

A SEDIMENTARY INVESTIGATION OF A CORE TAKEN FROM LAKE St. LUCIA, ZULULAND.

By

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A 12,2 m core was taken from southern False Bay, Lake St. Lucia. Samples from the core were subjected to sedimentary analyses which entailed both sieving and settling in water. Statistical analysis of the data indicates lagoonal and channel (river and estuarine) deposits. These sediments accumulated during the Flandrian Transgression from the Weischel glacial low sea-level stand. Carbon-14 dates of 2,400 and 3,960 B.P. were obtained from the deposits at 4 and 19 m depth respectively (Adler et al. 1966). These indicate a mean rate of sedimentation of 25,8 cm per century.

INTRODUCTION

Lake St. Lucia is a lagoon with an area of about 380 square kilometres, and an average depth of less than 2 metres. It is enclosed by a barrier complex up to 180 metres high.

Sea-level lowering concomitant with the Weischel Glaciation initiated deep valley incision. These valleys were subsequently flooded during the Flandrian Transgression (which started 18,000 B.P.), the barrier system developed and the vast lagoon system came into existence. The barrier, consisting mainly of aeolian deposits, is not entirely a Holocene feature, but in places can be seen to rest upon remnants of Pleistocene barrier-lagoon complexes. Lake St. Lucia has become markedly reduced in volume and surface area by sedimentation, swamp encroachment and segmentation. Most of the sediment has been introduced by rivers. Cf the mean annual runoff reaching the lake about half comes from the Mkuze. Prior to diversion to an outlet a few km to the south of the Estuary, the Umfolozi contributed large volumes of sediment as a result of the backflow up the Narrows.

Near the river mouth, where more coarse material is generally present, the sediment rises to above the water in due course. If conditions are favourable marshes may form, as has been the case at Mkuze, Mzinene and Hluhluwe River mouths, into Lake St. Lucia. The vegetation in the marshy areas tends to retard flood velocity compared to flow in a normal channel and increase settlement of suspended matter, but fine silt and colloidal materials such as clay would pass on into the Lake. The salinity of the water in Lake St. Lucia causes flocculation of clays. These are redistributed by wind-generated waves, so that the floor of the lake is more or less level.

In July, 1973 a number of cores were taken from Lake St. Lucia. These indicate local accumulations of over 30 metres of soft mud containing local concentrations of silt, sand and shell debris. Locally, coarse sand is found overlying the Cretaceous bedrock. This presumably records the post-glacial transgression. A carbon-14 date of 15,000 years was obtained from northern False Bay at a depth of -33 metres (Vogel, verbal communication).

METHOD

A core taken from southern False Bay (Fig. 1) was logged (Fig. 1b) and a representative sample of approximately 20 grams was selected every metre and at marked changes in texture.

In most sedimentary analysis it is desirable to remove all organic matter, but it is felt that with the St. Lucia Lake cores, any organic matter present may be an indication of the environment i.e. hippopotamus faeces. Therefore no attempt was made to remove the organic matter.

As St. Lucia Lake is a saline lake, soluble salts were present in the sediment. As these tend to cause flocculation of the fine clay particles it was necessary to remove them.

Disaggregation and Dispersion

After the soluble salt removal treatment, it was found that the sediment was fairly well disaggregated.

Sodium Oxalate was used as the dispersing agent. It was found after much trial and error that a working concentration of 2 grams per litre was the most satisfactory. Royce (1970) suggests a working concentration of 0,6 grams per litre but it was found that this was insufficient due to the unusually high clay content of the cores.

