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DEPOSITIONAL ENVIRONMENT OF THE BAHI FORMATION DEDUCED BY TEXTURAL ANALYSIS, NW SIRT BASIN, LIBYA

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إستقراء بيئة ترسيب تكوين الباهي بحوض سرت الترسيبي من خلال نسيج الصخور الرسوبي

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أجريت دراسة تفصيلية للجزء السفلي لتكوين الباهي ، بالجزء الشمالي الغربي من حوض سرت الترسيبي ، من أجل وصف نسيج الصخور واستنتاج بيئة الترسيب إلى جانب إختبار التقنيات الحديثة لإستنباط تلك البيئة.

الجزء السفلي من صخور الباهي الرملية عبارة عن رمال ناعمة إلى شديدة الخشونة ورديئة إلى متوسطة الفرز، وحيود حجم ناعمة إلى خشنة ، ومعيار تفرطح متوسط إلى مرتفع . وتشير مؤشرات التوزيع التكراري لحجم الحبيبات إلى تكون نموذج مزدوج ضعيف. وقد وجد بأن مؤشرات درجة الفرز والحيود منسجمة والطبوغرافية والمنحدرات القديمة.

وتدل استقراءات البيئة القديمة ، المبنية على مزج أربعة معايير حجم لحبيبات متباينة ، التي تم الوصول إليها من خلال إستعمال منحنيات الإحتمالات المتراكمة والتباين الطبقي الإقليمي في معايير حجم الحبيبة الواحدة ، على أن الصخور الرملية هذه قد غلبت على بيئة ترسيبها الظروف النهرية.

ABSTRACT

A detailed investigation of the lower part of the Bahi Formation in the northwestern Sirt Basin was undertaken to describe its sedimentological texture, to determine its environment of deposition as well as to test the existing techniques of environmental analysis.

The lower part of the Bahi sandstone is fine to very coarse, poorly to moderately well sorted, fine to coarse skewed, and mesokurtic to leptokurtic sand. Grain size frequency distributions tend to exhibit a weakely developed biomodality. Sorting and skewness, consistent with changes in local paleotopography and regional paleoslope.

Environmental interpretations based on four bivariate grain size parameters combinations were achieved with cumulative probability curve techniques and with the regional stratigraphic variations in single grain size parameters. A fluvial sand body environment is deduced.

INTRODUCTION

Many previous workers have used the grain size distribution of classic sediments to characterise depositional environments, to recognise the mechanisms of sediment transport and deposition, and to differentiate between environmental settings (Folk and Ward, 1957; Passega, 1957, 1964; Mason and Folk, 1958; Steward, 1958; Friedman, 1961, 1967; Moiola and Weiser 1968; Passega and Byramjee, 1969; Visher, 1969; Folk, 1974; Moshrif, 1980; Abu El-ella and Coleman, 1985).

There have been no detailed grain size analysis of the Bahi Formation in the northwestern part of the Sirt Basin (Az Zahara-Hofarah Platform). Mechanical sieve analysis ($\frac{1}{2}$ phi) were carried out on a total of forty five samples of the Bahi sandstone in the A2-32, A4-32 and F6-32 boreholes (Fig. 1). These samples cover most of the succession, except for the uppermost part (a glauconite-bearing marine sequence) which has not been analysed because of unavailability of samples.

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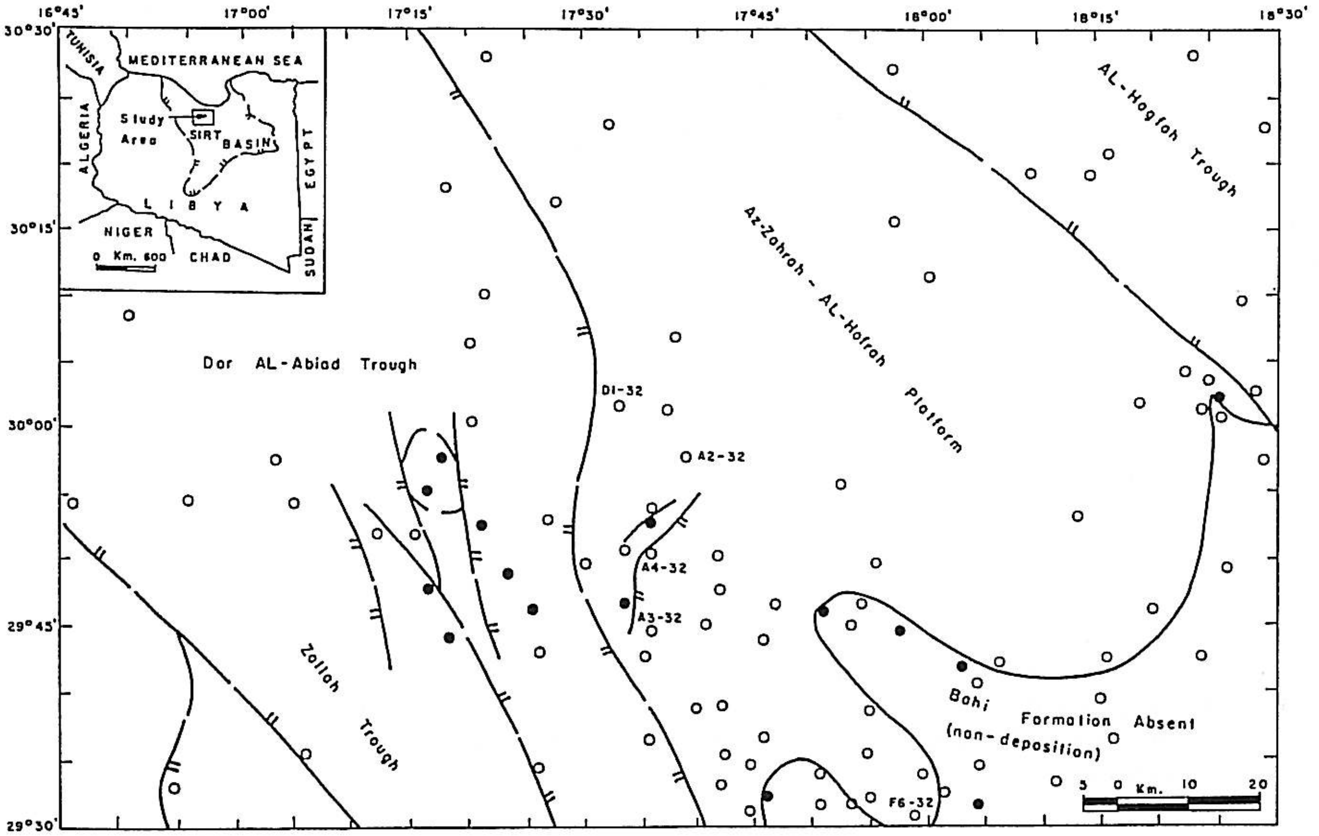

FIG. 1. Map showing the geographic location of the study area.

