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THE EFFECT OF DEPOSITIONAL SANDSTONE ENVIRONMENT ON SAND GRAIN SIZE AS PREDICTED FROM WELL LOGS DATA PARAMETERS

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ABSTRACT
Attempts have been made in the past, with some success, by different researchers to develop a generalized mathematical relationship between formation sand grain size and petro physical properties obtained from well logs such as porosity, water saturation, among others. These mathematical prediction models have been found to provide more reliable information about in-situ grain size distribution of Tertiary pay sands.
This paper goes further to highlight the big effect of depositional environment on the grain size distribution of Tertiary formation sands of the Niger Delta environment. The highlight of the results is the development of mathematical relationships between, median grain size and cementation factor on one hand as well as median grain size and formation ratio activity among others. The results have shown that there are differences in prediction models for the different depositional environments such as Distributaries Channel , fills/Point bar sands, Braided river channels, Barrier bars/Barrier foots among others. It is believed that the trends and models established in this study will form a solid foundation for a more accurate prediction of formation sand sizes when the right petro physical parameters are known. This will prove useful to production engineers, petro physicists and production/reservoir geologists especially with respect to gravel pack design and sediment logical studies.

KEYWORDS*; Niger delta environment, Grain size , Water saturation , Gravel parked, Braided river, Paysandú Reservoir, Geologist , and Distribution tertiary*

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INTRODUCTION

Sedimentary formations, in general, are composed of sandy or clayey particles which have been eroded from larger particles in the earlier stages of a river and deposited in the latter stages of the river. The deposit formed would then undergo a series of physical, chemical and biochemical changes otherwise known as diagenesis. The sedimentary rock so formed is made up of a framework of sand grains cemented together and interconnected pores.

The characteristic features of the sedimentary particles otherwise known as formation textural properties are of great importance to the petroleum engineer in that they influence to a large extent such important reservoir properties as porosity, permeability and ultimate yield strength of the rock. More importantly, when sand failure occurs within the reservoir rock, leading to sand production with the reservoir fluids and subsequent damage to downhole and equipment, the formation textural properties are a major consideration in gravel-pack design as a sand control measure. These formation textural properties are grain size, sorting, shape, roundness and packing. Of these, grain size and sorting are believed to be of most relevance to reservoir properties. Grain size and-sorting are dependent mainly on two major factors; the source rock material from which the sediments were eroded and the environment(s) under which they were deposited. The influence of the source rock material is however overshadowed by the physical or hydrodynamic conditions prevailing in the environment in which the deposit is formed. It is thus the objective of this paper to highlight the depositional environment as the main factor influencing the sizes and sorting of sand grains in the Deltaic sedimentary formation.

Usuahy, ample information on the grain sizes occurring in the sedimentary formation may be obtained by taking side wall cores of the formation or samples from production lines, both of which have the shortcoming of not giving representative samples. Full rubber-sleeve coring which is intended to im|jrq[1]ve this, is very expensive besides the general problem of core damage Onyeneyin[1]

In the recent past, various studies have been carried out on the influence of, and the relationship between formation sand size and petro-physical properties of the formation.

K.J. Weber[2] had discovered that the depositional environment of a sand body in the Niger Delta influences the shape and the response obtained on gamma ray and SP logs. This, he believed is because the gradual change in grain sizes in the upward direction (fining or coarsening sequence) is almost always accompanied by an increase or reduction in the formation radioactivity. Thus one can identify the depo-environment of a reservoir sand by its gamma ray or SP log shape, though a more accurate picture is obtained by examining its grain size distribution, faunal and mineral content, bioturbation structures, etc.

W.A. Pryor[3] in a systematic and thorough sampling of unconsolidated sand from three depositional environments also found that porosity and permeability are related to sand genesis.

K.A. Alafun[4] while investigating the possibility of predicting permeability from grain size data in the Niger Delta, related cementation factor derived from resistivity and porosity logs to the sorting of sand grains and porosity.

