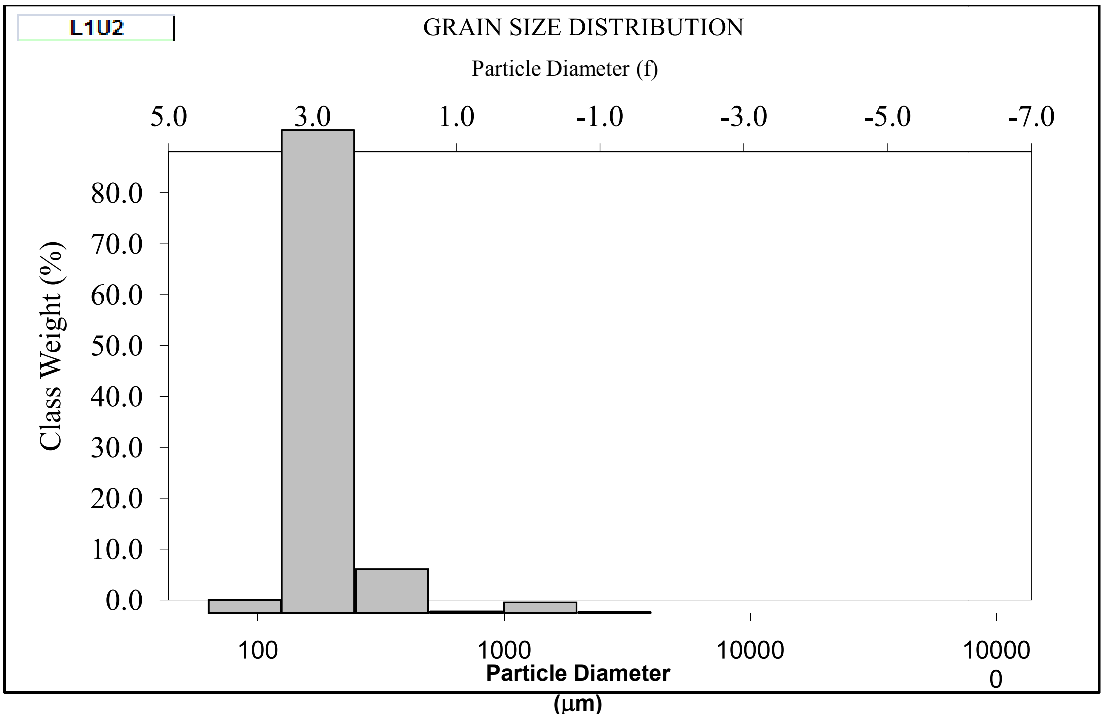



**Fig. 18.**

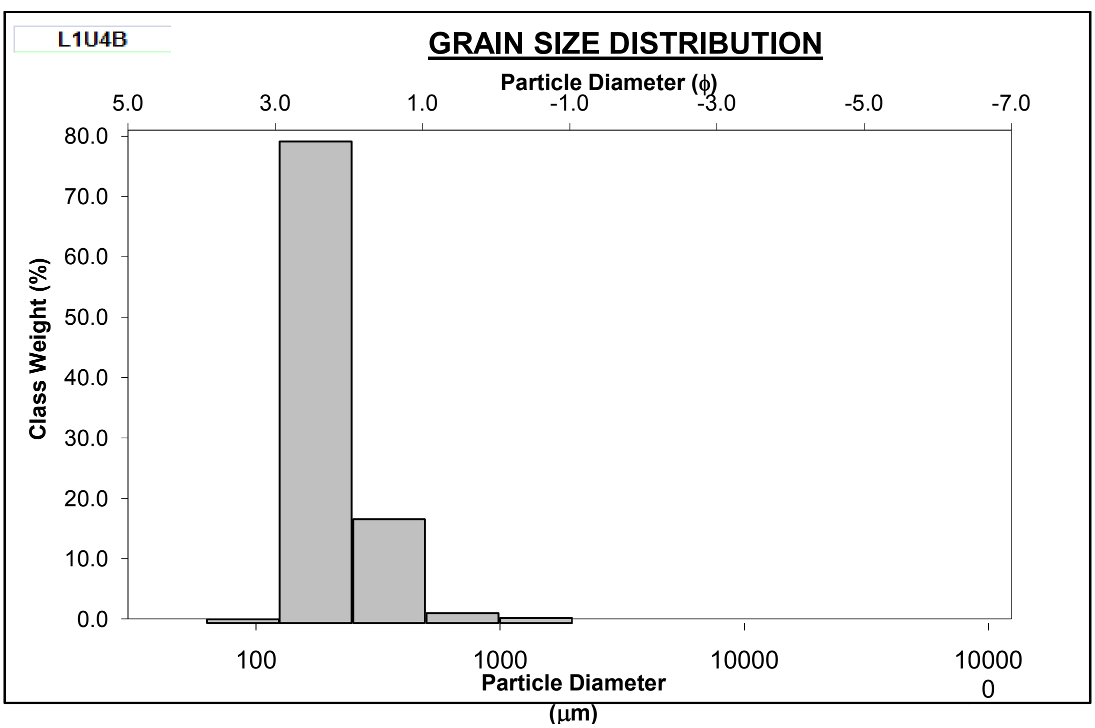



**Fig. 19.**

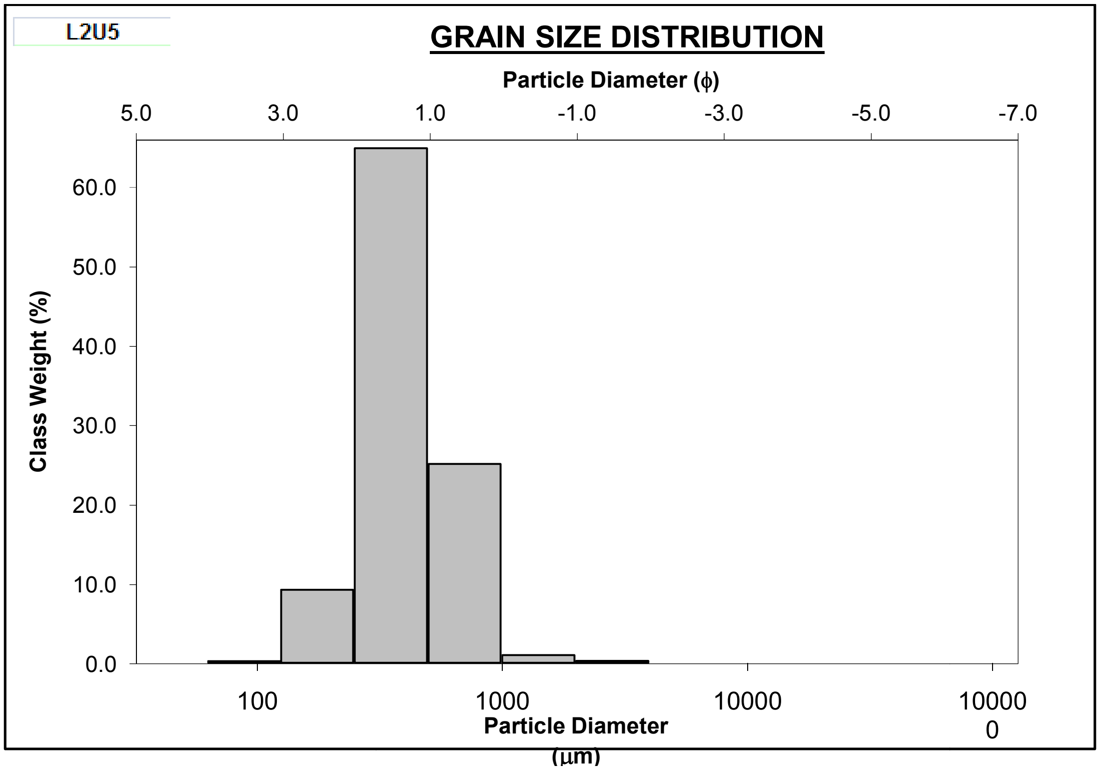

L2U5
GRAIN SIZE DISTRIBUTION
Particle Diameter (ϕ)
5.0
3.0
1.0
-1.0
-3.0
-5.0
-7.0
Class Weight (%)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
100
1000
10000
10000
0
Particle Diameter
(μm)