The work was carried out with the following objectives: To determine vertical and lateral texture variation within the Bahi Formation; to give a clear idea of the depositional environments of the formation and to throw light on the transporting agents of the sediment.

STRATIGRAPHY

The Bahi Formation is found in the subsurface of the northwestern part of the Sirt Basin. It attains a maximum thickness of about 110 meters in A3-32. In various places, the Bahi Formation is overlain by the Lidam Formation or other younger Upper Cretaceous formations (Argub, Rachmat, Sirt, Kalash, etc.), ranging in age from Cenomanian to Maastrichtian, and it is seen to unconformably overlie the Cambro-Ordovician Hofra Formation; in the D1-32 borehole, it rests uncomformably on Devonian sediments. It can be concluded, then, that the Bahi Formation is a diachronous unit, ranging in age from Cenomanian to Maastrichtian (Sghair, 1990).

At the beginning of the Cenomanian and continuing the Maastrichtian, a transgressive sandy base is recognised which has been given various names in the Sirt Basin (Bahi, Maragh, Basal Sandstones, etc.). During this timespan a major transgression took place in northern Libya. The Bahi Formation at the base of the succession is made up of interbedded sandstone, siltstone, conglomerate and shale. Sandstone is the most common lithology: it is usually medium to coarse in texture with subangular to angular quartz grains. Glauconite is common in the uppermost part, 3 to 6 meters, thick, but seems to be absent in the lower part. The siltstone and shale are red or mottled. Usually there is a basal conglomerate 3 to 6 m thick), consisting of rounded quartzic pebbles with a sandy or shaley matrix (Barr and Weegar, 1972).

METHOD AND PROCEDURES

In the laboratory, samples were evenly crushed and checked using a binocular microscope to ensure that the grains were completely separated. The samples were dried and 50 grams were weighed and sieved using $\frac{1}{2}$ phi sieve intervals for 15 minutes on a Ro-Tap shaker. Each fraction was weighed by a beam balance accurate to one hundredth of a gram and the frequencies were then obtained. From the grain-size analysis data, cumulative frequency curves were drawn on arithmetic probability paper using a phi scale. Other grain-size parameters determined include maximum size, median size, and "C" the first percentile in the grain-size distribution (Passega, 1957).

Grain size statistical parameters; mean size, standard deviation, skewness and kurtosis, were calculated using linear interpolation on the weight percentage distributions and the following formulas (Folk and Ward, 1957):

$$\text{Mean size} = \frac{P16 + P50 + P84}{3};$$

$$\text{Standard deviation} = \frac{P84 - P16}{4} + \frac{P95 - P5}{6.6}$$

$$\text{Skewness} = \frac{P16 + P84 - 2P50}{2(P84 - P16)} + \frac{P5 + P95 - 2P50}{2(P95 - P5)};$$

$$\text{Kurtosis} = \frac{P95 - P5}{2.44(P84 - P16)}$$

Where P16, P50 etc. are the grain size in phi units (−log 2 of grain size in mm) corresponding to the 16th, 50th, etc. percentiles on the cumulative curve of grain size distribution. Subsequently, graphs of all possible parameters were made.

GRAIN SIZE DISTRIBUTION

The most commonly used method of displaying the results of grain size analysis is by plotting cumulative percentage against grain size, expressed on a logarithmic scale. The comparison of grain size curves and the interpretation of separate populations is aided by the use of log probability plots. The interpretation of the shapes of cumulative grain size distributions in terms of sedimentary response to hydraulic conditions has attracted the attention of many geologists (e.g. Visher, 1969; Freeman and Visher, 1975). The cumulative curve for each sample was first drawn separately, then the curves representing each borehole were compounded on the same plot. Representative cumulative curves are given in Figs. 2a–c. It should be kept in mind that the record reflected by the grain size analysis has been affected by diagenetic changes in that some grains have been enlarged by overgrowth and some reduced in size by pressure solutioning. An additional problem in the grain size distribution studies is that the same sedimentary processes occur in a number of environments and thus textural results are similar. Bearing these constraints in mind, examination of the different segments in each cumulative curve leads to the following general observations:

(1) The suspension population represents about 10% of the distribution in most samples. This may also contain small heavy minerals which belong to the 'tractive' load.