Beard and Weyl[5], also in working with synthetic sands, discovered that well-sorted sands tend to have higher porosities than poorly sorted ones and that porosity in well-sorted sand is independent of the grain size.

In the first major work on the \ numerical prediction of formation sand size, Onyeneyin[1] established a correlation between the sand size and the permeability derived from irreducible water saturation and porosity which gave good predictive values of the grain sizes. From the foregoing, one can clearly see that sand grain size and sorting can be related to porosity, log derived cementation factors and formation radioactivity on the basis of the depositional environment of the particular sand body.

SEDIMENTARY DEPOSITIONAL ENVIRONMENTS OF THE NIGER DELTA

A sedimentary depositional environment can be defined as a geomorphic unit in which deposition of sediments takes place. It is characterized by a unique set of hydrodynamic, (physical), biological and chemical processes operating at specific rates and intensities. These processes impart sufficient imprints on the sediments so that a characteristic deposit is formed. Grain size distribution as well as sedimentary sequences are usually part of such imprints.

Depositional environments are often times of a complex nature since the physical, chemical and biological processes operating within an environment can vary strongly from place to place, such that the sediment types produced also vary. This usually results in sub-environments within a broader environment. Young & Shukwu[9]

The Niger Delta Environment
The Niger Delta region can be divided into four main environments, namely:
The Coastal Plain (Upper and Lower)
The Intradelta
The Delta Front
The Prodelta.

The Upper Coastal Plain

This part of the delta features the meandering stage of the river and associated deposits. Important among these deposits are:

(a) ***The Point Bars*** - These are formed as a result of lateral migration of the river during floods and subsequent deposition of sediments on the convex banks of the meandering river channel. Deposition usually occurs during foods which thus makes the rate of deposition very high. The sand grain sizes of these point bars are usually in the range of 63 to 350 microns and are moderately sorted. Like most fluvial sediments, point bars exhibit the fining upward characteristic which means that the sand grain sizes become progressively smaller in the upward direction. Often times, there is a clayey or very fine grained layer present on top of the deposit as a thin seal.On gamma ray log, this peculiar fining upward characteristic of fluvial deposits is reflected by a low constant formation radioactivity value gradually increasing toward the top of the . Shevron[6]

(b) ***Channel Fills*** - These are the result of deposition in abandoned (cut off) river channels. Deposition occurs very rapidly at die initial stage but slows down with the passage of time. Channel fills exhibit a wide range of grain sizes ranging from 63 to 500 microns; which also become smaller in the upward direction. Sorting among channel fills is usually poor.

(c) ***Natural Levees*** - These are wedge-shaped ridges of sediments formed on the borders or banks of streams. They slope gently from the bank into the flood basins away from the river channel. They are often better developed on the convex sides of rivers, like point bars..Natural levees are formed by the deposition of suspended sediment on river banks when waters of a river overtop its banks during floods. Thus, stream velocity reduces, and much of the sediments are

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deposited near the channel, with grain sizes decreasing away from the channel. Grain sizes are usually less than 200 microns with very good sorting ..Zeidler [7]

(d) ***Crevasse Splay Sands*** - These are distinct channels that have been cut across the river banks and through natural Levee deposits by flood water during high floods. Excess water bearing sediment thus leaves the main channel through the crevasses and sedimentation takes place. These type of sands are mostly formed on convex sides of the meandering river channel, and are coarser grained than the associated natural levee deposits in which they are embedded. Grain sizes range from 100 - 300 microns and are usually poorly sorted.

The Lower Coastal Plain

Closer to the coast on the tidal flats, the river subdivides into many distributaries which often further subdivide themselves into channels. The channels have a tendency to meander, but are known to be more or less straight channels in the recent delta. Thus, it is mainly point bar and channel fill deposits that are formed here. The point bar sands here are similar to those found in the upper coastal plain while the distributary channel fills resemble the point bars formed further upland. Grain sizes are in the 100 - 500 micron range with very poor sorting.