FIG. 1: LAKE ST. LUCIA SYSTEM

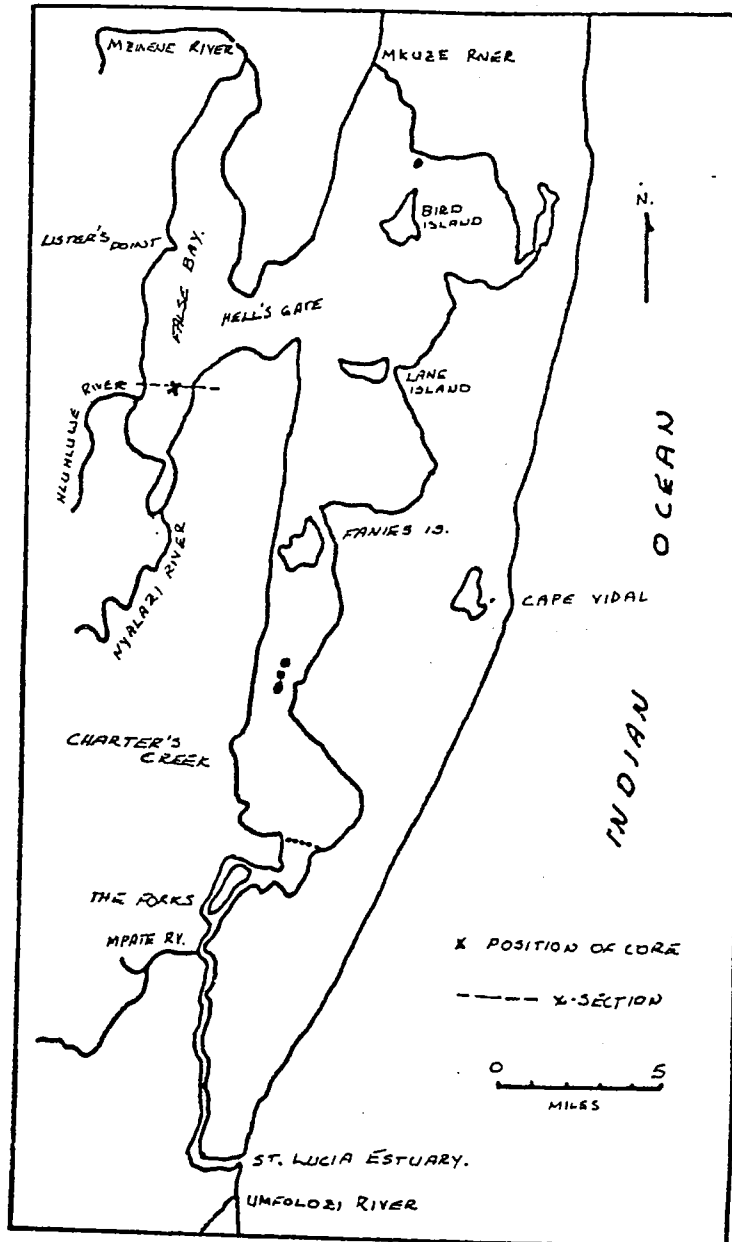


FIG. 1b: LOG OF CORE

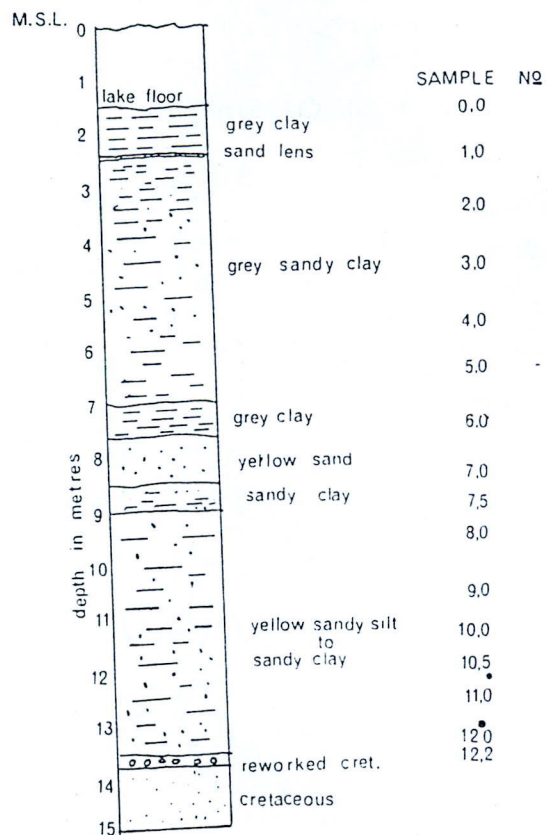
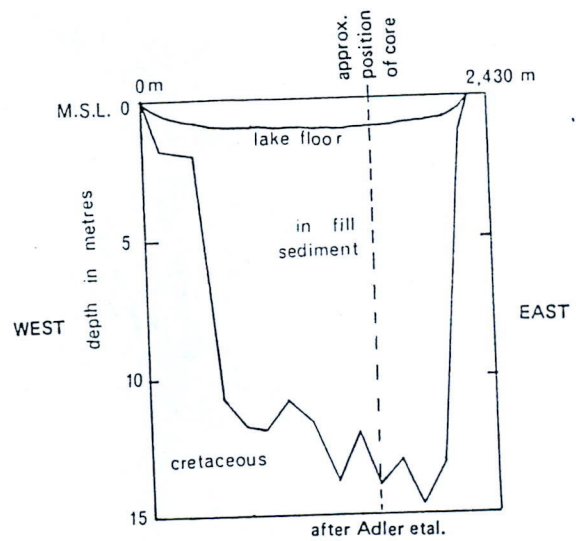


FIG. 1c: X-SECTION OF SOUTHERN FALSE BAY



Sieving

Royce (1970) suggests having a coarse fraction of about 200 grams and weighing each sieve class to 0,01 grams. Due to the high clay content in the fine fractions of these cores, this weight could not be attained. It was therefore decided that the coarse fraction weight should be greater than two grams and each sieve class should be carefully weighed to 0,001 grams.

Fine Fraction pipette analysis

Wadell's modification of Stokes Law was used, (Fig. 2), due to the non-spherical shape of the particles and the high clay content of the fine fractions. The fine fractions, 5-phi and less, were found in some cases to be 80% clay.

FIG. 2:

DIAMETER O UNITS	DEPTH CENTIMETRES	TIMES OF SETTLING		
		HOURS	MINUTES	SECONDS
4	20	0	1	00
5	10	0	2	59
6	10	0	11	59
7	10	0	47	51
8	10	3	12	00
9	7	8	58	00
10	5	25	43	00
11	5	106	50	00

RESULTS

Microscopic studies of the coarse fractions (Fig. 3).

It must be noted that the relevant quartz percentages are approximate. Quartz grains, with a red oxide covering, are thought to have been blown into the lake from Pleistocene deposits and are important as they alter the size distributions. In the lower 4 metres of the core the quartz grains appeared rounded and eroded, which suggests they were not wind blown. The basalt pebbles must have been brought by rivers. The shell fragments were seen as indications of marine influence in the lake. The foraminifera which were tentatively identified as *Ammonia Becarii* (Linné), and are associated by Phleger (1960) with inner lagoon, lower lagoon, beach and fluvial marine environments. *Ammonia Becarii* is essentially a benthonic marine foraminifera, of Holocene age. Due to *Ammonia Becarii* being the most dominant and in some cases the only foraminifera found, the environment could be assumed to be inner lagoonal or fluvial marine where sufficient land runoff reaches the lagoon. Unmodified oceanic water very rarely reaches the area except at times of reduced runoff. Inner lagoon areas are 10 to 20 miles from the inlet, and have a distinctive water mass. Inner lagoonal fauna also occur in hypersaline lagoons. There is a tendency for the benthonic foraminifera to have very large standing crops in hypersaline waters. This is also the case at some river mouths. In hypersaline lagoons there is a constant replenishment of plant nutrients from fresh water replacing that lost by evaporation (Phleger, 1963).

