DEPOSITIONAL ENVIRONMENTS OF THE EOCENE MIRADOR AND MISOA FORMATIONS MARACAIBO BASIN, VENEZUELA [1)]

F.R. VAN VEEN [2)]

SUMMARY

Outcrops and cored sections of the Lower-Middle Eocene Mirador and Misoa formations in and around Lake Maracaibo have been analysed sedimentologically and palacontologically in order to establish depositional environnents.
ments.

Three genetically distinct sandstone units could be recognised: the fluviatile point bar, the deltaic distributary channel-fill and the offshore bar or barrier beach. Each of these units is characterised by a specific vertical grain-size trend and sequence of bedding types.

A fluviatile environment is typical for the Mirador Formation, whereas deltaic plain and delta-fringe environments obtained during deposition of the Misoa. The Misoa constitutes overall a transgressive sequence interrupted by several phases of delta-building which become less important upwards. The Mirador and Misoa sediments are thought to form parts of one alluvial deltaic compelx of Mississippi size. A deltaic source for the basinal turbidites of the Trujillo Formation, which is the lateral equivalent of the lower part of the Misoa, is likely. The Misoa grades vertically and laterally into the holo-marine shales of the Pauji Formation.

1) Presented at the IV Venezuelan Geological Congress, Caracas, November 1969. Published by permission of Compañía Shell de Venezuela.

2) Cía. Shell de Venezuela, Apartado 809, Caracas, Venezuela.

The writer is grateful to his colleagues, G.A. Gamero for his valuable assistance in the detailed core descriptions, J.P.H. Kaasschieter for his palaeontological analyses of core samples, and D.H. Porrenga for carrying out boron determinations and for making X-ray photographs of cores.

INTRODUCTION

The Eocene stratigraphy of the Maracaibo Basin has recently been the subject of a thorough revision by the Eocene Nomenclature Committee of the Asociación Venezolana de Geología, Minería y Petróleo (1968). In the present study two of the Eocene formations, the Mirador and the re-defined Misoa were scrutinised sedimentologically and palaeontologically with a view to establishing depositional environments.

Emphasis was placed on the determination of grain size distributions, the interpretation of primary sedimentary structures and the sequential arrangement of different lithologies. Several outcropping sections of both Misoa and Mirador were investigated and from the many cored Misoa sections in the oilfields of Lake Maracaibo two representative sections have been selected for discussion.

The Misoa Formation in the subsurface is of great economic importance, having produced some 8×10^9 bbl of oil to date.

MIRADOR FORMATION

The Mirador Formation was first described by F. de Loys in a private report (1918) and defined by Garner (1928). The type area is the Cerro Mirador in the Colón District of Zulia State, where a thickness of about 250 m (820 ft) was measured of pure white sandstones, very fine to medium grained with locally