Around the distributary channel fills, natural levee and crevasse sands can be found. The levee sands are usually clayey to fine-grained in texture (less than 150 micron) and poorly sorted. In the distributary channel fills, the upward fining characteristic is usually pronounced in the upper parts, and this can be seen on the gamma ray log by a gradually increasing value of radioactivity. A funnel shape is thus seen on the logs. This is similar to the response of point bars and channel fills on the same log, but they can be distinguished by correlation.

The Intradelta

This is the portion of the delta very close to the Coastline and partially influenced by wave action. Only the finer river sediments reach this zone. Sub environments formed here are mainly tidal channel fills and river mouth bars.

Tidal channel fills are formed by alternate deposition of fluvial and marine sediments during low and high sea tides respectively. They therefore consist of a series of thin cross-bedded sandy sequences which fine upwards, as other fluvial sediments and are separated by thin marine clay beds. These clay breaks give the channel fills a serrated character on the SP and gamma ray logs. Distributaries channels of the lower coastal plain generally become tidal in the seaward direction. This can often be observed while correlating distributaries channel sands in the seaward direction.

River mouth bars are dumps of river material at the mouths of rivers. This is due to the sudden reduction in stream velocity. Rate of deposition is usually high and the sediments are usually fine grained (less than 15 microns) and well sorted. Lagoon and back swamp deposits may also be found in the intradelta. Intradelta deposits usually exhibit the fining upward character of fluviatile sediments which makes them to be easily identifiable on gamma ray logs as well as by correlation.

The Delta Front

This region, which is about 10m below the coastline, is characterized by prevalent wave action. The deposits are mainly high-energy barrier beach sands otherwise known as barrier bars. They are usually fine-grained (60 - 250 microns) and also well sorted. They are usually broad and sheet-like and lie parallel to the coast. Sand grain size increases in the upward direction (upward coarsening), and this is almost always accompanied by an upwardly increasing permeability. On gamma ray logs, barrier bars can be recognized by the upward decrease in radioactivity often reaching a low constant value. Similar to logs produced by channel deposits. However, clay breaks in barrier bars, unlike those found in tidal channels, are usually creatable over large distances.

The Prodelta

This environment usually lies below the active wave level and is thus very quiet, comprising the finest river sediments, silts and clays. Sedimentation is usually rapid, but the deposits formed are often much disturbed by burrowing by living organisms. This type of deposit is known as barrier foot and usually forms the frontal part of coastal barrier bars. Sand grain size increases upwards and marine shale interculations are common. Thus on gamma ray log, barrier foot deposits usually exhibit an upwardly decreasing high gamma radiation, and a serrated character. Plant remains can usually be found here.

SEDIMENTATION AND DIAGENESIS

The vertical sequence of sediments in the boreholes of recent, tertiary delta deposits reveal clearly the characteristic cyclic nature of the sedimentation processes with a sequence of tidal or distributaries channel fills overlying a transgressive deposit which in turn overlies barrier bar and barrier foot sediments. This is because of the lateral relationship between these environments and the progradation of the Delta with passage of time. Menzel [8] . Digenetic processes normally follow sedimentation but they do not affect the grain size distribution thus it can be seen that grain size distribution in a given sand body is influenced almost completely by-its depo-environment.

DEVELOPMENT OF NUMERICAL EQUATION FOR GRAIN SIZE DISTRIBUTION

The primary objective of this paper is the presentation of an empirical equation which can be used in predicting grain size distribution. Data used in this work were the grain size data obtained from over three hundred sidewall cores from thirty reservoirs in the Niger Delta, and the corresponding petrophysical properties from the appropriate logs. The parameters of interest generally here are:

(i) Median grain size and sorting coefficient from side wall cores.
(ii) Porosity from density, neutron and sonic logs.
(iii) Formation radioactivity from gamma ray logs.

These parameters have been chosen because:

Median grain size and sorting coefficient are two sufficiently good measures' of the central tendency and variation of the grain size distribution of a given sand unit.