This environment is typical of present day St. Lucia. At times it is hypersaline, the level being below sea-level and there is a constant inflow of sea water into the area (van Heerden, 1971). This is usually during the dry winter months. In summer there is a high runoff and a reduction in salinity. These two factors combined can account for the high foraminifera percentage in the last 3 to 4 metres of the core. The Hluhluwe River is in close proximity and the slope of the floor is away from the river mouth.

FIG. 3:
CONSTITUENTS
OF
COARSE
FRACTIONS

DEPTH	QUARTZ - ROUNDED %			QUARTZ-ANGULAR %	QUARTZ-OXID. COVER %	FELSPAR	HEAVY MINERALS	MICAS	SHELLS - COMPLETE	SHELLS - FRAGMENTS	FORAMINIFERA %	OSTRACODS	RADIOLARIA	SPONGE NEEDLES	ALGAE	ORGANIC MATTER	SEEDS	INSECTS	BASALTS	Fe CONCRETION, PEBBLES	SANDSTONE-QUARTZITE
	10	30	0	0	0		X			X	50	X	X	X	X	X		X	X	X	
0,0	35	15	0	0	0		X		X	X	50	X		X	X	X		X	X	X	
1,0	60	0	0	0	0		X	X		X	30	X				X			X	X	
2,0	75	0	0	0	0		X			X	20	X				X	X				
3,0	20	65	0	0	0	X	X	X	X	X	10			X	X	X		X			
4,0	70	10	5	0	0		X		X	X	5				X				X		
5,0	70	5	5	5	5		X			X	5								X		X
6,0	70	5	5	5	5		X			X	0										X
7,0	70	5	5	20	5		X			X	0										X
7,5	70	50	50	50	50		X		X	X	0			X	X						X
8,0	45	45	0	0	0	X	X			X	2				X	X				X	
9,0	0	50	50	50	50					X	0				X						X
10,0	65	15	0	0	0	X					1	X	X		X					X	X
10,5	25	25	50	50	50						0				X						X
11,0	0	45	45	45	45					X	5	X	X							X	X
12,0	0	40	60	60	60						0									X	X
12,2	0	50	50	50	50					X	0				X						X

FIG. 4: TABLE OF RESULTS

DEPTH	0,0	1,0	2,0	3,0	4,0	5,0	6,0	7,0	7,5	8,0	9,0	10,0	10,5	11,0	12,0	12,2
MEDIAN	6,4	4,4	5,6	6,4	4,25	1,88	5,8	2,35	1,9	2,27	2,88	3,0	6,2	6,7	7,6	4,0
MEAN	6,16	5,3	5,56	6,35	4,69	1,93	6,36	2,23	2,0	2,79	4,76	5,3	6,54	6,23	6,7	5,78
DISPERSION	3,76	3,70	3,86	3,01	2,66	2,29	2,82	1,87	2,02	1,92	3,51	2,04	2,89	2,27	2,05	3,78
SKENNESS	-0,002	0,36	0,038	0,019	0,197	0,194	0,137	-0,058	0,654	0,465	0,911	0,784	0,115	-0,321	-0,596	0,591
KURTOSIS	1,113	1,202	1,082	0,875	0,524	0,542	2,09	1,348	2,431	0,951	1,095	1,910	1,014	0,986	2,704	0,587
SAMPLE	0,0	1,0	2,0	3,0	4,0	5,0	6,0	7,0	7,5	8,0	9,0	10,0	10,5	11,0	12,0	12,2

Ostracods are generally associated with high runoff areas (Phleger, 1964). In samples 0,0; 1,0; 2,0 and 3,0 the combination of ostracods and forams would suggest an inner lagoonal environment with some land runoff, similar to present day conditions.

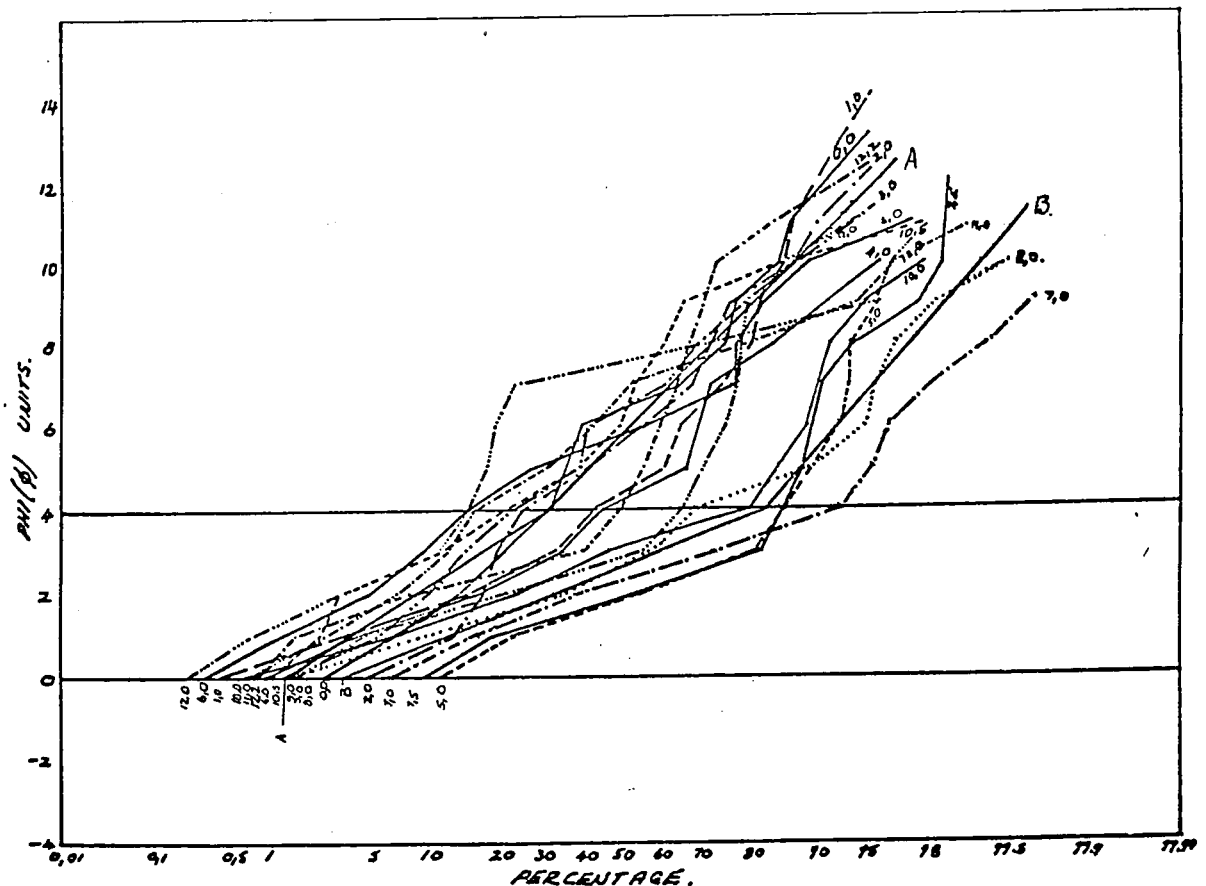
Descriptive Measures of Size Distribution