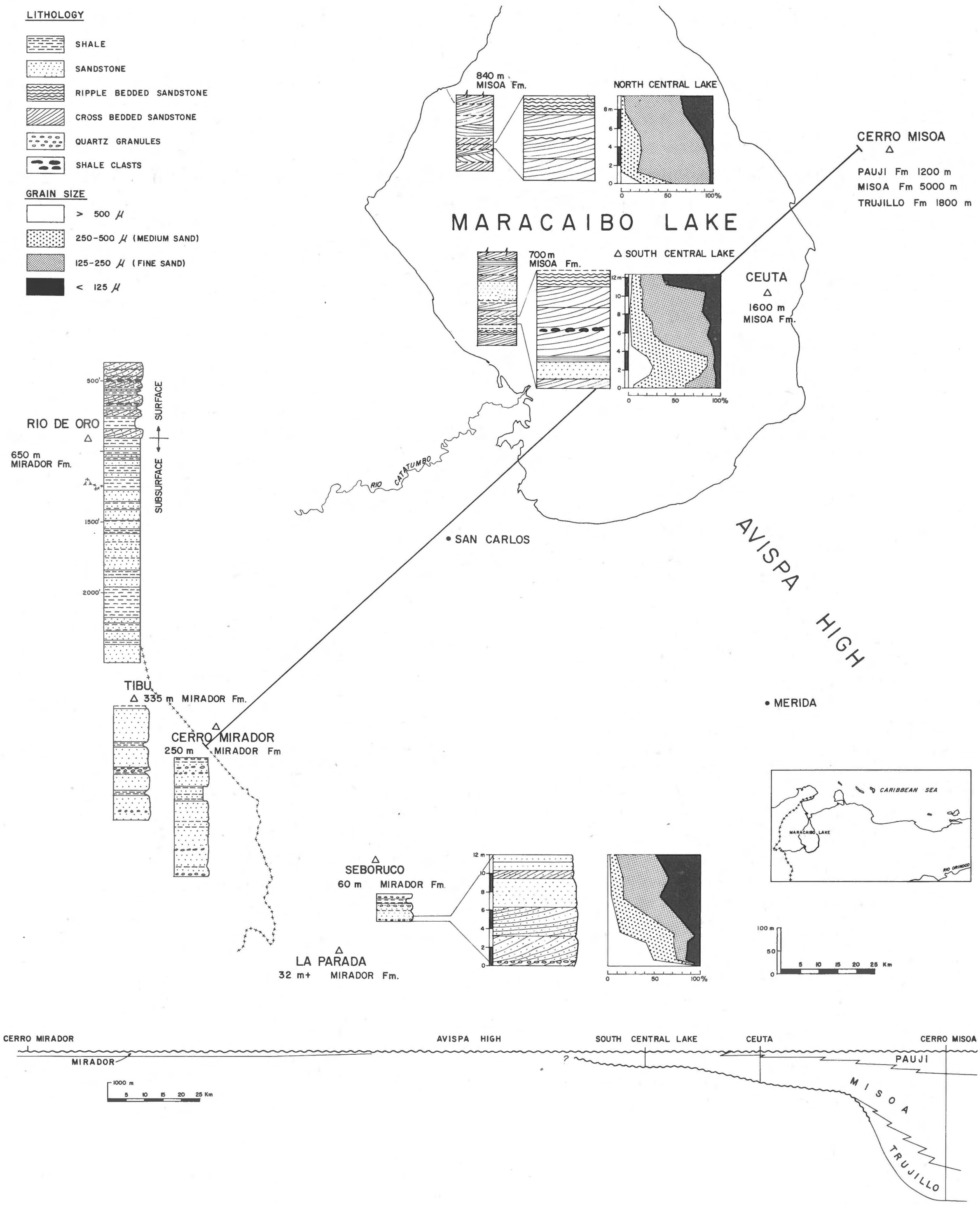


Fig. 1
Stratigraphic section location map, including lithological columns of the Mirador Formation and selected point-bar sequences. Stratigraphic cross-section through the Maracaibo Basin.

streaks or beds of quartz granules or pebbles; carbonaceous material occurs throughout the sandstones. A few shale intercalations occur, especially in the upper third of the formation. Thin coal layers are interbedded in the shales (fig. 1). From De Loys' sections which have been published by Brondijk (1967b) a sand percentage of 85% can be calculated.

RIO DE ORO SECTION

About 70 km to the north-north-west, wells on the Río de Oro anticline penetrated a thickness of about 650 m (2130 ft) of Mirador Formation of which about 50% consisted of sand. The upper 165 m of the formation is exposed along the road from Rosario to Río de Oro where it cuts the eastern flank of the Río de Oro anticline. The outcropping formation consists of an alternation of sandstones ranging in thickness from 4 to 40 m and poorly exposed shales of up to 20 m thickness (fig. 1). The thick sandstone bodies are of a composite nature; individual sands are often lenticular and are separated by sandy or silty clay layers or lenses varying in thickness from a few millimetres to 2 meters. A typical depositional unit is built up as follows: large-scale cross-bedded (metre- scale) sandstone overlies a shale bed with sharp contact. The erosional nature of the contact is emphasized by the presence of irregularly shaped clay fragments dispersed in the basal part of the sand body (fig. 2). This massive sand layer may vary from 1-4 m. It is overlain by thinner beds of sandstone displaying decimetre-scale cross-bedding. These in turn are overlain by ripplebedded (centimetre-scale cross-bedded) sandstones with intercalated shale lenses and layers which increase in number and thickness in an upward direction. A gradual transition into shales with silt or very fine sand ripples and laminae is sometimes noted and completes the sequence. Cutting into this upper shaly part of the unit are massive cross-bedded sands of the next depositional unit. Due to erosion the upper shaly parts of a unit are often lenticular (fig. 3) or not preserved.

The grain size decreases upwards in these sand bodies. In a typical example a variation in median grain size from 300 micron (medium grained) at the base to 100 micron (very fine grained) at the top of a sand was measured. These fining-upward sequences have been interpreted as point bars deposited in meandering rivers by lateral accretion. The upward decrease in grain size and bed thickness reflect the current velocity distribution within the channel (Visher, 1965). The sandy shales and shales represent abandoned channel, overbank or back swamp deposits.

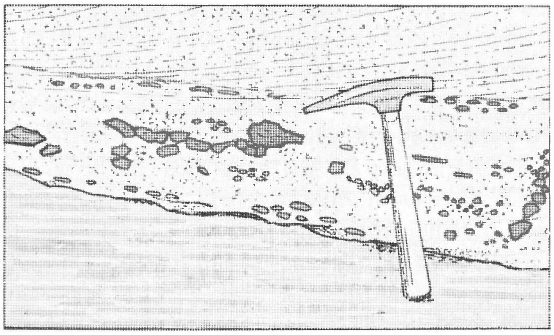


Fig. 2
Detail of the erosional contact of a point-bar sand with underlying shales. Mirador Formation, outcropping in Río de Oro anticline.

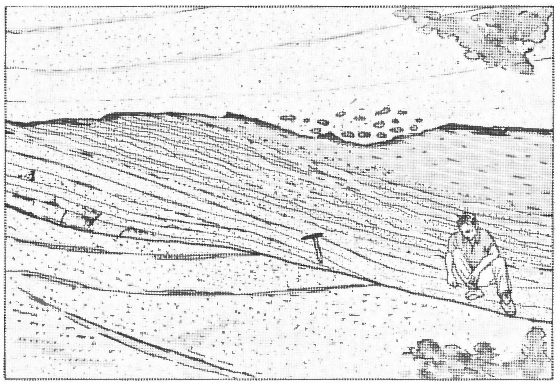


Fig. 3
Superimposed point bars in Mirador Formation, outcropping in Río de Oro anticline. Festoon crossbedded sandstones at the base of the outcrop contain some thin shale lenses. Bed thickness gradually decreases in an upward direction and increasing amounts of shale intercalations occur. Decimetre scale cross-bedding is replaced by centimetre scale cross-bedding. The point-bar sequence is topped by a shale with siltstone streaks and ripples. The next point-bar eroded part of the previous one, thus reducing the upper shale to a lens. Note local concentration of shale clasts at the base of the massive point-bar sand. (Drawn after a photograph.)

SEBORUCO SECTION

In a section about 70 km south-south-east from the type area along the La Fría-Seboruco road, the Mirador Formation measures only 60 m of which 95% is sand (fig. 1). The lower 40 m of the sequence is built up of superimposed sand beds measuring from 1 to 4 m and often showing m-scale festoon cross-bedding. Streaks of quartz granules and pebbles may occur at the base of the cross-bedded units or lining the foresets. In the middle of this sand section there occurs a single shale lens which, over a 5 m outcrop, is seen to decrease in thickness from 3 m to 20 cm. In the upper 20 m more shale or sandy shale intercalations appear ranging in thickness from 10-60 cm.