Porosity and sorting coefficient have already been correlated via a lithological exponent by Alafun[4] which is actually log-derived cementation factor. Median grain size of formation sand usually decreases with increasing formation radioactivity (due to increasing clay. content), except where the formations and itself is radioactive so that the trend is beclouded. The underlying factor in the data gathering process is however the depositional environment of the reservoir where the particular cores were taken. This was interpreted from (i) the full description of the core including grain size distribution, faunal and heavy mineral content, and presence of glauconitic; (ii) gamma ray log shapes and by correlation with adjacent sands. The median grain size was taken as the second quartile diameter which corresponds to the mesh size at the 50 percentile cumulative frequency mark on the ogive while the sorting coefficient was taken as the square root of the ratio of the first quartile diameter to the third quartile diameter. The petrophysical parameters are:

(a) ***Porosity***: Obtained from Density logs and sonic logs, or combination of logs. In this case cross plpts of density-neutron, density-sonic and sonic-neutron logs are available from which the porosity of a given formation can be read directly if its lithology is known as it in the in Niger Delta.
Radioactivity: This measure of the natural radioactivity of the encountered formation can be read directly from the gamma ray log response.
Cementation Factor which is a measure of the degree of cementation between the individual grains of the rock matrix can be computed indirectly from the resistivity logs as follows:

From Archie's formula, $F = a/Ø^m$
Where a, is an empirical constant, 0 is porosity, F is formation resistivity factor and m is the cementation factor. Alafun computed the cementation factor to be:
$m = 2.2 - 1.06$, $Ø = 0.09\ S_o$ Where S_o = sorting coefficient from sidewall core
Ø = log derived porosity and m is the cementation factor referred to in this equation as lithological exponent.

In order to establish the desired relationships, between median formation sand grain size and the petrophysical properties of the formation, the data were divided into groups according to the depositional environments and then grain size data matched with the log-derived parameters for each group so as to establish correlations and mathematical relationships on depot environment of the sand in question. Table 1 shows sample compilation of the data set utilized.

Data Analysis and Mathematical Correlations

The data analyses have mainly been done by graphical techniques which includes making cross plots of grain size parameters versus the petrophysical parameters and thereby establishing trends for relationships. It is recognised that cross plots do not provide exact results since the equations generally obtained, or fitted curves, are somewhat influenced by the observer. However, efforts have been made to use sufficient accurate data which makes the trends of most of the cross plots obtained to serve as a first and good approximation for the exact mathematical equations which can be obtained by linear or polynomial regressional analysis.
Accurate mathematical relationships have therefore not been proposed in this paper but it is believed that the trends and models proposed will serve as a solid foundation for predicting grain sizes from log-derivable formation properties.
In collating data points into groups of depositional environments, care was taken to note that certain environments such as distributary channel fills and point bars have very similar grain size characteristics and so can be grouped together. Certain problems did arise in the grouping of depositional environments. Data on some environment types were found to be scanty and inconclusive which made their utilization difficult and thus were discarded.
The results of the cross plots for porosity versus sorting for different depo-environments are as presented in Figures 1. Other cross plots include:
1. Porosity versus Median Grain Size
2 Median Grain Size versus Cementation Factor (Fig.2)
3 Median Grain Size versus Formation Radioactivity (Fig.3)

In all, the following equations were distinctly derivable from the cross plots:
(a) $\log D = a + bm$ from Grain size (D) versus cementation factor (m) correlation for different Depo-environments.

Table 2 shows the values of a and b for different Depo-environments.

(b) $\log D = C_1 \log GR + C_2$

Where D is Grain size.

GR = formation radioactivity

C_1 = slope of best fit line and

C_2 = intercept on D-axis

Table 3, shows the value of C_1 and C_2 for different depo-environments.

Thus, depending on the depositional environment, the particular Mathematical correlations can be utilized.