Data on the particle size distribution for the particular samples were obtained in the form of percent weight of sediment in various size classes. The measure of size distributions used were the phi notations of Folk and Ward (1957).

These are:—

$$\begin{aligned} \text{Median} &= \phi 50 \\ \text{Mean} &= \frac{\phi 16 + \phi 50 + \phi 84}{3} \\ \text{Dispersion} &= \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6,6} \\ \text{Skewness} &= \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 95 + \phi 5 - 2\phi 50}{2(\phi 95 - \phi 5)} \\ \text{Kurtosis} &= \frac{\phi 95 - \phi 5}{2,44(\phi 75 - \phi 25)} \end{aligned}$$

FIG. 5: COMPARISON OF CUMULATIVE PERCENTAGE CURVES



Each of these sets of approximations utilize data read directly from a cumulative size-frequency curve plotted on probability paper.

Folk and Wards' (1957) statistical approximations were chosen as a greater number of points are utilized compared to Trask (1932) and Inman (1952). These parameters are considered superior for cases of highly skewed and multimodal distribution, (Royce, 1970). The Folk and Ward convention of closing the open end of curves, obtained by pipette analyses, by a straight line drawn from the last measured value to 100%, was discredited. This, because it is felt that normalizing the fine tail of distribution is not justified, due to the high colloidal percentage of these samples and their varying size distributions. Instead the graphs were extended along the general slope of the curve up to 95%. However, this was rarely necessary. (See Fig. 4 – Table of Results).

PRESENTATION AND INTERPRETATION OF SEDIMENT SIZE DATA

Frequency distribution curves (Fig. 5).

Quantitative size data were obtained to interpret the history and method of deposition.

It was found that considering the mode and shape of frequency distribution curves had an interpretive value. E.S. Visher (1969) studied frequency distribution curves present in ancient sands and showed that these can give a very good indication of the environments of deposition. Due to the high percentage of the fine fractions of this core, none of Visher's results were found to be applicable. From Fig. 5, 2 basic sets of curves appear, Type A and Type B.

Type A – this exhibits mixing of two normal distributions, as is shown by the “zig-zag” nature of these curves (Royce, 1970). This curve shows a high fine fraction percentage. It can thus be assumed that this is an unstable environment i.e., although indicative of fine fraction deposition, maybe out of suspension, there is another active influence on the environment, which may be due to wind redistributing the sediment.

Type B – this is a far more regular curve and indicates a more stable, higher energy curve with a greater proportion of coarser material. The various curves would be subdivided as follows:–

	<u>TYPE A</u>	<u>INTERMEDIATE</u>	<u>TYPE B</u>
	0		
	1		
	2		
	3		
		4	
			5
SAMPLE NO.	6		7
			8
			9
			10
	10,5		
	11		
	12		
	12,2		

This would seem to indicate two different processes with some mixing of the two. As we see later on this fits into the overall picture.

Histograms were found to be inadequate for these grain size studies. Firstly their shape depends on the choice of class limits. Secondly there is no quantitative way of comparing histograms of different samples (Carver, 1971, pg. 111).

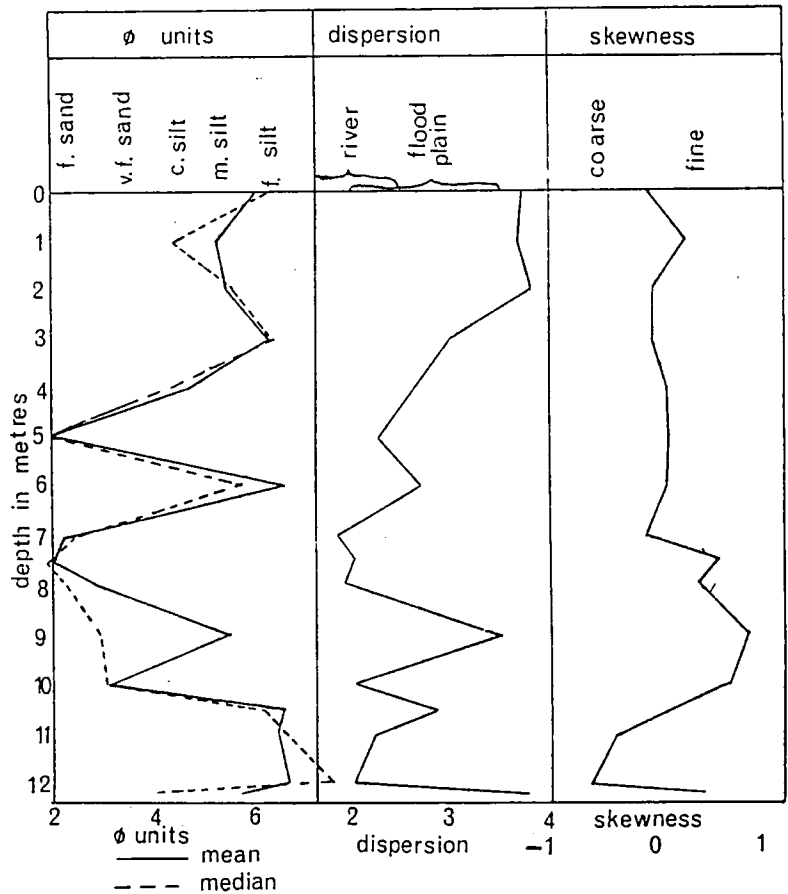
Sediment Size Statistics (Fig. 6)