**Fig. 20.**

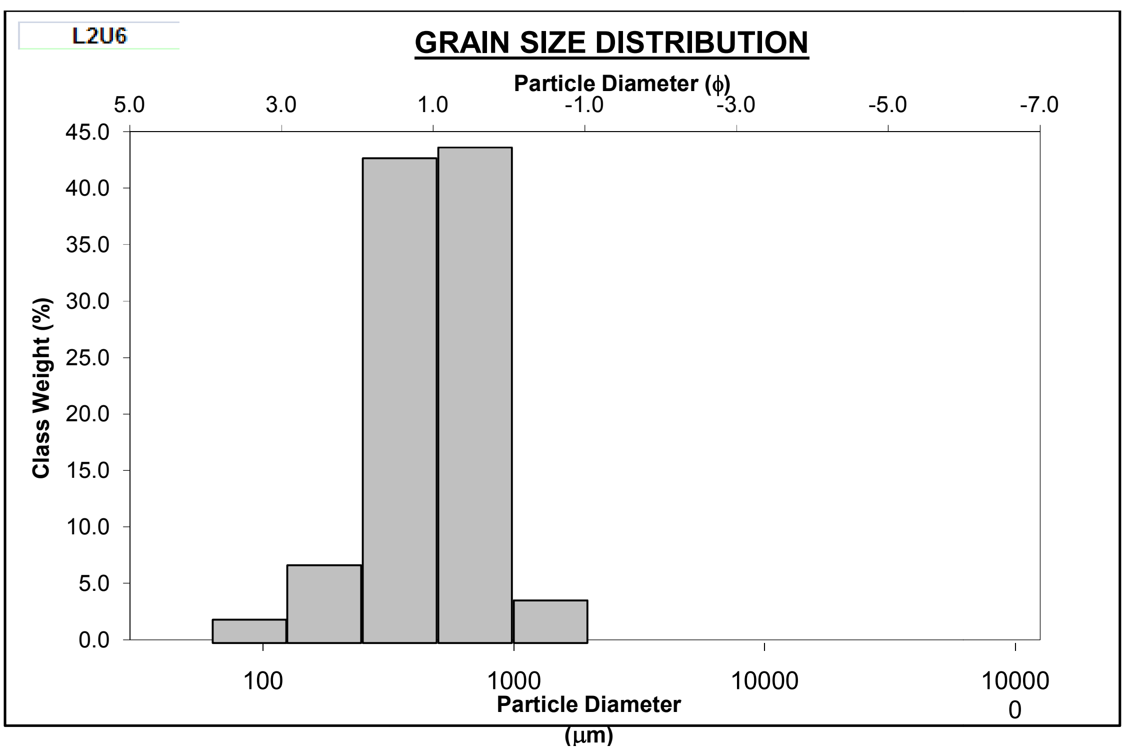

L2U6
GRAIN SIZE DISTRIBUTION
Particle Diameter (ϕ)
5.0
3.0
1.0
-1.0
-3.0
-5.0
-7.0
Class Weight (%)
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
100
1000
10000
10000
0
Particle Diameter
(μm)