PRESENTATION AND DISCUSSION OF RESULTS

Table 1a; Porosity Versus Sorting Relationship

Depo-Environment	Correlation Obtained	Remarks
Distributaries channel fills and Point bar sand Braided River Channel Tidal Channel fills Barrier bar/Barrier foot	No definite trend observed. Clusters of Points with no distinct pattern. Cloud of points with no distinct pattern. Clustering of Points Clusters of data points	Need for more data points to justify good trend. More data points needed. Not correlatable to other clusters by eyeball

TABLE 1b: INITIAL ESTIMATES OF CONSTANTS FOR LOG D VERSUS M RELATIONSHIP

DEPO-ENVIRONMENT	A	b
Braided River Channels	-1.50	4.437
Tidal Channel Fills	-1.50	4.647
Barrier Bar/Foot Deposit	-1.27	4.1

The clusters obtained from the foregoing analysis could not be collated by simple overlaying and eyeball techniques to produce a definite trend. It could be seen however, that with more accurate cluster analysis, a definite relationship can be evolved between porosity and sorting. Thus, more advanced techniques will need to be developed for a better result combined with the existence of more data points. This will form the basis of the next stage of work on this continuing project.

Thus, it is clear so far that a sorting versus porosity relationship can be developed based on the depositional environment because environments where wave action is predominant so that sediments are worked and reworked, produce deposits of well sorted sand grains and high porosities, while other environs where this winnowing action is not present and sediments are simply dumped, produce deposits with poor to moderate sorting of the sand grains and lower porosities. Klark [10.] Expressed as a mathematical correlation for specific regions, this relationship will prove useful to the production geologist in sedimentological studies of reservoirs as well as to the production engineer as an aid to gravel pack design.

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Table 2; MEDIAN GRAIN SIZE VERSUS CEMENTATION FACTOR

Depo-Environment	Correlation Obtained	Remarks
Braided river Channel Sands	Straight line with negative slope	Good foundation for grain size prediction
River Channel fills/Point Bars	Straight line with identical slope	Good for grain size prediction
Tidal Channel fills	Straight line with negative slope but with more scatter of data point	Needs some regression analysis
Barrier Bar/food sands	Straight line with negative slope	

The Median grain size is correlatable with log-derived cementation factor by a straight line with negative slope relationship for all the Depo-environments. This implies that cementation factor increases with decreasing median grain size. This might be due to the postulation that charge water is more abundant in fluviomarine/beach sediments which are fine grained than in fluviatile deposits which are coarser. This may not be true however, since the abundance of sea water during diagenesis is not dependent on the environment of deposition. A geologic reason for this is thus difficult to come by. Moreover, it can be seen that the straight line is better developed for the river channel fills and braided river deposits (Fig. la) than in the tidal channel fills (Fig. Ib). This is probably due to the presence of clay breaks between sand layers in. the tidal fills which would tend to distort cementation and mar an otherwise clear relationship. It should be noted, nevertheless, that median grain size is a product of depositional environment while cementation factor is a product of diagenetic processes influenced by depo-environment.

POROSITY VERSUS GRAIN SIZE RELATIONSHIP

For all environments considered, porosity showed no direct correlation with mean grain size of formation sand, which agrees with Beard and Weyl'sassertion.[5] median grain size versus formation radioactivity.

As can be seen in Figure 3, formation radioactivity as per gamma ray logs is correlatable with median size of formation sand on the logarithmic scale for all depo-environments. This is due to the fact that radioactivity increases with increase in shale or clay content, which increases with decreasing grain size. The straight line relationship is represented by

$\text{Log } D = C_1 \log GR + C_2$ as previously defined. *

CONCLUSIONS

The following conclusions can be drawn:

Porosity versus sorting relationship per depositional environment facies, can be developed by accurate cluster analysis method. This relationship will be a useful aid in gravel pack design, and for sediment logical studies of reservoirs.