River (channel) deposits have generally, a dispersion of less than 2,5. Mud (clay, silt) deposits have

a dispersion greater than 2. (Folk and Ward, 1963, pg. 46). "Flood-basin" type sedimentation is least skewed and channel deposits most skewed.

	DISPERSION	SKEWNESS
0,0	"Flood-basin"	"Flood-basin"
1,0	"Flood-basin"	"Flood-basin"
2,0	"Flood-basin"	"Flood-basin"
3,0	"Flood-basin"	"Flood-basin"
4,0	"Flood-basin"	"Flood-basin"
5,00	Channel	"Flood-basin"
6,00	"Flood-basin"	"Flood-basin"
7,00	Channel	"Flood-basin"
7,5	Channel	Channel
8,0	Channel	Channel
9,0	"Flood-basin"	Channel
10,0	Channel	Channel
10,5	"Flood-basin"	"Flood-basin"
11,0	Channel	"Flood-basin"
12,0	Channel	"Flood-basin"
12,2	"Flood-basin"	Channel

FIG. 6:
PLOT OF MEAN, MEDIAN
DISPERSION AND SKEWNESS
(FOLK) vs DEPTH



Binary Plots

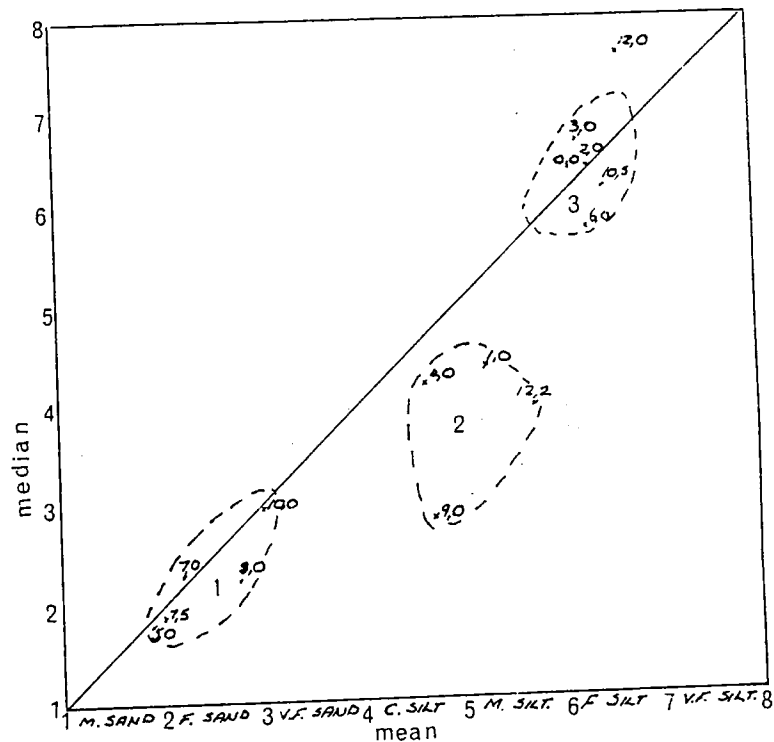
1. Median diameter vs Mean diameter (Fig. 7).

This plot serves to place the samples into three apparent corridors:-

- Group 1 - 5,0; 7,0; 7,5; 8,0; 10,5 - fine sand range.
- Group 2 - 1,0; 4,0; 9,0; 12,2 - coarse silt range
- Group 3 - 0,0; 2,0; 3,0; 6,0; 10,0; 11,0 - medium silt range

(12,0 falling just out of Group 3). This is interesting as Group 1 has the same sample members as Type B frequency distribution curve. Group 2 and Group 3 have the same sample members as Type A curve. This pattern emerges in most of the binary plots to follow. Thus, Group 1 are apparently channel deposits. Groups 2 and 3 are "flood-basin" or lagoonal mud deposits.

FIG. 7: PLOT OF MEDIAN DIAMETER vs MEAN DIAMETER



2. Folk skewness vs Mean Diameter (Fig. 8).

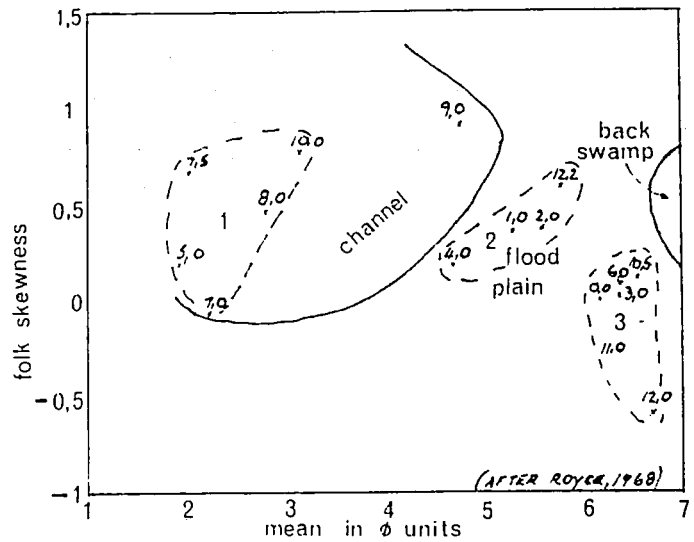
Corridors for the plot were those used by Royce (1968). It is very interesting to note that once again the samples fall into three groups.