Occasional fining-upwards sequences were found, defined by a decrease in grain size and bed thickness upwards. Shale fragments, such as occur in the basal part of similar sequences in the Río de Oro section, have not been noted. In *Quebrada La Parada*, near Mina Lobatera, the upper 32 m of the Mirador is composed entirely of sandstones which are predominatly m-scale cross-bedded. One fining-upward sequence was found near the top of the formation (fig. 4). Lithology and bedding suggest that the Mirador Formation in the Seboruco and La Parada sections has been deposited in braided and/or meandering rivers.

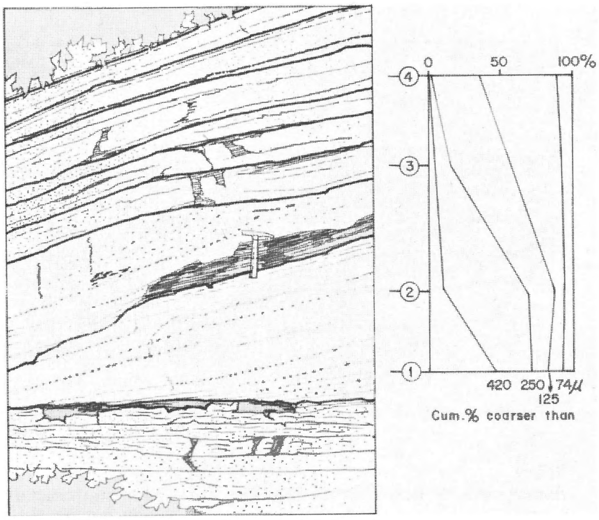


Fig. 4
Fining-upward sequence, interpreted as a fluvial point bar. Mirador Formation, Quebrada La Parada section. 1.80 m large-scale festoon cross-bedded sandstone is overlain by an equal thickness of finer grained sandstones in decimetre beds. In the latter sandstones there is some indication of ripple bedding. Cumulative grainsizes of four samples are shown on the right. (Drawn after a photograph.)

TIBU SECTION

A fourth section of Mirador sandstones has been described by González Guzmán (1967) from wells in the Tibú area, Colombia. The formation ranges there in thickness from 323 m (1064 ft) to 347 m (1138 ft) of which the lower 240 m (790 ft) have been analysed palynologically.

Apart from providing a Lower to Middle Eocene age determination, the palynological study also gives indications about the depositional environment by recognizing various palaeoecological floral associations. Thus González Guzmán recognizes alternating savanna, fresh-water and brackish-water floras corresponding to fluviatile, deltaic plain and brackish swamp environments. The cyclical occurrence of these floras is explained by the shifting of vegetation belts as the result of sea-level fluctuations.

These palaeoecological findings are in agreement with the recognition of braided and meandering streams based on sedimentological criteria.

MISOA FORMATION

The Misoa Formation was originally described by Garner (1926) from the Sierra Misoa. Because of much confusion regarding the lower boundary, the formation has recently been re-defined by Brondijk (1967a).

In combined sections from the type area about 5000 m (16,000′) of sediments were measured. These consisted of alternating composite sandstones and silt stones and laminated shales. A few limestone beds are intercalated in the lower part of the formation.

To the south of the type area rapid thinning occurs towards the Avispa massif, a northwest-southeast trending high which may extend into the subsurface of Lake Maracaibo (Brondijk, 1967b). To the west of the type area, in Lake Maracaibo, where the Misoa sandstones form major oil reservoirs, the formation is greatly reduced in thickness. For instance, in the Ceuta Field it measures only about 1600 m (5250 ft). Further west again, in the centre of the Lake, the thickness is even more reduced by truncation to 1000 m (3280 ft) or less (fig. 1). In the subsurface the formation has been subdivided into a number of informal units, grouped into the B and C Members. This subdivision is based upon electrical log markers and significant vertical changes in sand content (W a l t o n, 1967). Some of these units can be recognised over large distances, e.g. the C2, C4 and the C5, whereas others have little value for regional correlation due to lenticularity of sands and lateral facies changes.

Accompanying the thinning of the formation a marked increase in sandpercentage takes place, as exemplified by a north-south cross-section through Lake Maracaibo (fig. 6).

STRATIGRAPHIC SETTING

Over most of the subsurface of Lake Maracaibo the Misoa Formation lies on various Paleocene formations. Towards the north-east the basal part of the Misoa Formation grades laterally into the Trujillo Formation which is composed of marine shales and turbidites. In the same direction the upper part of the formation grades into marine shales of the Paují Formation as shown in the section of fig. 1.

The age of the Paují and Misoa Formations has, on palaeontological and palynological grounds, been established as Lower to Middle Eocene, whereas the Trujillo Formation is considered to be mainly Lower Eocene, possibly extending into the Paleocene and Middle Eocene (AVGMP, 1968, G e r m e r a a d et al. 1968).

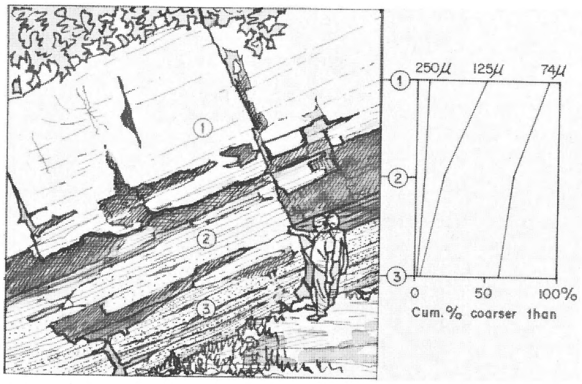


Fig. 5
Coarsening-upward sequence, interpreted as a barrier bar, in Misoa Formation, Río Misoa. Dark shales with silt ripples and some burrows at the base of the outcrop are overlain by 1.75 m ripple-bedded sandstones, with decreasing amount of shale intercalations upwards. Small burrows occur. These sediments are followed by 1 m of ripplebedded sandstones, containing vertical burrows. The massive sandstone topping this sequence measures about three metres and contains long vertical burrows. The cumulative grain-size distribution of three samples from this outcrop is shown. (Drawn after a photograph.)