A first approximate equation relating medium grain size to log-derivable cementation factor has been developed for different depo-environments. .A mathematical model for obtaining grain size from gamma ray logs for different depo-environment has also been developed which provides a more accurate prediction of grain size from well log correlation.

The results' of this study have provided a reasonable eye opener for more intensive studies in future with more field data provided and further development of empirical relationships by accurate regression analysis. It is however believed that the trends and models established in this study will form a solid foundation for a more accurate prediction of formation sand sizes when the

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right parameters are known. This will prove useful to production engineers, petro physicists and production/reservoir geologists.

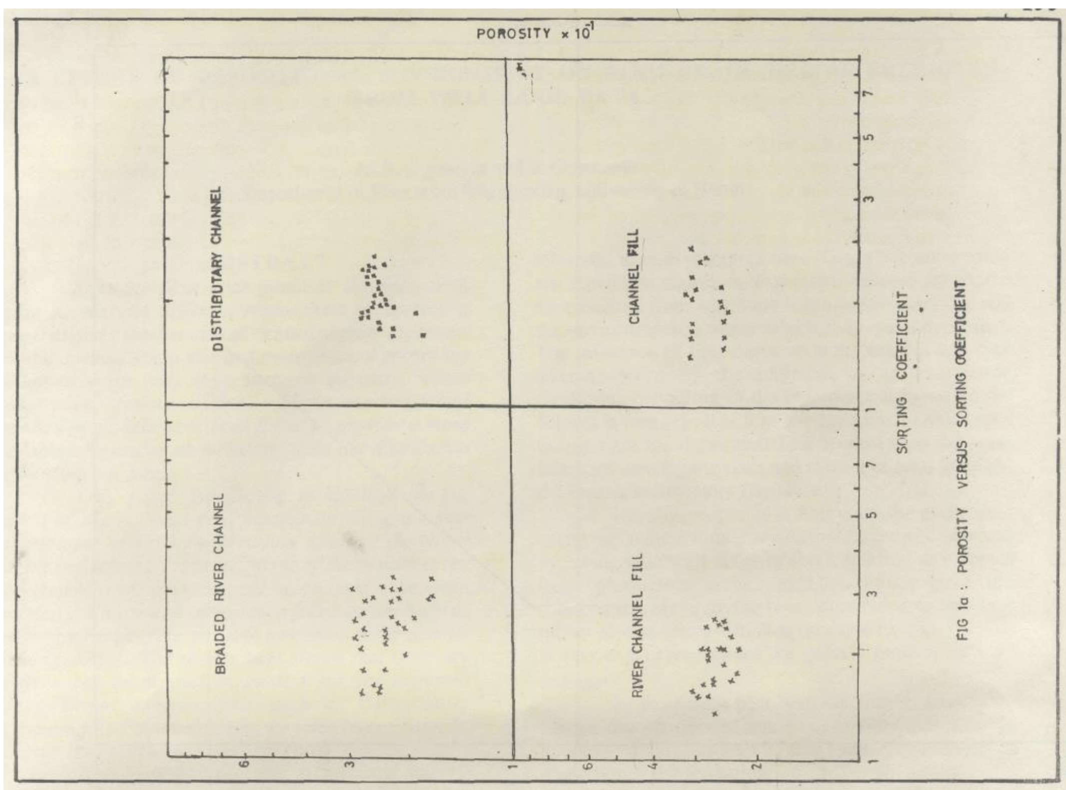

FIG 1a : POROSITY VERSUS SORTING COEFFICIENT

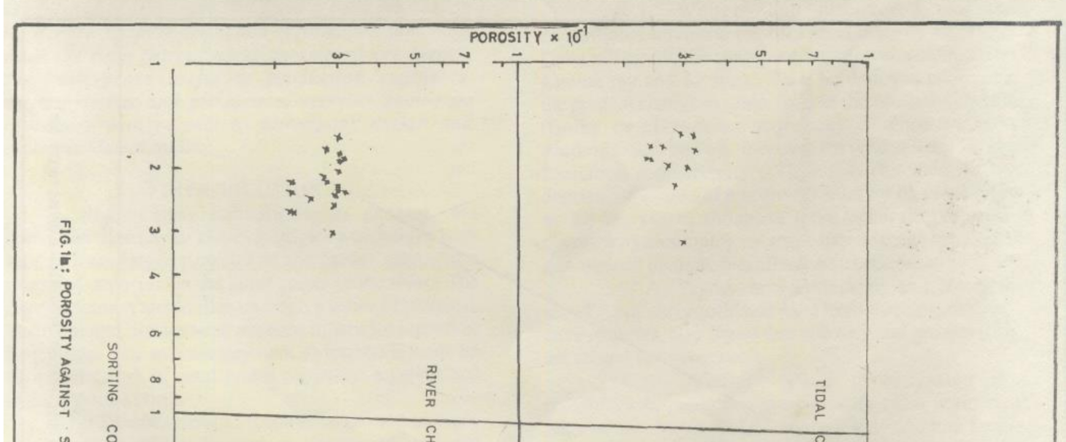

FIG. 1b: POROSITY AGAINST

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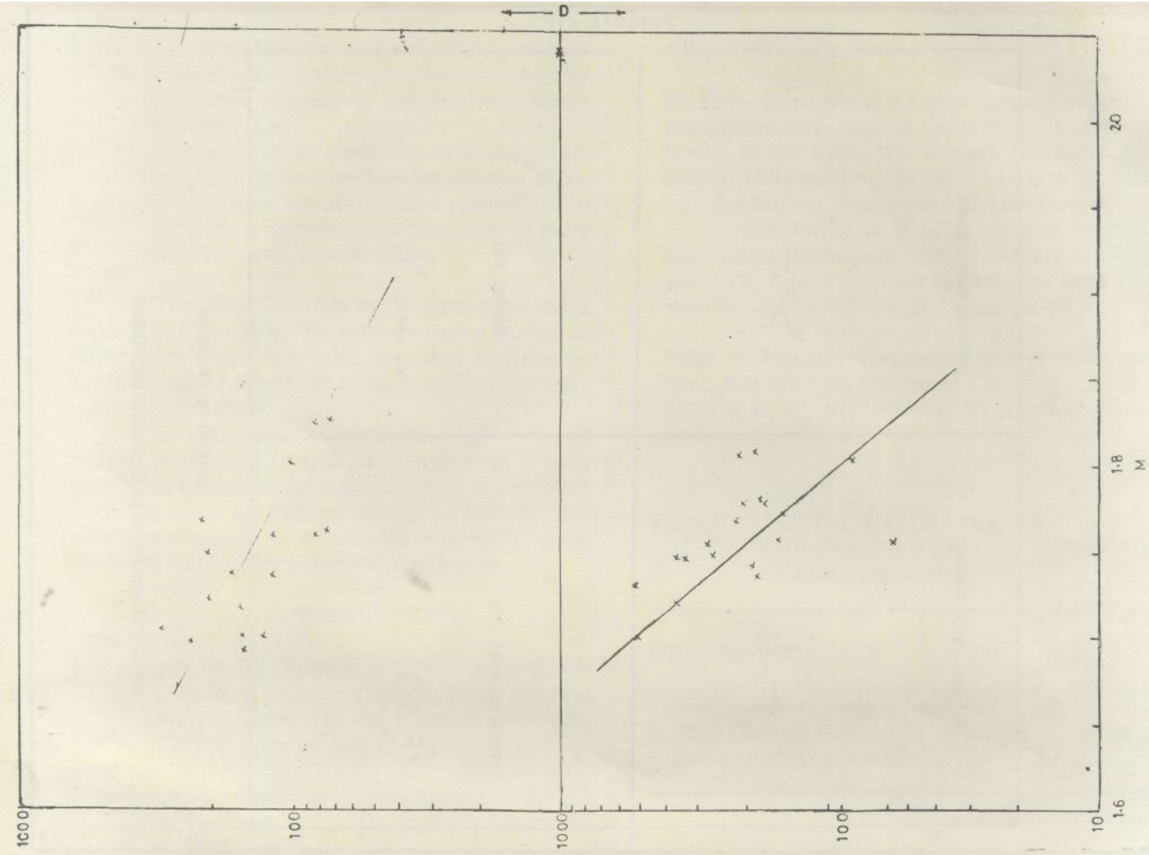