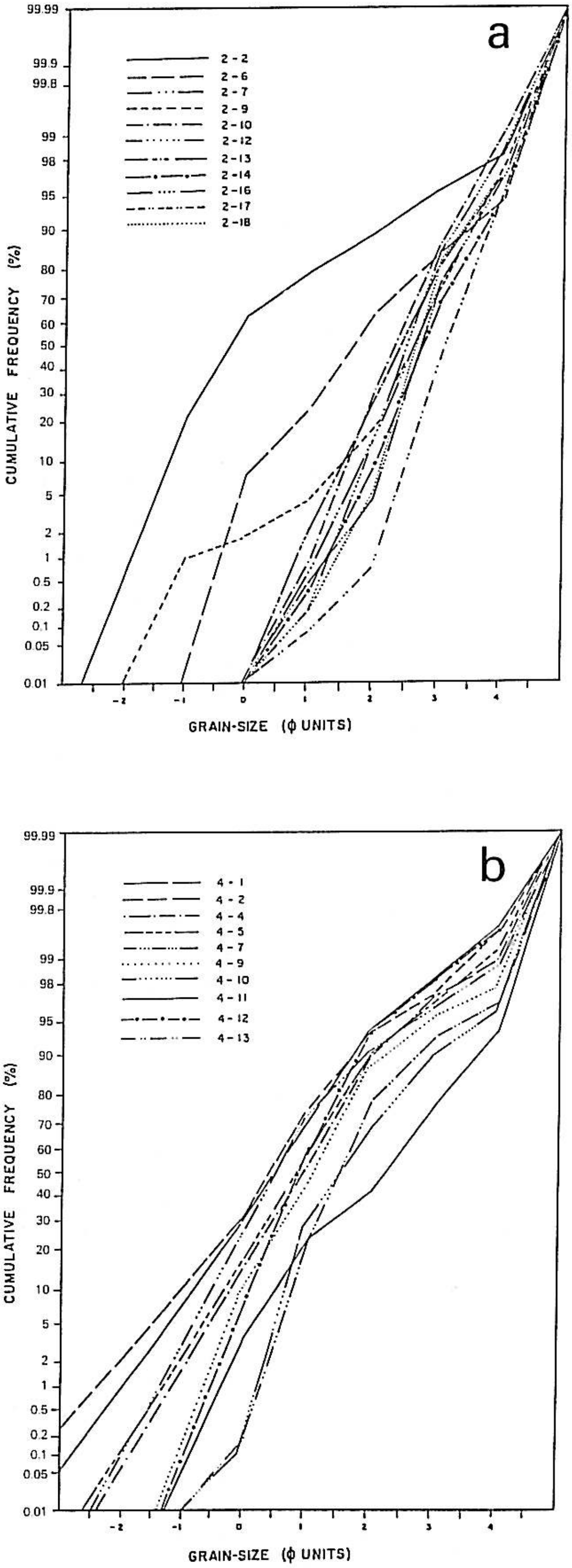

FIG. 2. Cumulative-frequency curves, showing the relationship between sediment transport dynamics with populations and truncation points in a grain-size distribution.

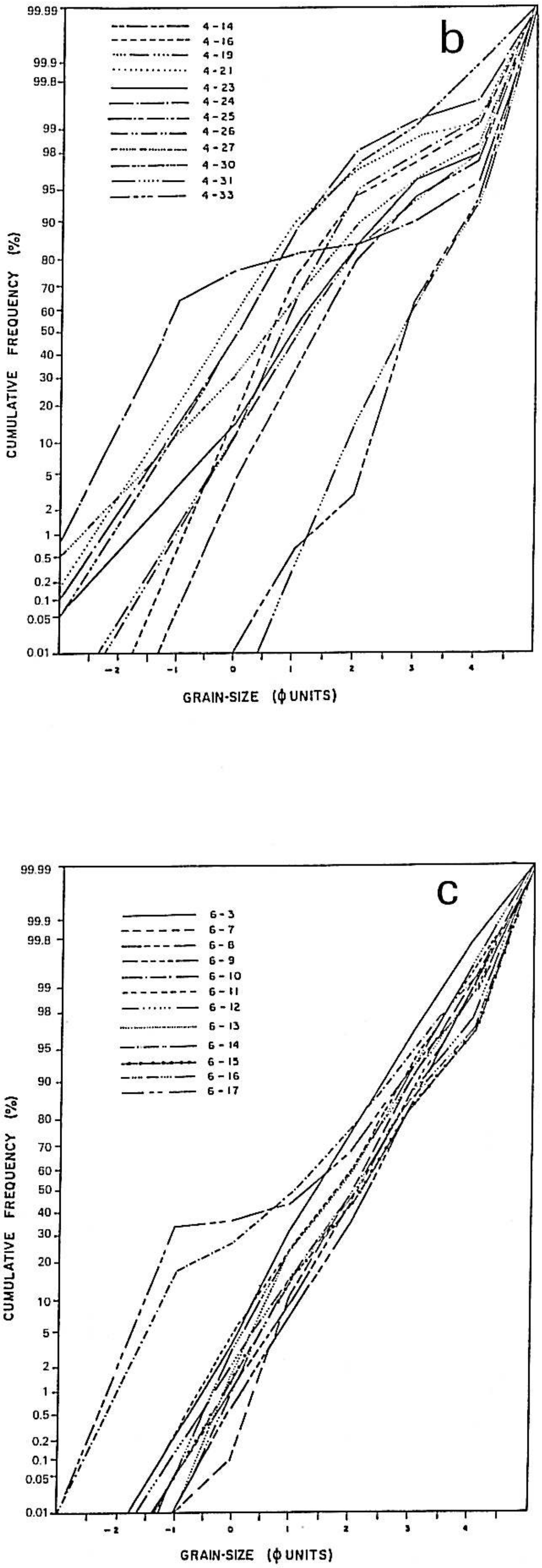

FIG. 2.—*Contd.*

(2) The saltation population is well developed: it represents more than 85% of the distribution.

(3) The traction population is usually very small and represents only about 1% of the distribution, except for a few samples where it represents more than 60% of the distribution. This reflects two main modes of transportation of the Bahi sediment; a saltation load transport for most samples and surface creep or rolling transport for others.

STRATIGRAPHIC VARIATION IN GRAIN-SIZE PARAMETERS

The formulae of Folk and Ward (1957), and Folk (1974), have been used in this study, to determine grain size statistical parameters (mean size, standard deviation, skewness, kurtosis), because they cover most of the sediment distribution data for the Bahi samples especially in the tails of the distribution. Vertical profile for each borehole in the Bahi Formation shows the stratigraphic variation in mean size, standard deviation, skewness and kurtosis (Figs. 3a–c).

Mean Characteristics

The mean size value of the Bahi sediment in the A2-32 borehole ranges between 3.13 to 1.75 phi (very fine to fine sand) in most of the samples. One sample has a value of −0.02 phi (very coarse sand) in the upper part of the section. However, this section can be divided into two parts according to the mean size value, the sediment in the lower part being very fine to fine sand and, in upper part, very coarse sand (Fig. 3a). Whereas in the A4-32 borehole the mean size values range between 2.95 to −1.50 phi (fine to very coarse sand). Here the Bahi sandstone can be divided according to the mean size of the sediments. In the lower part, the mean size value shows a coarsening upward pattern from fine into coarse and then very coarse sand followed by repetitive grading from medium to coarse sand. In the upper part the mean size values range from fine to medium into coarse and very coarse sand (Fig. 3b). While the mean size value in the F6-32 borehole ranges between 2.23 and 0.43 phi (fine to coarse sand). According to the grain size values the Bahi sandstone can be divided into; the lower part, coarsening upward from fine to medium to coarse sand, and the upper part, also coarsening upward, ranging from fine to medium sand (Fig. 3c). Generally, the overall mean size values of the three borholes exhibit a coarsening upward trend from very fine sand to very coarse sand. This variation in mean size could be related to variation in the energy of transporting agents and/or change in the source of the sediment during deposition.