- Group 1 - 5,0; 7,0; 7,5; 8,0; 10,0
- Group 2 - 1,0; 2,0; 4,0; 12,2
- Group 3 - 0,0; 3,0; 6,0; 10,5; 11,0; 12,0.

These bear a striking resemblance to groups obtained in 1 above. The pattern is similar in all the binary plots to follow.

Using the Royce (1968) corridors, Groups 1 and 2 are apparently "flood-plain" (lagoonal mud) and Group 3 is channel deposits (river or estaurine).

FIG. 8: PLOT OF FOLK SKEWNESS vs MEAN DIAMETER

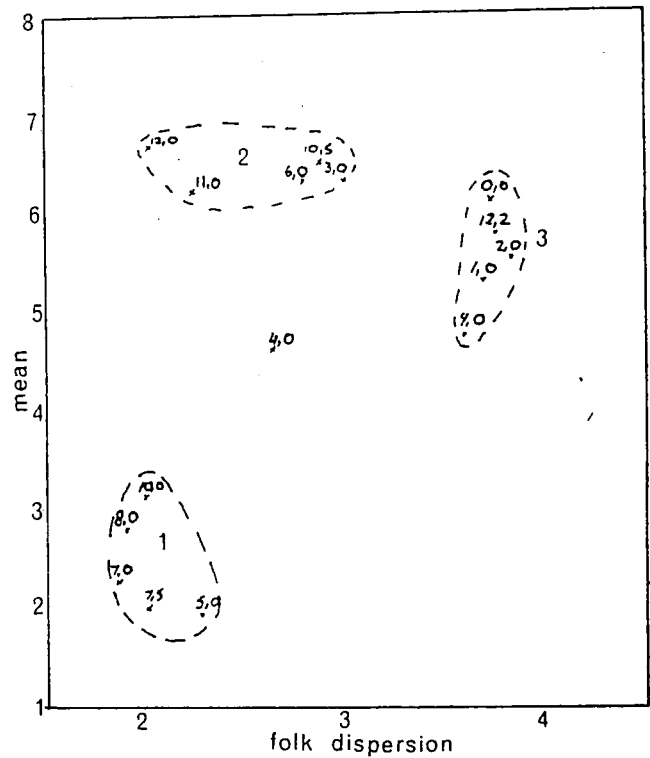


3. Mean vs Folk Dispersion (Fig. 9).

Three corridors can be drawn:-

- Group 1 - 5,0; 7,0; 7,5; 8,0; 10,0
- Group 2 - 3,0; 6,0; 10,5; 11,0; 12,0
- Group 3 - 0,0; 1,0; 2,0; 9,0; 12,2

FIG. 9: PLOT OF MEAN vs FOLK DISPERSION



Group 1 – these could be assumed to be channel deposits due to the coarseness of the mean and the better sorting, compared to Groups 2 and 3.

Group 3 – by the fineness of the mean and being very poorly sorted, these could be assumed to be mud deposited in a quiet environment e.g., a sheltered lagoon with little or no tidal effect, some distance from a channel.

Group 2 – here 3,0; 6,0 and 10,5 could almost form a subgroup. By the fineness of the mean and the better sorting than Group 3 these could be assumed to be lagoonal mud deposits with sorting due to either tidal effects or wind-wave action.

11 and 12 could represent lagoonal mud deposits, but with some tidal or other sorting action. They may have been on the edges of a river or tidal channel. Due to the age of the sediments any feldspar present would have been decomposed to clays which could have a marked effect on the sorting. Sample 4 could represent the change from a channel deposit to a mud, or even the mixing of two environments, a mud lagoonal deposit with the coarsening effect of a channel cutting through at some stage. This could represent extreme floods in the Hluhluwe and Nyalazi rivers.

4. Folk Dispersion vs Folk Skewness (Fig. 10).

Four corridors can be drawn here:

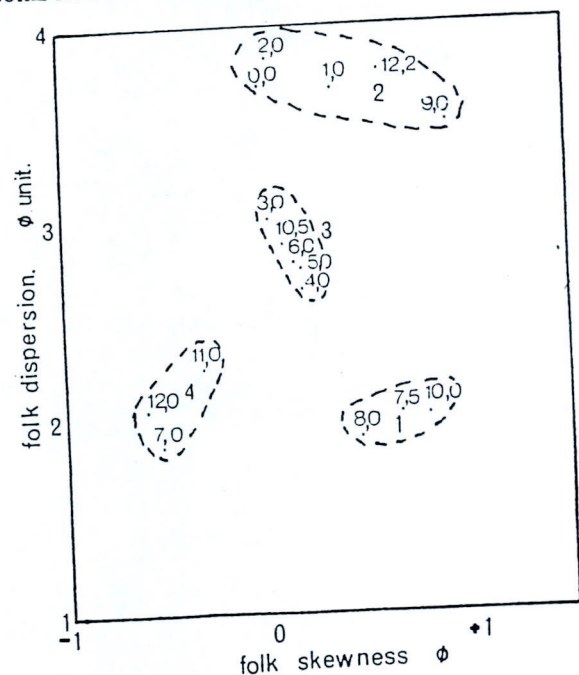
Group 1 – 7,5; 8,0; 10,0; due to the dispersion being better than in the other groups, these could be assumed to be channel deposits, in which the velocities were not so high, or there were seasonal changes in influx of sediment. The resulting flow velocities giving rise to the fairly high skewness. This could represent river and/or estuarine channel deposits.