RIO MISOA SECTION

In Río Misoa the majority of sand bodies in the Misoa Formation show a coarsening-upward sequence. Interlaminated shales, which are frequently burrowed, gradually change in an upward direction into thin-bedded sandstones with shale interlaminations. These in turn grade into ripple-bedded sandstones which are overlain by a massive sand layer ranging in thickness from 1-6 m. In some cases low-angle, inclined bedding was noted in these sandstones. Typical is the occurrence of carbonized plant remains and of vertical burrows (*Skolithos?*) up to 1 m long and about 5 mm wide. The contact with the overlying shales is always sharp. Several of these units may be super-imposed, forming pronounced ridges with stratigraphical thicknesses of several tens of metres. Alternating with these sandy complexes are thick, laminated shales. The grain size in the sand units shows a marked upward increase resulting from deposition in progressively shoaling water (fig. 5).

It is possible that the sands were deposited in front of, or to the side of a delta either as a barrier island complex (H a y e s and S c o t t 1964), delta front sheet sands, or bar finger sands (F i s k 1955, 1961).*

One reason why it is not possible to be specific as to the exact environment is that the external geometry of these sand bodies is not known. In this connection it should be pointed out that our knowledge of Recent models of alluvial sediments is much more complete than that of shallow marine deposits. M a c K e n z i e (1965, p. 200-205) and S t a p p (1967) discuss several aspects of the problems involved when attempting to interpret ancient deposits

---

* A schematic representation of some depositional environments in a river/delta model is given in fig. 7.

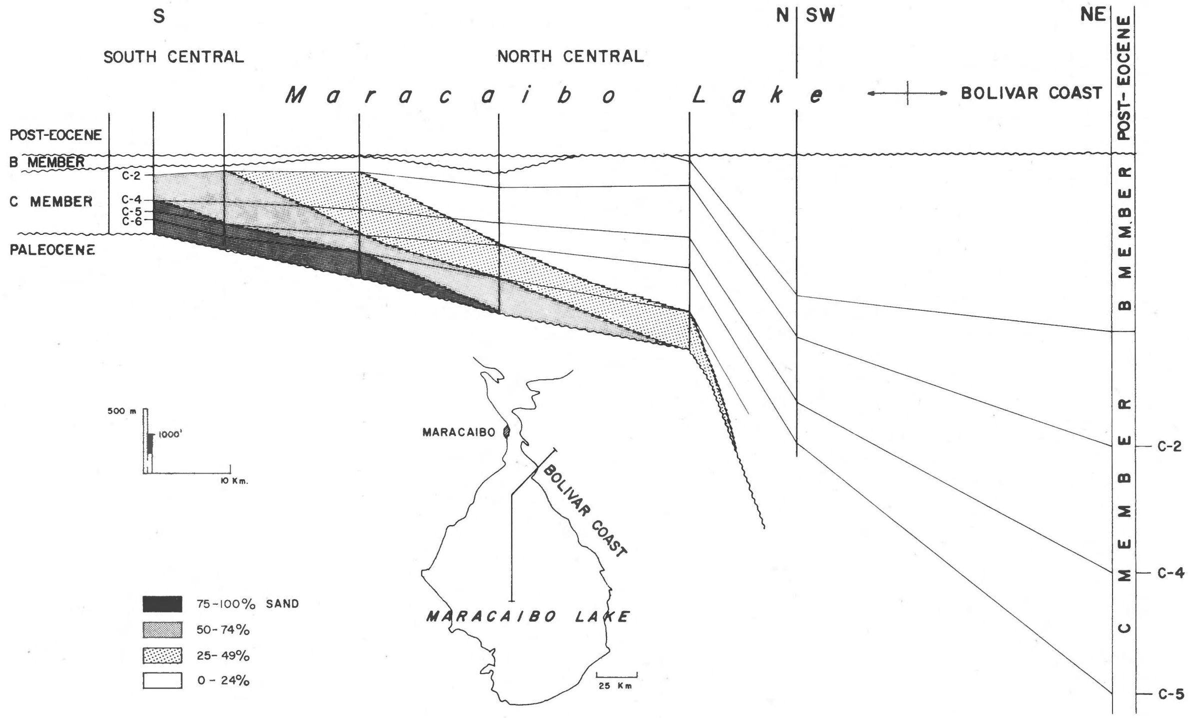


Fig. 6
Cross section showing decreasing sand-percentages to the north in the C-member of the Misoa Formation.

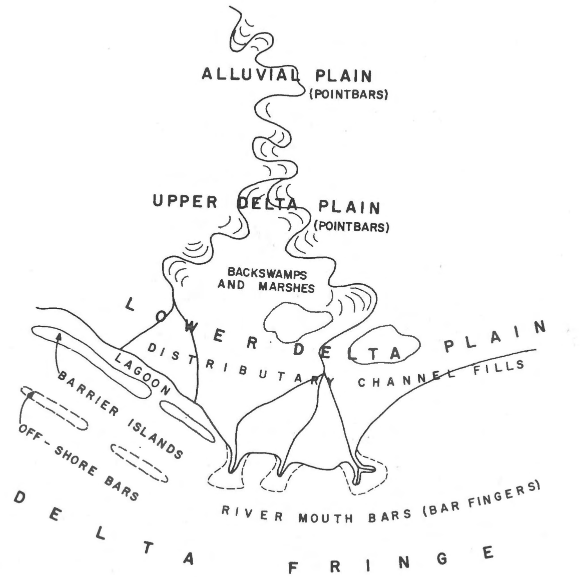


Fig. 7
Schematic representation of various depositional environments in a river/delta complex.

by the analog method. Especially in the case of delta-front environments a lack of knowledge of the kind and distribution of sedimentary structures in the Recent model makes difficult the precise interpretation of many ancient sediments. The latter, when well exposed, are often much better known in vertical section than the Recent deposits.