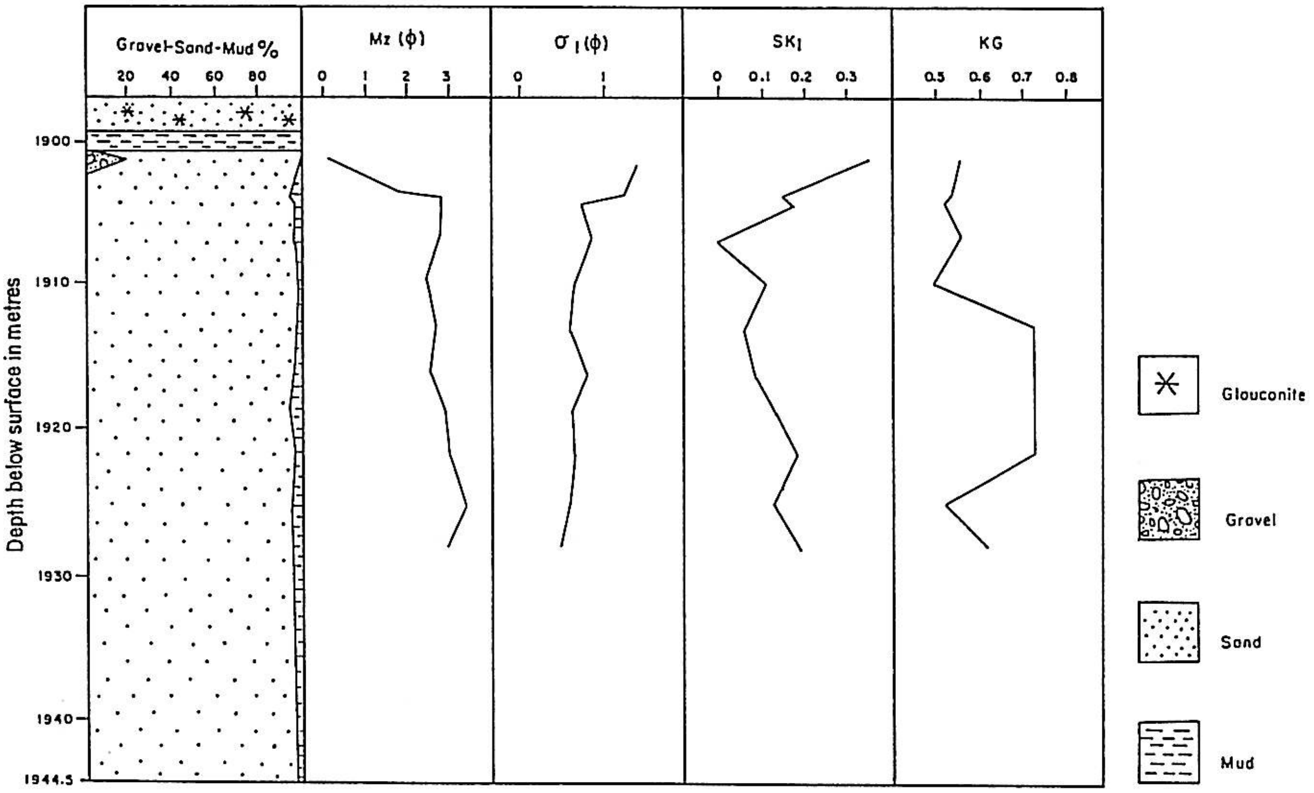

FIG. 3a. Vertical variation of gravel-sand-mud composition and grain-size parameters in the Bahi Formation (A2-32 borehole).