**Fig. 21.**

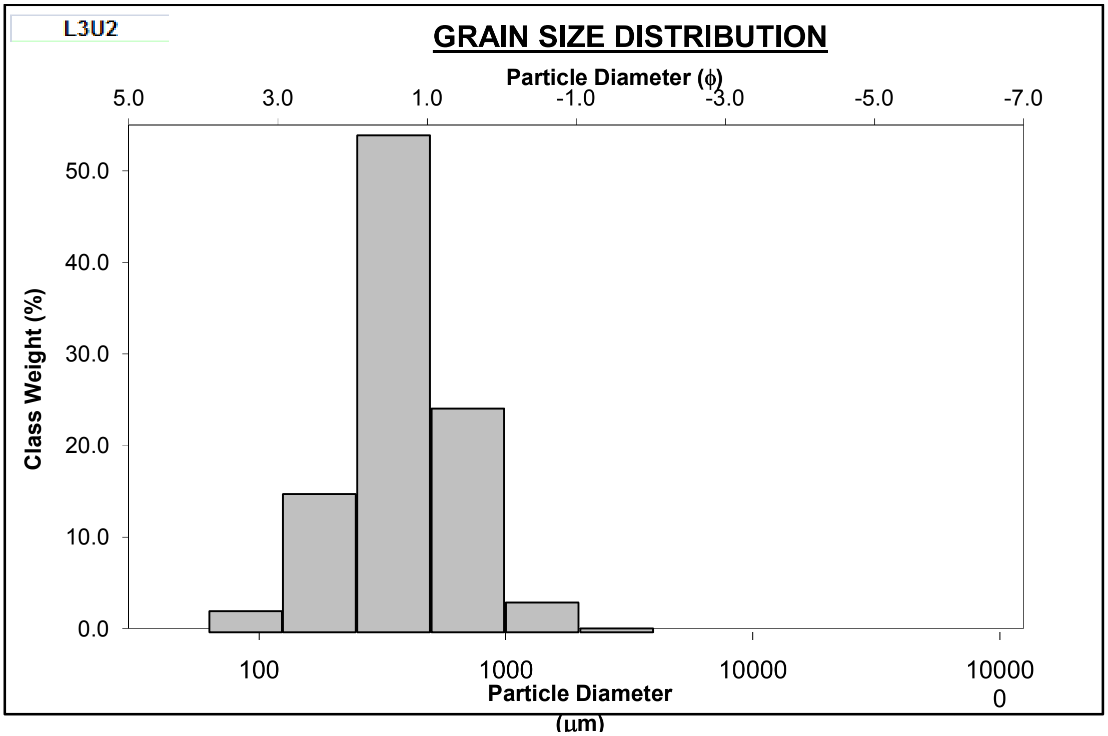

L3U2
GRAIN SIZE DISTRIBUTION
Particle Diameter (ϕ)
5.0
3.0
1.0
-1.0
-3.0
-5.0
-7.0
Class Weight (%)
50.0
40.0
30.0
20.0
10.0
0.0
100
1000
10000
100000
Particle Diameter (µm)

Fig. 22.