FIG.2: GRAIN SIZE (D) AGAINST CEMENTATION FACTOR (M)

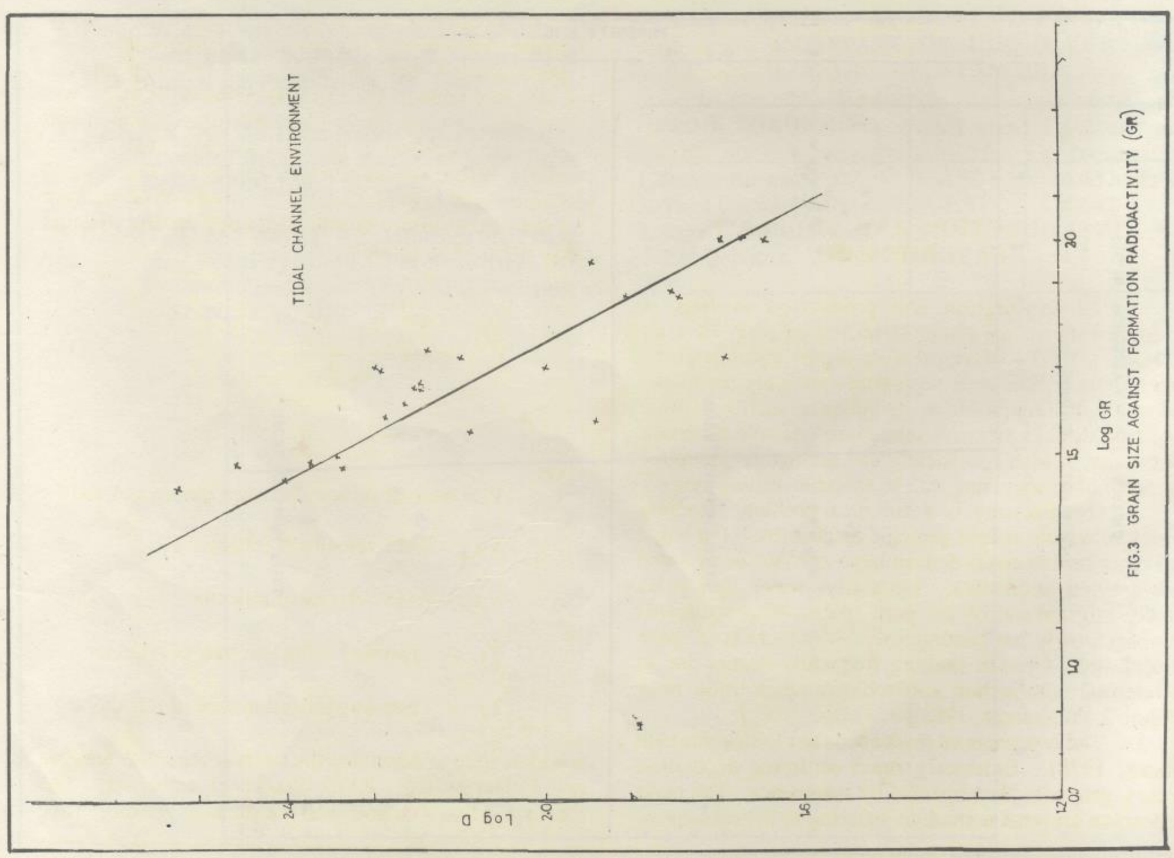

FIG.3 GRAIN SIZE AGAINST FORMATION RADIOACTIVITY (GR)

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