As the author could only investigate sedimentologically the upper part of the Misoa Formation as exposed in Río Misoa, no environmental interpretation can be given for the lower part of the formation which overlies the deep-marine Trujillo sediments (fig. 8). However, from the lithological description in figure 1 of Brondijk (1967a), it is likely that similar, near-shore marine sands occur throughout the formation.

From the subsurface, two continuously cored Misoa sections will be discussed in some detail.

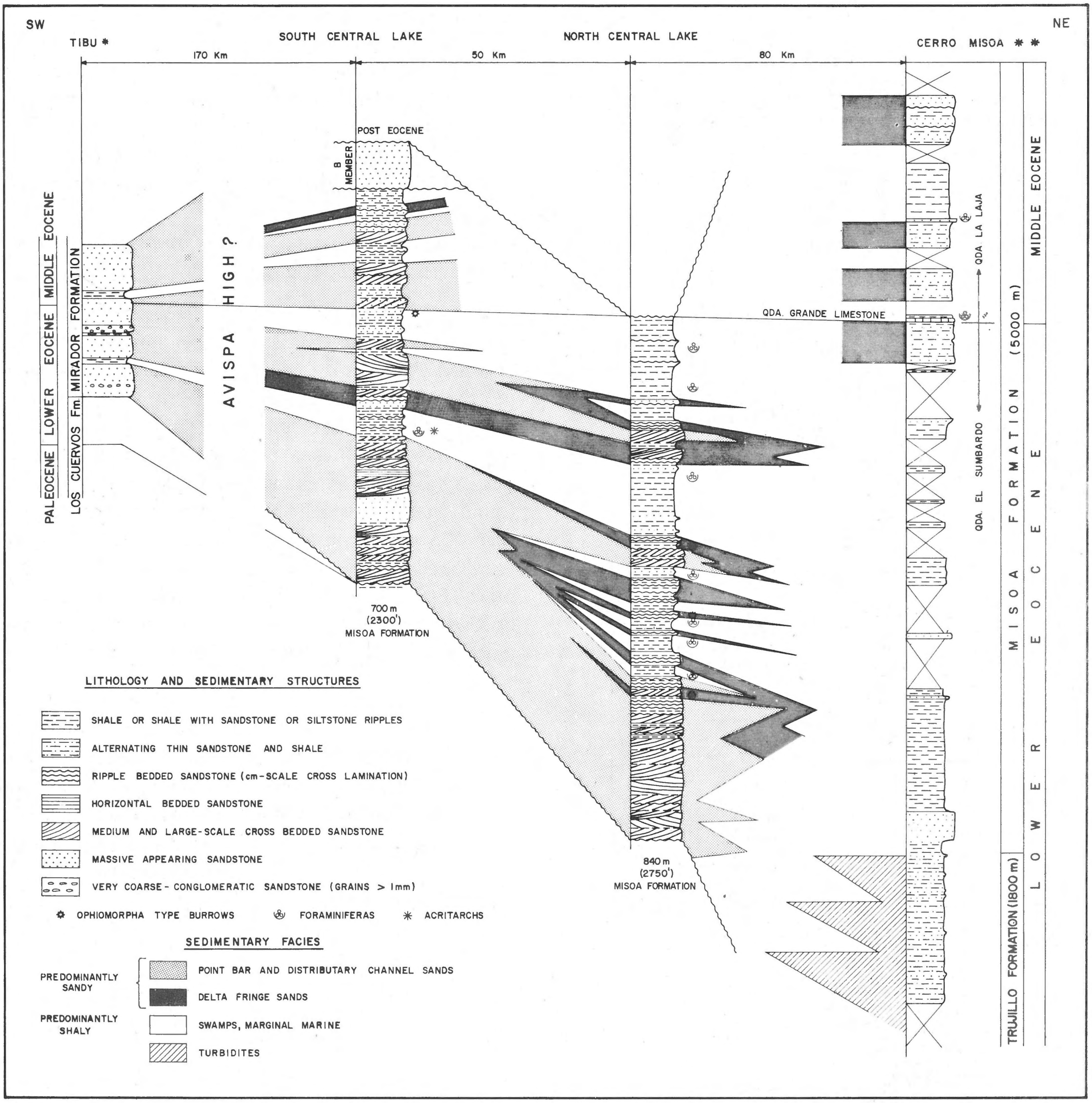


FIG. 8 SCHEMATIC REPRESENTATION OF FACIES DISTRIBUTION IN THE MIRADOR AND MISOA FORMATIONS.

* * COMPLETE SECTION PUBLISHED IN BRONDIJK' 67 FIG. 1
* SEDIMENTARY STRUCTURES NOT REPORTED

Fig. 8
Schematic representation of facies distribution in the Mirador and Misoa formations.

NORTH CENTRAL LAKE SECTION

Sand Types

In a North Central Lake well, 840 m (2750′) of the Lower Eocene part of the C Member were analysed sedimentologically and palaeontologically. Three genetically distinct sandstone types were recognised (fig. 9).

Type I has a sharp lower boundary and the erosional nature of the contact is indicated by the presence of irregularly shaped shale fragments in the lowermost part of the sand (fig. 10 a, b). The sandstone can be divided into three parts:

A) a lower, dominantly massive zone or dm-scale cross-bedded zone, which locally shows contorted bedding (fig. 10 c, d, e).

B) a middle, ripple-bedded (cm-scale cross-bedded) or horizontally-bedded zone with occasional shale partings, (fig. 10 g, f) and

C) an upper shaly zone which is often characterized by flaser bedding (fig. 10h).