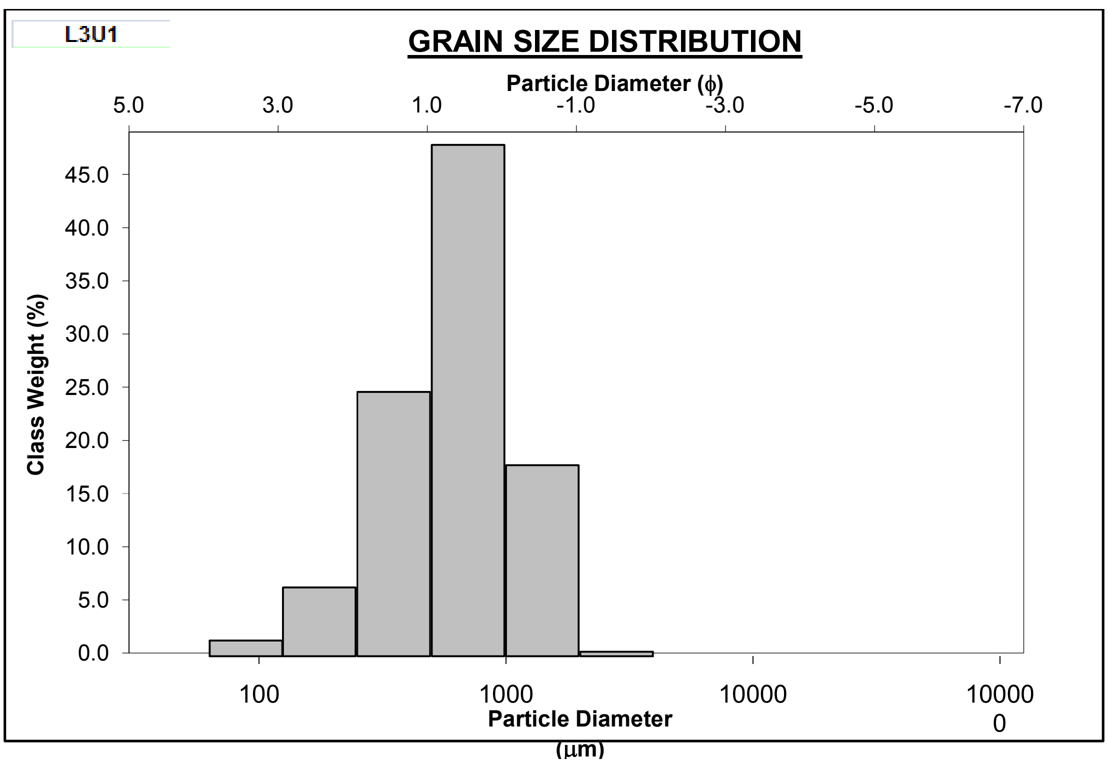

L3U1
GRAIN SIZE DISTRIBUTION
Particle Diameter (ϕ)
5.0
3.0
1.0
-1.0
-3.0
-5.0
-7.0
Class Weight (%)
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
100
1000
10000
100000
Particle Diameter (µm)

Fig. 23.

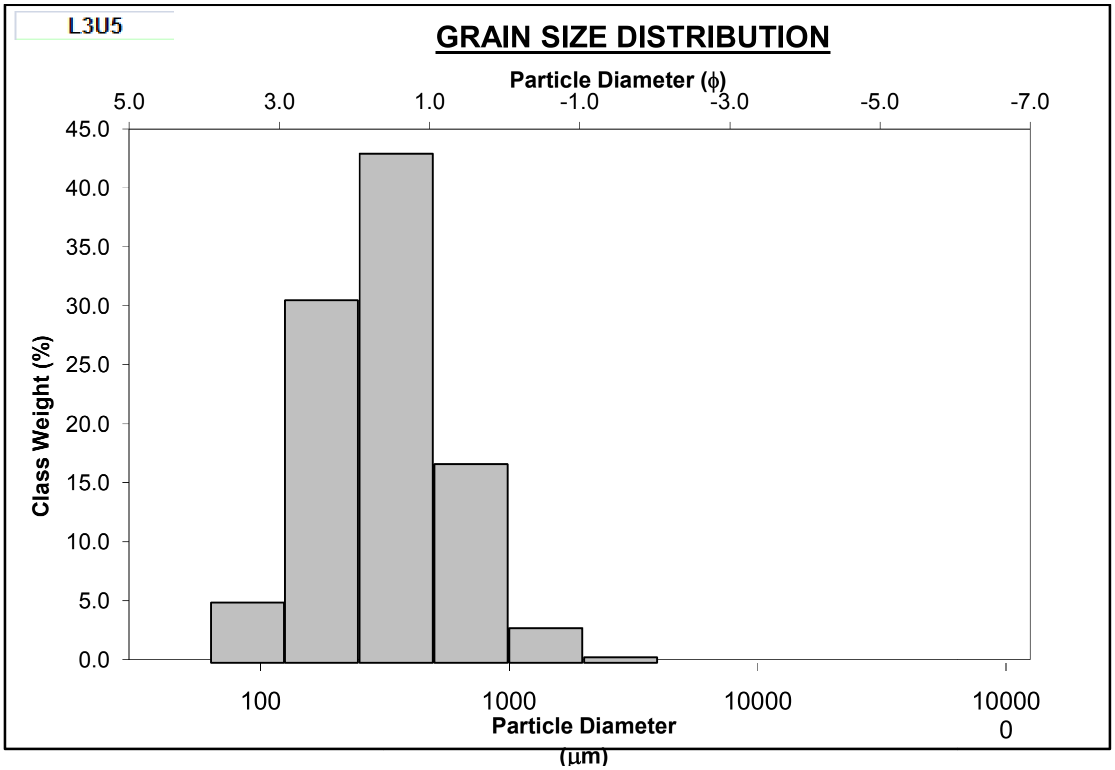



Fig. 24.