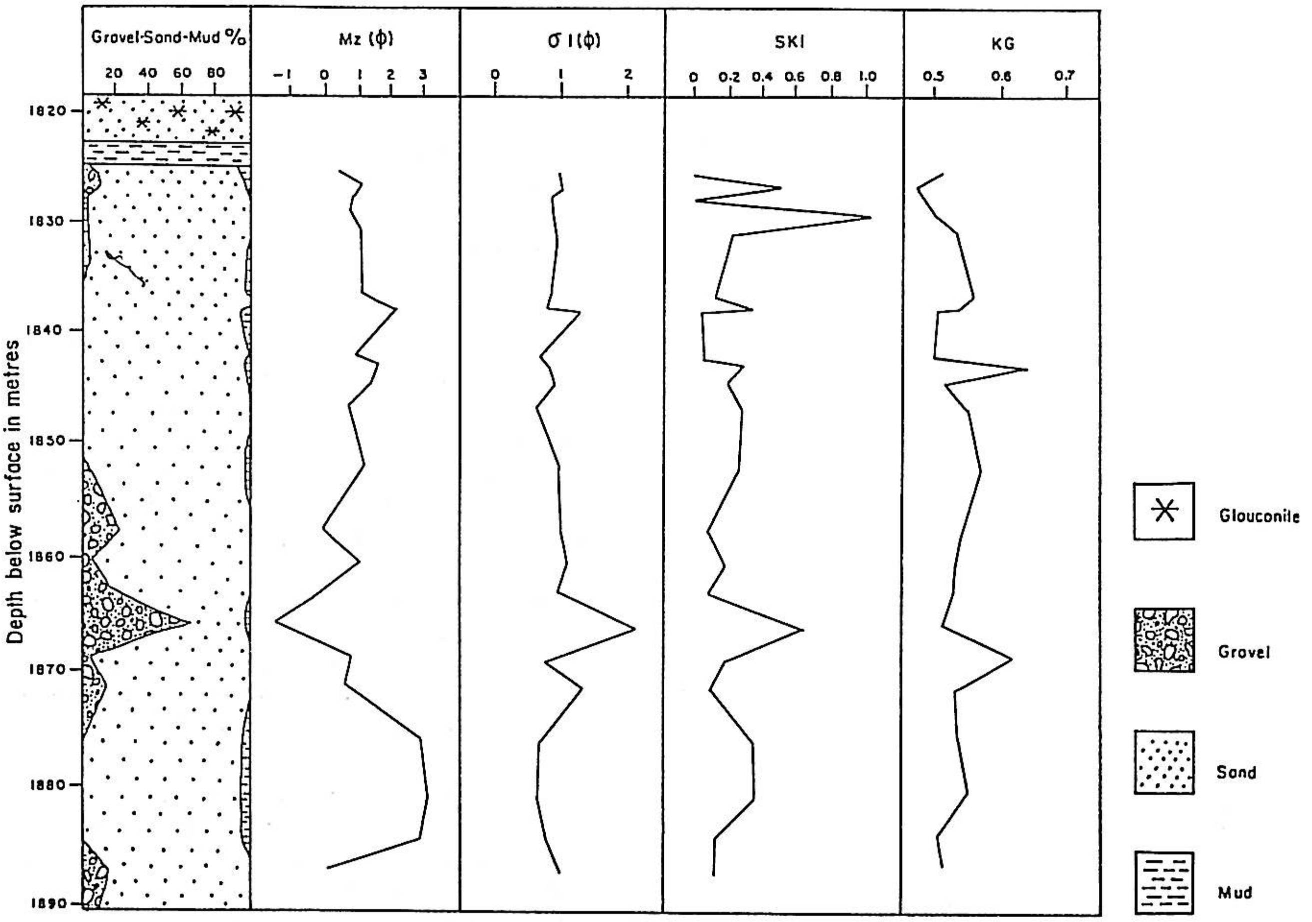

FIG. 3b. Vertical variation of gravel-sand-mud composition and grain-size parameters in the Bahi Formation (A4-32 borehole).

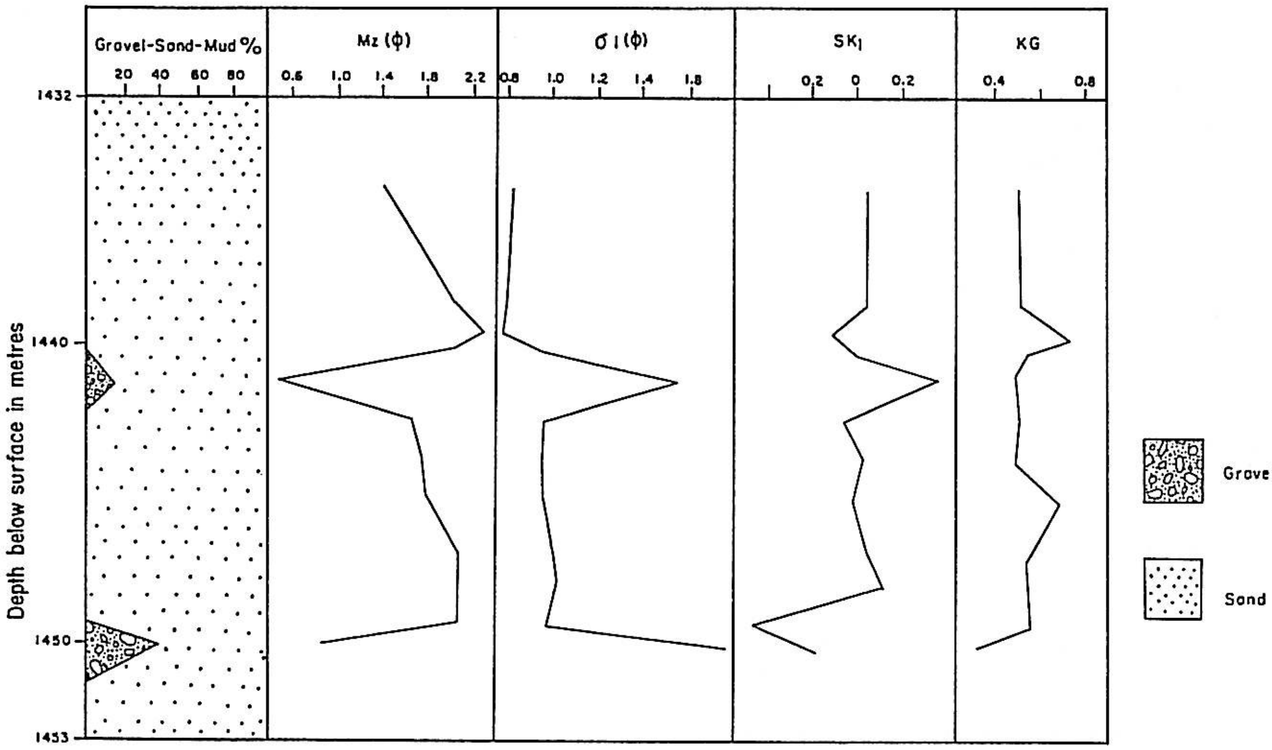

FIG. 3c. Vertical variation of gravel-sand-mud composition and grain-size parameters in the Bahi Formation (F6-32 borehole).

Sorting Characteristics

Most of the samples in the A2-32 borehole are moderately to moderately well sorted (8 out of 11) and show uniform standard deviation values ranging between 0.50 and 0.79 phi, with an average of 0.62 phi. The remaining three samples of which two are from the upper part of the section sampled, are poorly sorted, ranging between 1.19 and 1.37 phi, and one sample from the lowest part of the section is well sorted, 0.38 phi, (Fig. 3a). Whereas the samples from the A4-32 borehole are moderately to moderately well sorted (16 out of 22), and show uniform standard deviation values ranging between 0.60 and 0.98 phi with an average of 0.79 phi. The remaining samples are poorly to very poorly sorted and range from 1.03 to 2.09 phi with an average of 1.31 phi (Fig. 3b), whereas in the F6-32 borehole the samples are moderately sorted (10 out of 12), and show uniform standard deviation values ranging between 0.77 and 0.97 phi with an average of 0.8 phi, except for two samples from the upper and lowest part of the sampled section which are poorly sorted and range between 1.52 and 1.71 phi with an average of 1.62 phi (Fig. 3c). Lateral and vertical variation of the sorting in the Bahi sediment from one borehole to another may reflect different sediment sources but may also reflect the nature of the transporting agents at the time of deposition.