Though an overall upward decrease in grain size can be noted, there is a rather distinct change between the cross-bedded and the ripple-bedded parts of the sandstone which is clearly seen on the cumulative grain-size diagram (fig. 9.I). A relation exists between internal sedimentary structures and mean grain size as shown on Table I. It was also found that the weight percentage of grains smaller than 125 microns is always less than 30% for the dm cross-bedded/massive-bedded sandstones and always more than 30% for the ripple-bedded/horizontal-bedded sandstones. Textural characteristics of 364 samples taken from Type I sand bodies are plotted in fig. 11 A.

The grain-size distribution and type of bedding give an indication of the relative energy of the current. Part A can thus be interpreted as a high energy deposit, part B as intermediate and part C as a low-energy deposit. The vertical sequence in which these energy classes occur in a sand body are characteristic for its genesis.

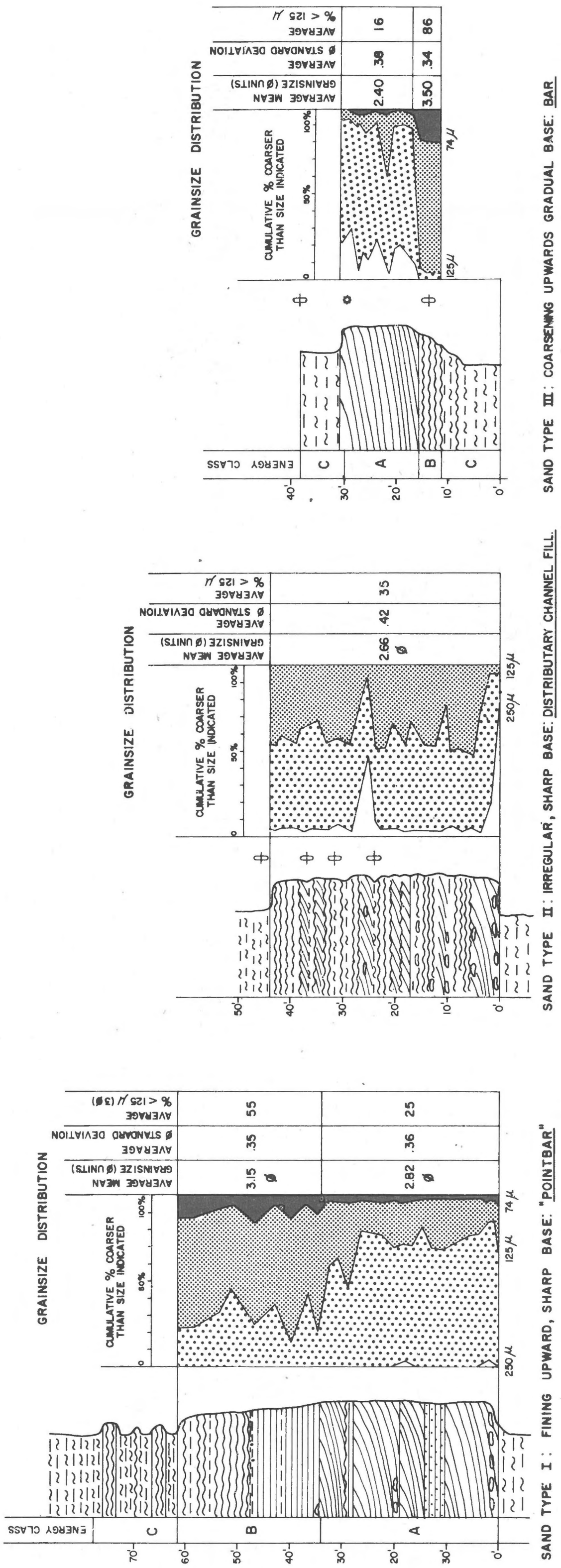


Fig. 9
Sand types in the subsurface Misoa Formation.

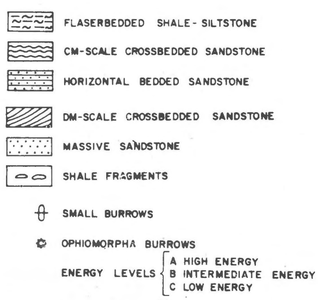


TABLE I
Grain-size and bedding-type of 515 sand samples from North Central Lake Well

Mean grain-size		very fine upper		fine lower		fine upper		medium lower
Phi scale	3.5		3		2.5		2	
Micron scale	88		125		177		250	
Number of grain-size analyses		152		291		58		14
Dm-cross-bedded or massive		0%		60%		100%		100%
Cm-cross-bedded		100%		40%		0%		0%

Except for a difference in scale of cross-bedding and grain size, Type I is basically the same as the one described from the outcropping Mirador Formation (fig. 4) and is likewise interpreted as a point bar sequence accumulated in a meandering river. Subsurface control shows that these point bars form extensive sheet sands with some irregularly distributed shale lenses.

Type II may, or may not, have a sharp erosional base and is characterised by a rapid alternation of dm-scale and cm-scale cross-bedded layers with frequent shale partings which are often burrowed and generally less than 1 foot thick. Though the sand body shows small-scale variations in grain size, corresponding to the different bedding types, there is no overall vertical grain-size trend. Clay galls and flakes occur frequently throughout the sand. These repeated changes in energy could be explained by assuming an incremental filling of a non-migrating distributary channel during successive periods of high discharge. Such channels are known to occur in the distal part of a delta. (Coleman et al. 1969, Kolb et al. 1966, Fisher et al. 1969). Sub-surface studies demonstrated that sand bodies of this type have elongate forms and grade, both laterally and distally, into ripple-bedded sands and shale.