Table 7.

| Sample ID | | L3U5 | | | | |
|---|---|---|---|---|---|---|
| | | Starting wt (g) = 46.60 | | | | |
| **Mm** | **phi (Φ)** | **Weight retained (g)** | **Corrected weight retained (g)** | **% Weight retained** | **Cum. weight retained (%)** | **% Pass** |
| 2.0 | -1.0 | 0.20 | 0.20 | 0.43 | 0.43 | 99.57 |
| 1.0 | 0.0 | 1.30 | 1.30 | 2.79 | 3.22 | 96.78 |
| 0.5 | 1.0 | 7.80 | 7.80 | 16.74 | 19.96 | 80.04 |
| 0.25 | 2.0 | 20.00 | 20.00 | 42.92 | 62.88 | 37.12 |
| 0.125 | 3.0 | 14.80 | 14.80 | 31.76 | 94.64 | 5.36 |
| 0.063 | 4.0 | 2.40 | 2.40 | 5.15 | 99.79 | 0.21 |
| Pan | | 0.10 | 0.10 | 0.21 | 100.00 | 0.00 |
| Total Weight (g) | | 46.6 | 46.60 | | | |
| Sieve Loss/Gain (g) | | 0.00 | | | | |

**Table 8. Calculated grain size parameters in the study area**

| Sample no. | Grain size | Sorting | Skewness | Kurtosis |
|---|---|---|---|---|
| L1U2 | 2.715 | 0.300 | -0.293 | 1.783 |
| L1U4B | 2.497 | 0.460 | -0.563 | 1.746 |
| L2U5 | 1.477 | 0.618 | -0.279 | 0.989 |
| L2U6 | 1.395 | 0.934 | 0.054 | 1.462 |
| L3U2 | 1.668 | 0.810 | -0.021 | 0.986 |
| L3U1 | 0.875 | 0.944 | 0.153 | 1.156 |
| L3U5 | 1.851 | 0.935 | 0.063 | 1.083 |
| Average | 1.783 | 0.714 | -0.127 | 1.315 |

### 6.4 Facie Analysis

**Table 9. Different facies and facie code used in this study**

| Different facies | Facie code |
|---|---|
| Lateritic facie | Lf |
| Clay stone facie | Cs |
| Bioturbited sand-stone facie | Bsf |
| Mudstone facie | Mf |
| Ferruginized sand-stone facies | Fst |
| Bioturbited mudstone facie | Bms |
| Crossbedded sandstone facie | Cbs |
| Grey shale facie | Gs |