Skewness Characteristics

Values of inclusive graphic skewness in the A2-32 borehole, range from the strongly fine skewed to near symmetrical, with an overall range between −0.01 and +0.34 (Fig. 3a), whereas in the A4-32 borehole, skewness values range from strongly fine skewness to a near symmetrical curve, with an overall range between −0.07 and 0.56, except for one sample which shows a strongly coarse skew 0.56, (Fig. 3b). In the F6-32 borehole, skewness values range from strongly fine skewed to strongly coarse skewed, with an overall range between −0.49 and +0.33 (Fig. 3c).

The overall average inclusive graphic skewness in the three boreholes show strongly fine skewed to a near symmetrical distribution. This asymmetry in the sediment distribution, both laterally and vertically, may result from multiple sources for the Bahi sediment.

Kurtosis Characteristics

In the samples from the A2-32 borehole, graphic kurtosis is leptokurtic to very leptokurtic with a range between 1.134 and 2.596, except for three samples from the middle and lower part of the sampled section which are mesokurtic (Fig. 3a). In the A4-32 borehole, the samples are leptokurtic to very leptokurtic with ranges between 0.134 and 1.517, except for eight samples which are mesokurtic and one which is platykurtic (Fig. 3b). In the F6-32 borehole, most of the samples are mesokurtic with ranges between 0.907 and 1.092. Two samples however are very leptokurtic, two are platykurtic and one sample is very platykurtic (Fig. 3c). Generally, the Bahi sediment in these boreholes is leptokurtic to very leptokurtic, indicating that the central part of the samples are better sorted than the tails, whereas some samples are mesokurtic, showing similarity in sorting between the central and the tails portions of the sediment distribution curves. This indicates different degree of sorting which may reflect multiple sources for the sediment and/or more than one mode of transportation.

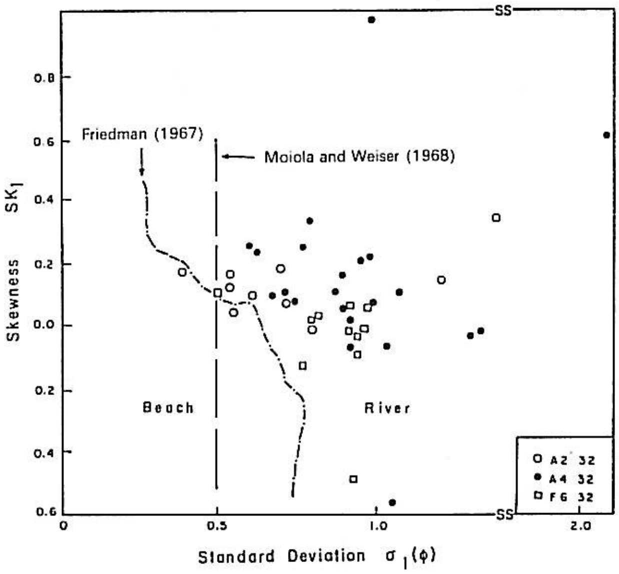

FIG. 4. Plot of inclusive graphic standard deviation against inclusive graphic skewness, showing the environment of deposition in the Bahi Formation in the boreholes studied, based on Friedman (1967) and Moiola and Weiser (1968).

ENVIRONMENTAL INTERPRETATION

For more than 30 years sedimentologists have been seriously attempting to use textural analysis to deduce depositional environments. Scatter plots of inclusive standard deviation against inclusive graphic skewness, inclusive standard deviation against graphic mean size and median against inclusive standard deviation have been constructed in an attempt to recognise the depositional environment or environments for the Bahi sediment.

Plots of inclusive standard deviation against graphic skewness have been used by many workers to differentiate between river and beach sands (e.g. Friedman, 1961 and 1967; Moiola and Weiser, 1968 and others). Friedman (1967) shows that a plot of inclusive graphic skewness versus inclusive graphic standard deviation gives a good separation between beach and river sands. Beach sands tend to be better sorted than river sands and thus tend to have lower numerical standard deviation values (Friedman, 1961). A plot of these two grain size parameters for the Bahi samples in the three boreholes is shown in Fig. 4. Using Friedman (1967) and Moiola and Weiser (1968) boundary lines, the majority of the samples are classified as river sands except for one sample from the A2-32 borehole which is classified as a beach sand. None of the analysed samples in the three boreholes include the uppermost part of the formation which is known, on mineralogical grounds, to represent the initiation of a marine cycle (glauconitic sandstone).

Plots of standard deviation against mean size is also considered to be most effective in differentiating between depositional environments. Moshrif (1980) used a combination of the "environmental boundaries" of Friedman (1961, 1967) to differentiate between beach, dune and river sands. Applying these boundary lines to the Bahi samples from the three boreholes (Fig. 5a), most of them are classified as river sands, whereas a few samples from the A2-32 and A4-32 boreholes are classified as dune sands. Applying Moiola and Weiser's framework (1968) for these parameters (standard deviation and mean size), show, however, that all the analysed samples are classified as river sands (Fig. 5b).

Steward (1958) used a scatter plot of standard deviation against median to differentiate between

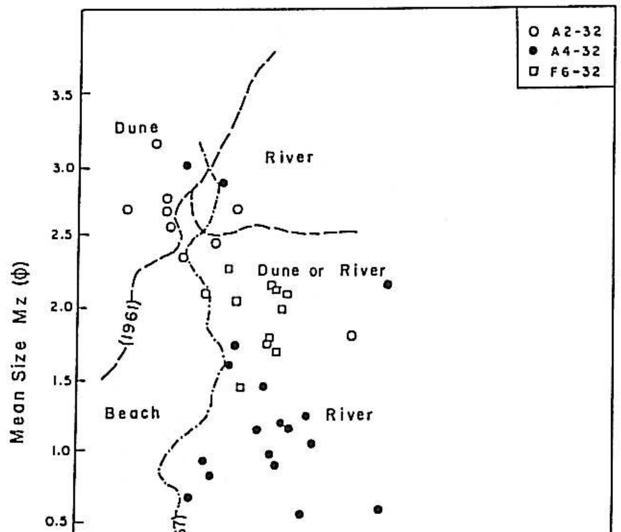

FIG. 5a. Plot of inclusive graphic standard deviation against mean size, showing the environment of deposition in the Bahi Formation in the boreholes studied, based on Friedman (1961, 1967).