Type III is characterised by a gradational base due to an increasing number and thickness of sand intercalations capped by a well developed sand body which usually has a sharp upper boundary. Textural characteristics of 180 Type III sands are plotted in fig. 11B. Mean grain sizes tend to be smaller than those of the Type I sands and sorting is on the whole better. In each sand unit a gradual increase in grain size and a change from ripple-bedded to dm-scale low-angle cross-bedded or massive sand can be observed reflecting an upward increase of energy. The under- and overlying shales are flaser-bedded with frequent small burrows whereas the sands often contain larger *Ophiomorpha*-type burrows. The latter are dentated to irregular on the outside and smooth on the inside and have a diameter of up to 1 cm. (fig. 10 j, k). Weimer and Hoyt (1964) report that *Calianassa* is the most likely group of organisms to have produced *Ophiomorpha* burrows. Burrows of *Calianassa major* are reported to occur in well sorted sands in strongly agitated waters. Weimer and Hoyt conclude that the association of abundant burrows in well-sorted massive bedded sandstones indicated wave-agitated littoral or shallow neritic conditions, whereas burrows in poorly sorted, well-bedded silty sandstones suggest deeper neritic conditions.

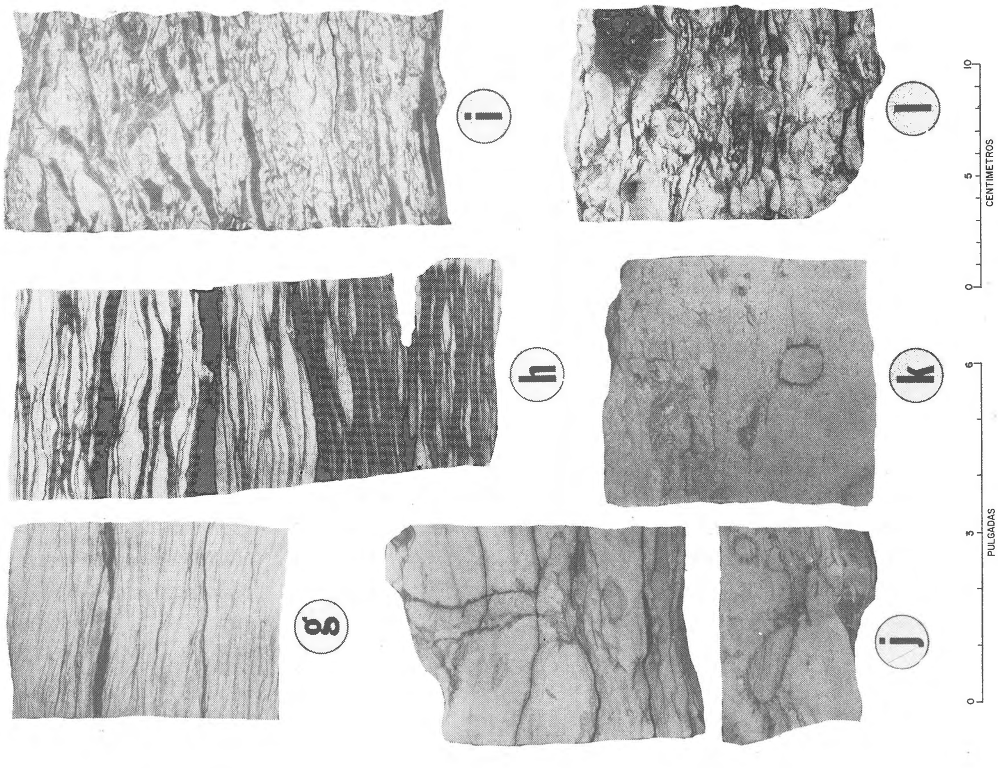
The well-developed massive, or low-angle cross-bedded, sandstones of type III were found to have elongate shapes. They are interpreted as barrier bars. The less well-developed ripple-bedded sands with *Ophiomorpha* burrows are interpreted as having been deposited in a shallow marine, delta-fringe environment. In general the latter show no specific grain-size trend.

Type III is basically similar to the unit described from the outcropping Misoa Formation (fig. 5).

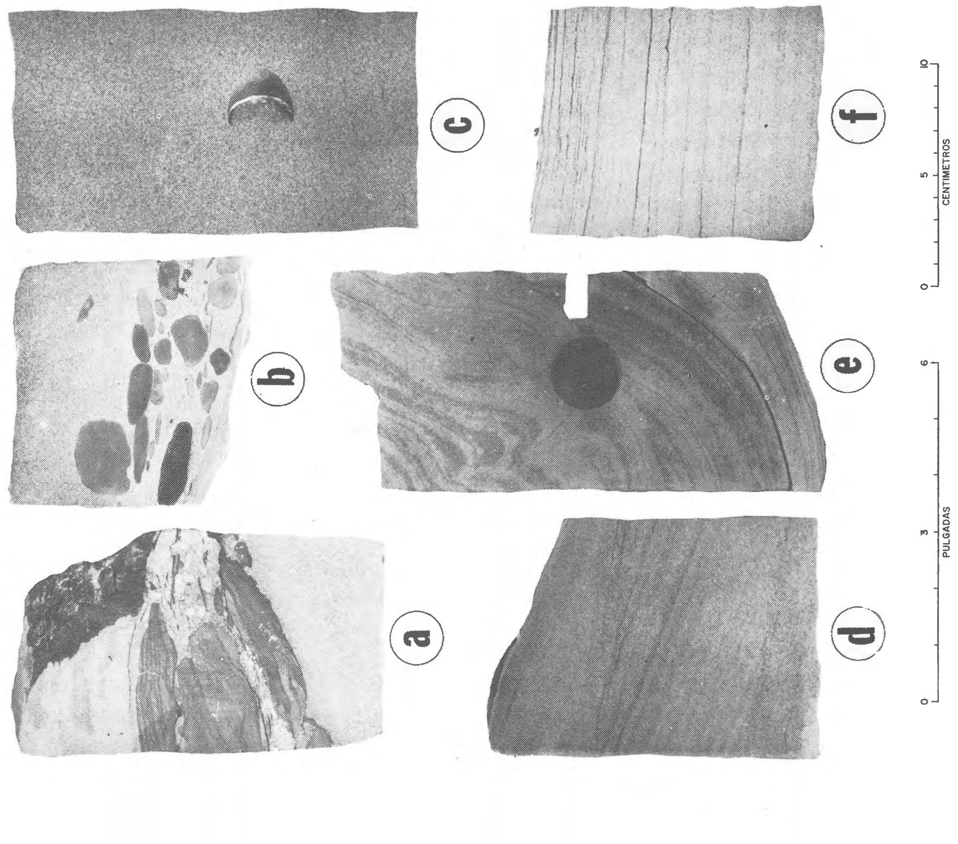
A summary of the principle characteristics of the three different sand-body types is given in Table II.