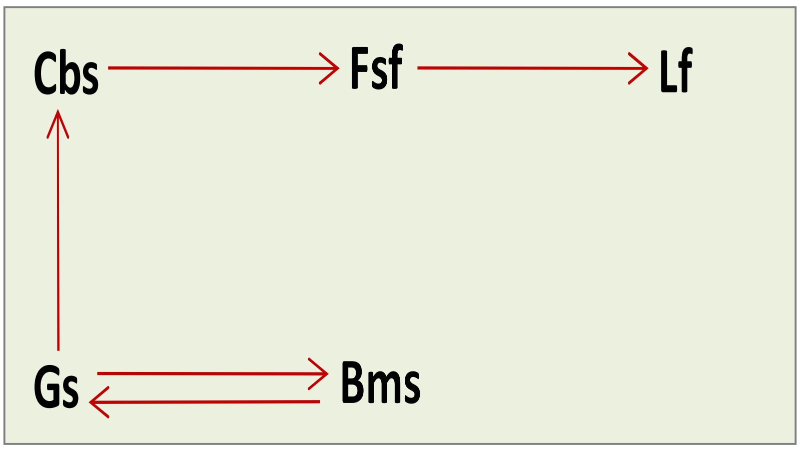



**Fig. 25. Individual FRD for LOC 1**

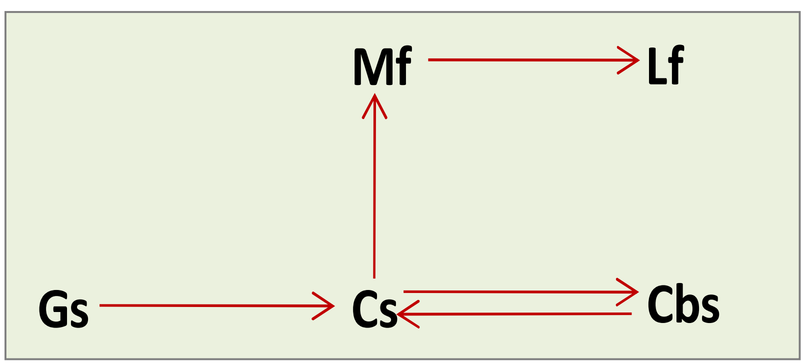



**Fig. 26. Individual FRD for LOC 2**

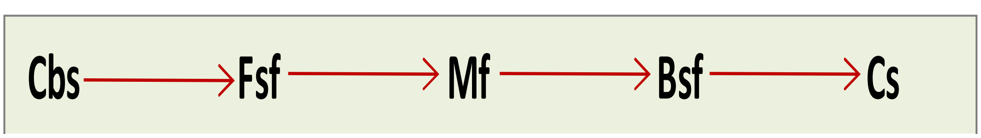



**Fig. 27. Individual FRD for LOC 3**

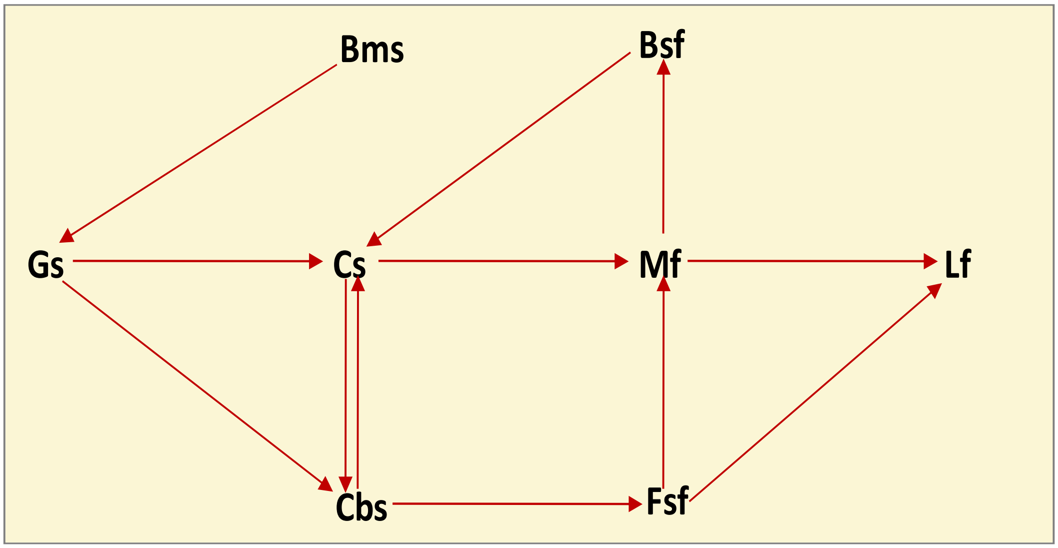



**Fig. 28. Composite frd for eocene sediments in the study area**

**Table 10. Tally matrix of the lithofacies for the Eocene sedimentary sequence of study area**

| | GS | CS | CBS | MF | LF | BMS | FSF | BSF | R. total |
|---|---|---|---|---|---|---|---|---|---|
| GS | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 3 |
| CS | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 3 |
| CBS | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 3 |
| MF | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 2 |
| LF | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BMS | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| FSF | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 2 |
| BSF | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| C. total | 1 | 3 | 2 | 2 | 2 | 1 | 2 | 1 | 14 |