Group 4 – samples in this group are:– 7,0; 11,0; 12,0. From the skewness and dispersion these could have been tidal channel deposits.

Group 3 – samples in this group are:– 3,0; 4,0; 5,0; 6,0; 10,5. The dispersion seems to suggest a lagoonal mud type deposit and from the skewness there appears to have been some channel-like effects which may have been due to strong influx of fine sediments from land run-off.

Group 2 – samples in this group are:– 0,0; 1,0; 2,0; 9,0; 12,2. 0,0; 1,0 and 2,0 could be representative of present day conditions. A non-tidal saline lagoon with some local currents set up by wind action. An influx of sediment only during seasonal floods and a fine sediment flocculation during low-flow drought months.

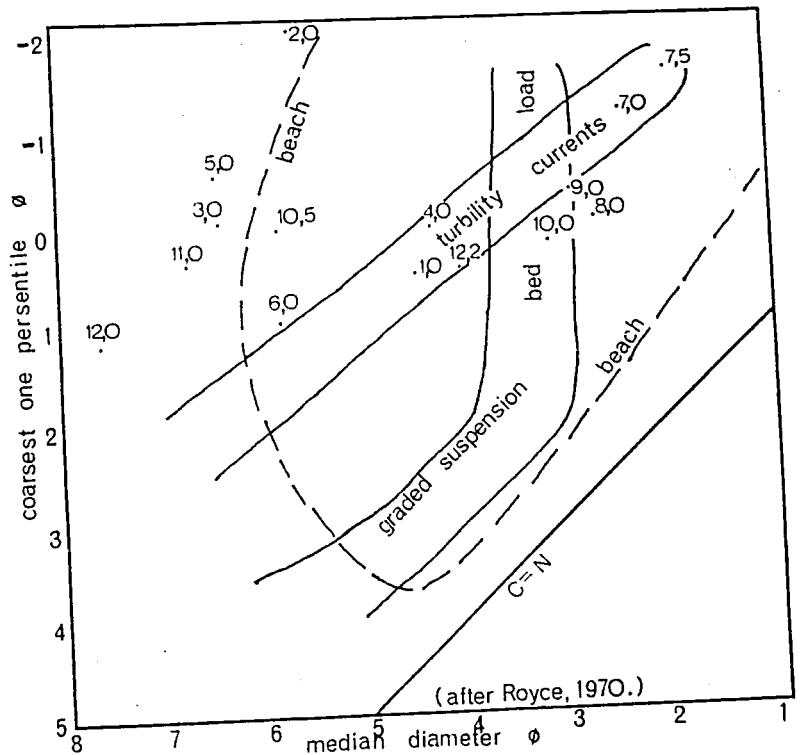
FIG. 10: PLOT OF FOLK DISPERSION vs FOLK SKEWNESS



5. Mean vs Coarsest One Percentile (Fig. 11).

Samples: - 1,0; 4,0; 7,0; 7,5; 8,0; 12,2. These appear to be in the turbidity zone. It is felt that there were no real turbidity current flows within the lake and it is possible for extensive burrowing to have this effect on sediments, (Hobday, personal communication). For the rest, no definite conclusion or bracketing can occur and it is felt that this is a very weak plot. Perhaps if more samples had been taken this would have had more value.

FIG. 11 PLOT OF COARSEST ONE PERCENTILE vs MEDIAN DIAMETER



6. Inman Dispersion vs Median (Fig. 12).

Inman dispersion is given by the formula:-

$$\text{Dispersion} = \frac{\phi_{84} - \phi_{16}}{2}$$

Phleger and Ayala-Castanares (1967) studied the marine geology of 3 interconnecting lagoons on the delta of the Feurte River, Mexico. From a study of 59 samples they plotted Median diameter against Inman's measure of sorting. They came up with a number of groups. These were superimposed on Fig. 12. Samples 0,0; 1,0; 2,0; 3,0; 4,0; 6,0; 10,5; 11,0; 12,0 and 12,2 fell into group V. Phleger and Ayala-Castanares' Group V were shallow water sediments on the inner lagoon side of tidal channels (Group III), where the clays and silts could not be winnowed out. The velocity here being much slower than the channels. Sample 9,0 fell into Group IV which were channel deposits. Due to a narrow inlet to the sea the velocities are not as high as Group III but are higher than Group V. The depth was between 8 and 15 metres. A corridor can be drawn about samples 5,0; 7,0; 7,5; 8,0; 10,0. Only sample 10,0 falls into Group III, tidal channel deposits. Group 1 - these were active channel deposits which experienced high velocities. It appears that samples 5,0; 7,0 7,5 and 8,0 fall in both Groups I and III. If this is so the velocities experienced by these sediments may have been as high as Group I but were not very consistent or of long duration. This assumption can be drawn from the lack of sorting to fall in Group I and the lack of fineness to fall into Group III. It does seem that samples 5,0; 7,0, 7,5; 8,0 and 10,0 were lagoonal tidal channels.

Depth not more than 10 metres. Samples 0,0; 1,0; 2,0; 3,0; 4,0; 6,0; 10,5; 11,0; 12,0; 12,2 can be assumed to be lagoonal or inter-lagoonal muds. Sample 9,0 apparently is a tidal channel, but of limited tidal range. Its depth is apparently about 8 metres. In Fig. 13 the rise of sea-level, after Shepard (1966) is compared to the approximate lake bottom level. From this it can be seen that the maximum depth of the lake below the approximate lake bottom level. From this it can be seen that the maximum depth of the lake below sea-level (at this particular core) for a particular time was 7.5 metres, 4,900 years ago. As sea-level rose so did the lake bottom level, but faster than sea-level, seeming to close the gap. Thus, the depth of the lake fits for cases 0,0; 1,0; 2,0; 3,0; 4,0; 6,0, with the level varying from 1.5 to 4.5 metres, with little or no tidal effect. At present there is no tidal effect in the lake. For samples 7,0; 7,5; 8,0; 9,0 the level varies from 5.0 to 7.0 metres. This also seems to fit the curve. With these deeper lake levels the tidal effect may have been quite marked. At sample 9,0 the sea appears to have been blocked off for some time. Samples 10,5; 11,0; 12,0; 12,2 could indicate either:—

- (a) a restricted inlet to the sea
- (b) The river discharges were much greater than they are at present and were discharging into a saline lagoon. Thus the clays and silts flocculated out.