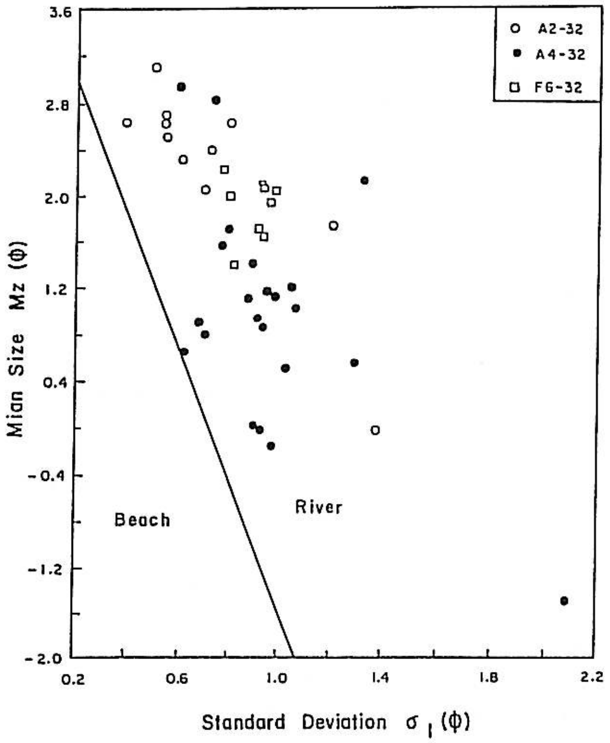

FIG. 5b. Plot of inclusive graphic standard deviation against mean size, showing the environment of deposition in the Bahi Formation in the boreholes studies, based on Moiola and Weiser (1968).

river processes, wave processes, and slow deposition in quiet water. Stewart's diagram (Fig. 6), shows that wave processes are responsible for most of the samples in the Bahi sandstone in the A2-32 borehole, and the river processes for most of the samples in the A4-32 borehole, except for two samples which fall on the wave processes side. Seven samples in the F6-32 borehole fall on the river processes side and one sample falls on the wave processes side. The remaining samples from the three boreholes fall outside both fields. They fall close to the river processes field, and their plot position may not be particularly significant. This suggests that the Bahi sediments were deposited under the changing mechanical conditions which would be expected as a fluvial regime passed, by degrees, into a littoral one.

Passega (1957, 1964) stated that sample point patterns representing the variations in a deposit of two parameters, C and M, are characteristics of the depositional agent. The C is the one percentile diameter (in micron), an approximation of the maximum grain size; and M is the fifty percentile particle diameter, the median. Passega stated that the CM pattern is geological tool which can be used to analyse the depositional conditions in recent sediments and thus enable a reconstruction to be made of the conditions of deposition for ancient sediment suites. The CM diagram illustrates the relationship between grain size

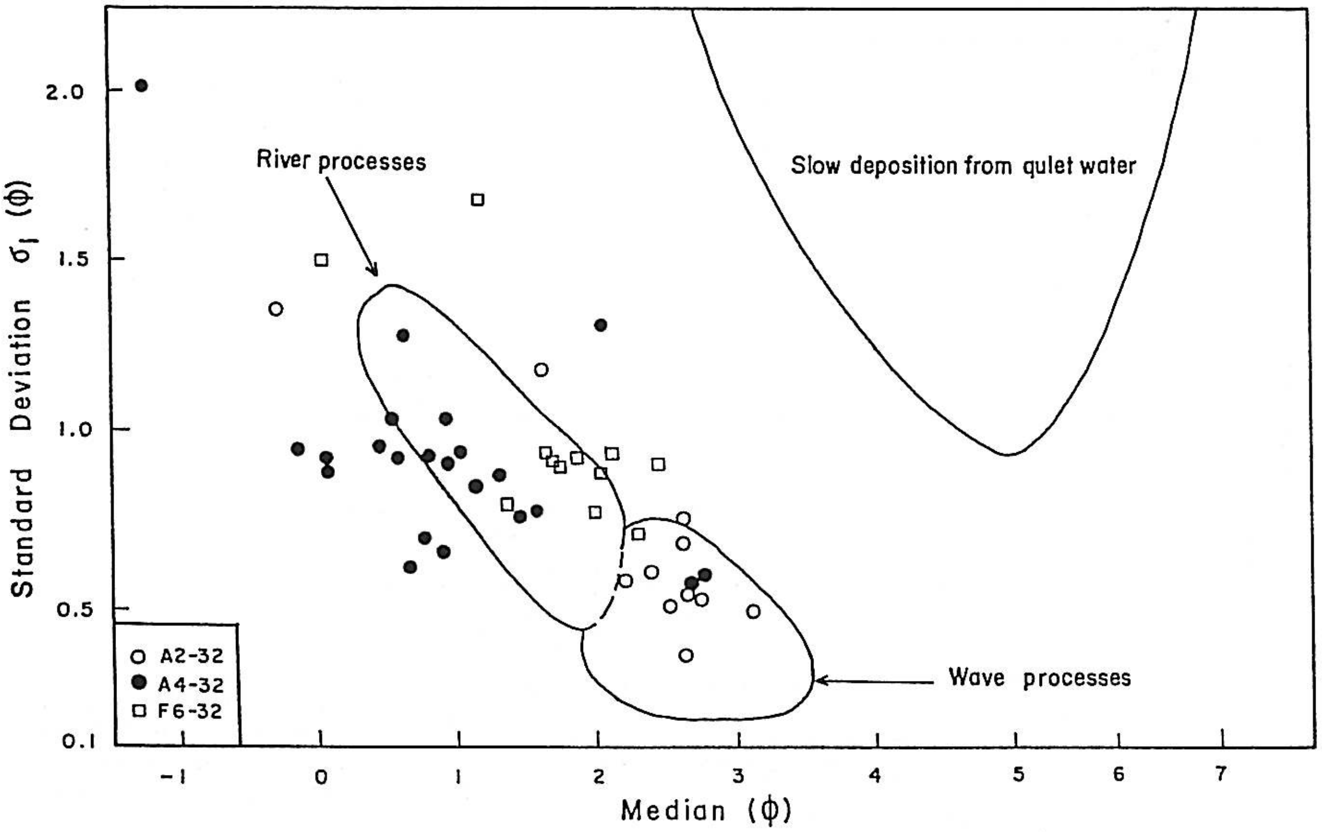

FIG. 6. Plot of inclusive standard deviation against median, showing the nature of deposition of the Bahi Formation in the boreholes studied, based on Steward (1958).