**Table 11. Transition probability matrix of the lithofacies sequence of the study area**

| | GS | CS | CBS | MF | LF | BMS | FSF | BSF |
|---|---|---|---|---|---|---|---|---|
| GS | 0.000 | 0.333 | 0.333 | 0.000 | 0.000 | 0.333 | 0.000 | 0.000 |
| CS | 0.000 | 0.000 | 0.500 | 0.500 | 0.000 | 0.000 | 0.000 | 0.000 |
| CBS | 0.000 | 0.333 | 0.000 | 0.000 | 0.000 | 0.000 | 0.667 | 0.000 |
| MF | 0.000 | 0.000 | 0.000 | 0.000 | 0.500 | 0.000 | 0.000 | 0.500 |
| LF | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| BMS | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| FSF | 0.000 | 0.000 | 0.000 | 0.500 | 0.500 | 0.000 | 0.000 | 0.000 |
| BSF | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

**Table 12. Independent trial probabilities matrix of the lithofacies of the study area**

| | GS | CS | CBS | MF | LF | BMS | FSF | BSF |
|---|---|---|---|---|---|---|---|---|
| GS | 0.000 | 0.214 | 0.214 | 0.200 | 0.200 | 0.187 | 0.200 | 0.187 |
| CS | 0.214 | 0.000 | 0.214 | 0.200 | 0.200 | 0.187 | 0.200 | 0.187 |
| CBS | 0.214 | 0.214 | 0.000 | 0.200 | 0.200 | 0.187 | 0.200 | 0.187 |
| MF | 0.143 | 0.143 | 0.143 | 0.000 | 0.133 | 0.125 | 1.133 | 0.125 |
| LF | 0.143 | 0.143 | 0.143 | 0.133 | 0.000 | 0.125 | 0.133 | 0.125 |
| BMS | 0.071 | 0.071 | 0.071 | 0.067 | 0.067 | 0.000 | 0.067 | 0.062 |
| FSF | 0.143 | 0.142 | 0.143 | 0.133 | 0.133 | 0.125 | 0.000 | 0.125 |
| BSF | 0.071 | 0.071 | 0.071 | 0.067 | 0.067 | 0.062 | 0.067 | 0.000 |

**Table 13. Difference matrix of the lithofacies for the eocene sedimentary sequence of the study area**

| | GS | CS | CBS | MF | LF | BMS | FSF | BSF |
|---|---|---|---|---|---|---|---|---|
| GS | 0.000 | 0.119 | 0.119 | -0.200 | -0.200 | 0.146 | -0.200 | -0.187 |
| CS | -0.214 | 0.000 | 0.285 | 0.300 | -0.200 | -0.187 | -0.200 | -0.187 |
| CBS | -0.214 | 0.119 | 0.000 | -0.200 | -0.200 | -0.187 | 0.467 | -0.187 |
| MF | -0.143 | -0.143 | -0.143 | 0.000 | 0.367 | -0.125 | -0.133 | 0.375 |
| LF | -0.143 | -0.143 | -0.143 | -0.133 | 0.000 | -0.125 | -0.133 | -0.125 |
| BMS | 0.929 | -0.071 | -0.071 | -0.067 | -0.067 | 0.000 | -0.067 | -0.062 |
| FSF | -0.143 | -0.142 | 0.143 | 0.367 | 0.367 | -0.125 | 0.000 | -0.125 |
| BSF | -0.071 | 0.928 | 0.071 | -0.067 | -0.067 | -0.062 | -0.067 | 0.000 |

## 7. CONCLUSION

This research work is the detailed facies analysis of the depositional environments and paleogeographic setting of the Eocene sedimentary sequence (Ameki Formations) exposed in the Umuahia area and paleoclimate during those periods. The Fine-grained facies association (FFA) which consist of Gs, Cbs, Cs, Mf and Fst and the Medium to Fine-grained facies association (MFA) which also consist of Bms, Bsf and Lf. It also shows medium-grained sand, moderately sorted to well-sorted sandstone, Skewness ranged from symmetrical to positive skewed and kurtosis showed leptokurtic. Deduction from facies analysis and grain size analysis shows that Ameki Formation consists of foraminifera and Mollusca as well as other organisms which indicate that Ameki Formation has deposited in the estuarine (Marine) environment.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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