Sample 5,0 could be due to a very high influx of sediments by river or due to some extremely high tides at this time.

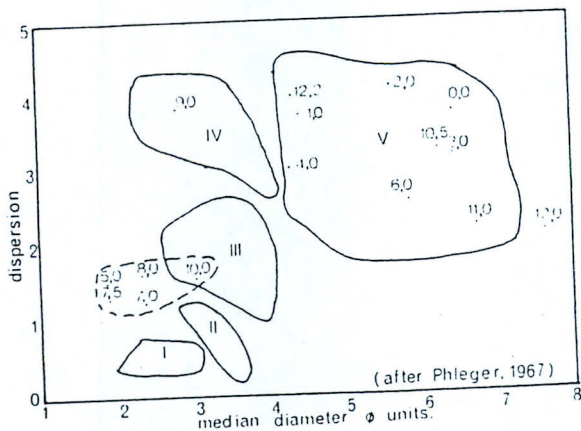
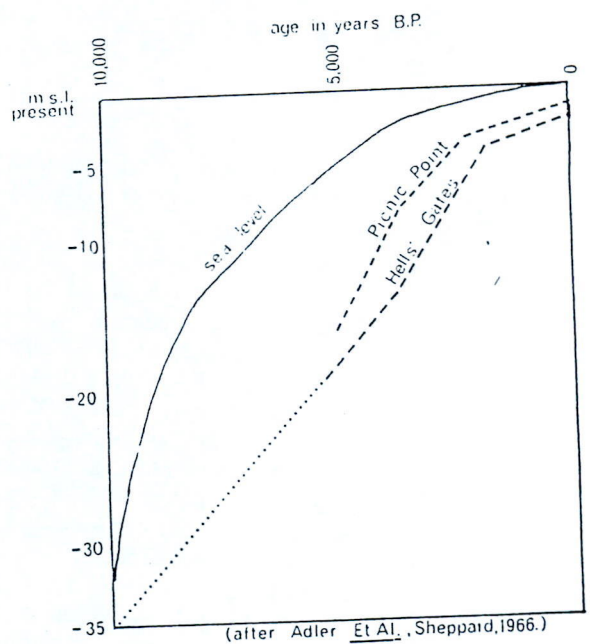


FIG. 12 PLOT OF INMAN DISPERSION vs MEDIAN DIAMETER

FIG. 13 SEA LEVEL AND LAKE SEDIMENT LEVEL CHANGES OVER THE LAST 10,000 YEARS



V RECONSTRUCTION OF THE PALEOENVIRONMENT

Sample 12,2 appears to be a flood-basin mud deposit. It must be remembered that this is a fairly old deposit, greater than 4,900 years and any feldspars present would have been made over to clays and thus effected the distribution curves. Upon logging this sample it appeared to be reworked cretaceous and thus may be representative of the Flandrian Transgression. The shell fragments apparently supporting this idea. In this case it could have been an estuarine deposit.

Sample 12,0 appears to be a flood-basin mud deposit and does not appear to have been saline. A shallow water deposit with good sorting which could have been due to a tidal effect or due to sorting by wave-wind actions.

Sample 11,0 - An apparent lagoonal mud deposit. The foraminifera and shell fragments present suggest a saline environment. The good sorting could be due to this being in close proximity to a tidal channel. Depth was apparently about 8 metres.

Sample 10,5 - A saline channel environment. Most probably tidal with a depth of not more than 10 metres.

Sample 9,0 - An apparent lagoonal tidal deposit with reduced velocities and therefore poorer sorting. This could be due to the narrowing of the inlet to the sea.

Sample 8,0 - It appears that the inlet was well formed and this represents a strong lagoonal tidal channel. This is further supported by it apparently being saline.

Samples 7,5 and 7,0 - These represent a period of strong tidal currents with an influx of fine sediment from land run-off which tended to flocculate out. Apparent high tides were eroding the barrier system and winds were blowing sand off the barrier into these channels, where it was reworked.

Sample 6,0. - Here it appears that the tidal effect was markedly reduced. The lagoon was still saline with sediment influx from land run-off. Flocculation was taking place due to the salinity. The inlet to the sea could have been restricted. No reworking and winnowing of the clays apparently took place. The lagoon may have been shallow, 1,5 to 4,5 metres.

Sample 5,0 - This represents strong tidal currents in a fairly deep channel. Environment comparable to sample 7,0 and 7,5 could have existed.

Samples 4,0 to 0,0 - These represent the gradual but progressively shallowing of the lagoon. Deposition of sediment by flocculation from suspension in a lagoon. Salinity ranges, which were originally very small have gradually increased to reach the present day high range. Evidence of this is the increase in Foraminiferal population. Tidal effects have decreased to practically nothing at the present day. This is due to the shallowing of the whole lagoon system. With no tidal effects there would be no winnowing and removal of the fine clay fractions. A decrease in land run-off and an increase in erosion of the catchment areas increasing the siltation effect.

CONCLUSION

A sedimentary analysis of this nature does appear to be of predictive value. Great care has to be taken in the sieving and settling analysis of the samples as even small errors can greatly influence the result.

It was at first felt that the fineness of the sedimentary particles may have resulted in results which would have had no predictive value. It is interesting to note that various workers, including Carver (1971), found that some of the binary plots used in this article were of no predictive value. This may have been due to the fact that they were working with coarser samples.

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