and the hydraulic conditions under which clastic deposits have accumulated. Passega (1964) subdivided the CM patttern by points N, O, P, Q, R and S into five segments each of which corresponds to a particular sedimentation mechanism. This implies that clastic sediments of a certain grain size are available under particular hydraulic conditions. The mechanism of transportation are represented mainly by rolling (NO); rolling and suspension (OP); suspension and rolling (PQ); graded suspension (QR) and uniform suspension (SR). Pelagic suspension (T) represents the finest sediments (below 15 micron). In 1969 Passega and Byramjee further subdivided the CM diagram into 9 classes as shown in Fig. 7. Data falling in classes I, II, III, and IX indicates that the grains have been transported by rolling while those falling in classes IV, V, VI, VII and VIII indicate grains which have been transported by saltation. The CM technique is mostly applied at the lamina scale but in this study has been applied to all grain size analysis samples even though the value may be limited.

Fig. 7, shows the distribution for the samples from the Bahi sediment in the three boreholes. Most of the samples in the A2-32 borehole fall within classes IV and V, indicating that they were transported by saltation, except for two samples which fall in classes I and II indicating that they were transported by rolling. In the A4-32 and F6-32 boreholes, most of the samples fall in class I indicating that they were transported by rolling, except for two samples in F6-32 borehole which fall in class IV indicating that they were transported by saltation.

CONCLUSIONS

Keeping in mind that grain diminution and overgrowth may modify the size characteristics of the sediment, and the fact that the cement may itself break down into grains the following general conclusions can be drawn:

Cumulative frequency curves show two main modes of transportation for the Bahi Sandstone; saltation load transport for most of the samples and surface creep or rolling transport for the others.

Histograms show that most of the Bahi Sandstone samples are unimodal for the A2-32 and A4-32 boreholes, with few samples showing biomodality in the latter borehole, whereas in the F6-32 borehole the majority of the samples show a biomodal distribution.

Sediment distribution in the formation exhibits a coarsening upward trend ranging from very fine to very coarse sand, moderately to very poorly sorted, characterized by a strongly fine to strongly coarse

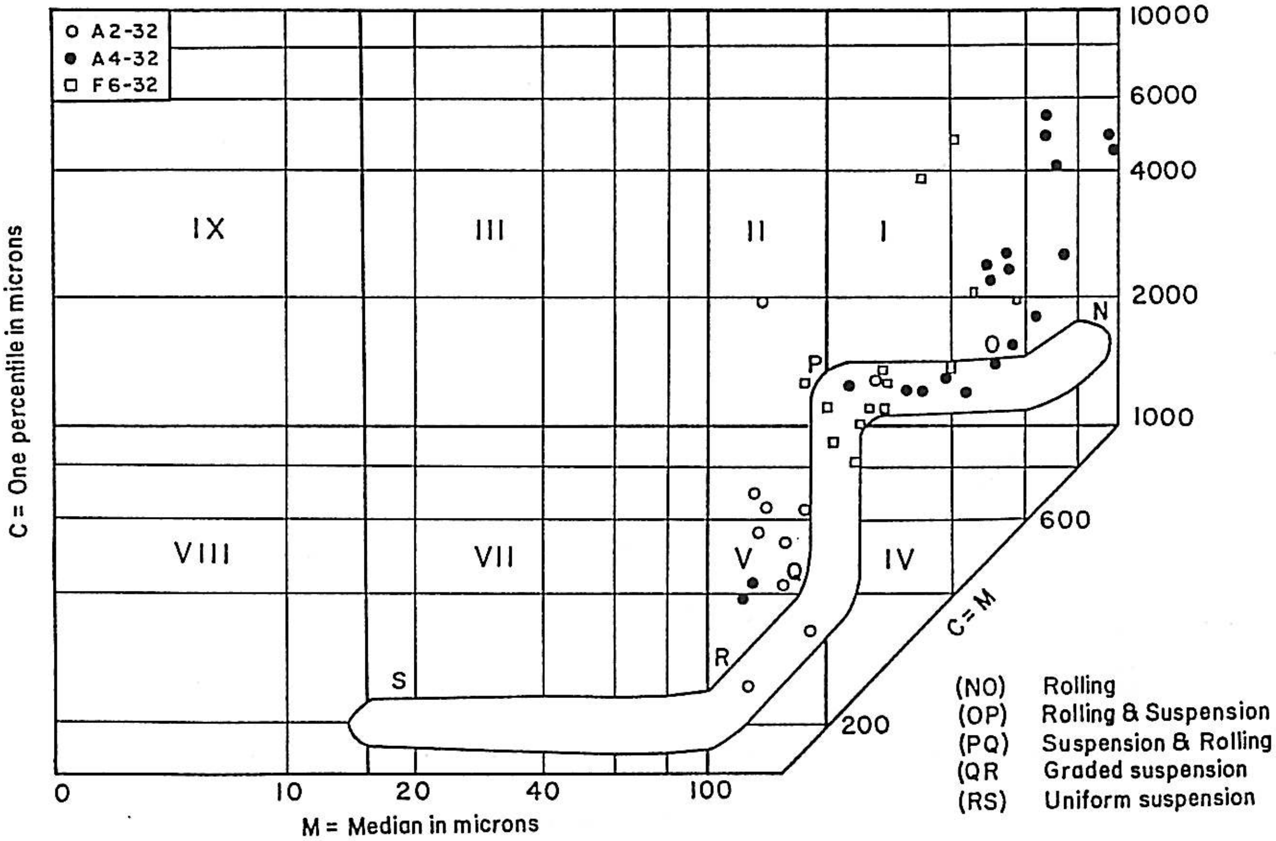

FIG. 7. Plot of C (1st percentile) against M (Median in diameter), showing the nature of transportation of the Bahi Formation in the boreholes studied, based on Passega and Byramjee (1969).

skewness which varies from leptokurtic to very leptokurtic with some samples being mesokurtic. This variation could be related to variation in the energy of transportating agents and/or changes in the source of the sediment during the Bahi deposition.

Sorting data plotted against mean size and skewness show that the Bahi Formation largely comprises river sands, with few samples which are to be regarded as beach sands.

Sorting evidence plotted against the median shows that the process agent for the Bahi sediment is river and wave systems.

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