Depositional environments in North Central Lake (fig. 12)

The basal 420 ft (128 m) of the core is built up of a number of superimposed fining-upward sequences. Some of the units are incomplete due to subsequent erosion. Sand comprises 85% of this interval, 70%



g
h
i
j
k
l
0 3 6 PULGADAS
0 5 10 CENTIMETROS



a
b
c
d
e
f
0 3 6 PULGADAS
0 5 10 CENTIMETROS

TABLE II
Characteristics of sand types

	Sand Type	Basal contact	Energy sequence	Organic activity (burrowing)	Sand geometry
I	Point Bar	Sharp	C B A	Absent	Sheet forming anastomosing
II	Distributary channel-fill	Sharp or graded	Irregular	Moderate	Elongated
III	Barrier beach or shallow-marine bar	Graded	A B C	Moderate-significant	Elongated

being high-energy sand and 15% intermediate-energy sand.

The thickness of the individual sand units ranges from 12-62 ft (4-19 m), that of the shales from 2-12 ft (0.6-4 m). Microfauna and burrowing are absent. These sediments have been deposited as fluvial point bars, probably in an upper delta plain, where subsidence and sedimentation were in near equilibrium. The cyclical repetition of fining-upwards sequences may be partly explained by shifting of the river channels. The sands form sheets with irregularly intercalated shale lenses.

The following 320 ft (97.5 m) section contains 64% of sand. The majority of the sands belong to the intermediate energy class B, but high-energy sands are also present, decreasing in quantity upwards. The predominant sand type is the distributary channel fill ranging in thickness from 27-51 ft (8-15 m). One 16 ft. bar sand containing *Ophiomorpha* burrows occurs in this interval.

A very poor microfauna, consisting of *Haplophragmoides* spp. and single occurrences of *Miliammina* and *Trochammina* spp., was found in shales from this interval.

The environment of deposition is interpreted as lower deltaic plain where non-migrating distributary channels prevailed. The sediments accumulated during a time when the delta retreated over previously deposited upper deltaic plain sediments.

The next interval of 600 ft (183 m) starts with a 56 ft (17 m) shale, overlain by 40 ft (12 m) of ripple-bedded sands. A 12 ft coarsening-upward sand is followed by a predominantly shaly section, which is characterised by flaser bedding and burrowing. Intercalated in these shales occur several 1-9 ft thick sands and three somewhat better developed coarsening-upward bar sands of about 20 ft (6 m) each.

A poor microfauna, consisting of *Haplophragmoides* spp. *Miliammina* sp. cf. *M. fusca* and *Trochaminina* spp., occurs throughout the section. In the upper part a single occurrence of *Quinqueloculina* sp. was found. This foraminiferal assemblage can be

Fig. 10
Photographs of lithological types found in cores of the Misoa Formation
a. Conglomerate of quartz, shale and coal pebbles in a sandy matrix (basal part of a pointbar).
b. Rounded shale fragments in a sandy matrix (basal part of a pointbar).
c. Massive sandstone (lower part of a pointbar).
d. Decimeter-scale cross-bedded sandstone (lower part of a pointbar).
e. Ibid, contorted.
f. Horizontal-bedded sandstone (middle part of a pointbar).
g. Centimeter-scale cross-bedded sandstone (upper part of a pointbar).
h. Interlaminated shale, siltstone and sandstone showing flaser bedding (upper part of a pointbar or lower part of a shallow marine bar or barrier beach).
i. Sandstone with irregular shale fragments (mottled bedding) (lower part of a distributary channel).
j. Sandstone with *Ophiomorpha*-type burrows (upper part of a bar or barrier beach).
k. Ibid.
l. Burrowed sandstone and shale.

interpreted as a marginal marine fauna. Phleger (1960) defined marginal-marine as, "to include marine marshes, estuaries, lagoons and bays, beaches and the adjacent part of the continental shelf. These environments all have one thing in common – they are more affected by the land than are the environments farther offshore; much or most of the land-derived sediment is deposited here".

Sedimentological and microfaunal evidence thus point to shallow water deposition near a delta.

A sudden sand increase to 81% occurs in the overlying 105 ft (32 m) of section. The interval is formed by two distributary channel fills, deposited during a renewed advance of the delta.

These channel sands are overlain by a 20 ft (6 m) shale and a 26 ft (8 m) ripple-bedded shaly sand with *Ophiomorpha* burrows, interpreted as delta fringe sediments.

A listing of the vertical sequence of sand units and their energy classes for the entire lower cored interval (1356 ft, 413 m) is presented in Table III. Only intervals of 2 ft or larger have been classified.

A 350 ft (105 m) shaly section which overlies the previously described sand has not been cored. These shales may represent a time of transgression when the delta build-out came to a temporary halt.

The upper core starts with a well developed coarsening-upward sand body, probably representing a barrier beach formed in front of the again advancing delta. The delta prograded further and laid down a distributary channel sand which in turn is overlain by a 55 ft (170 m) shaly section which was only partly

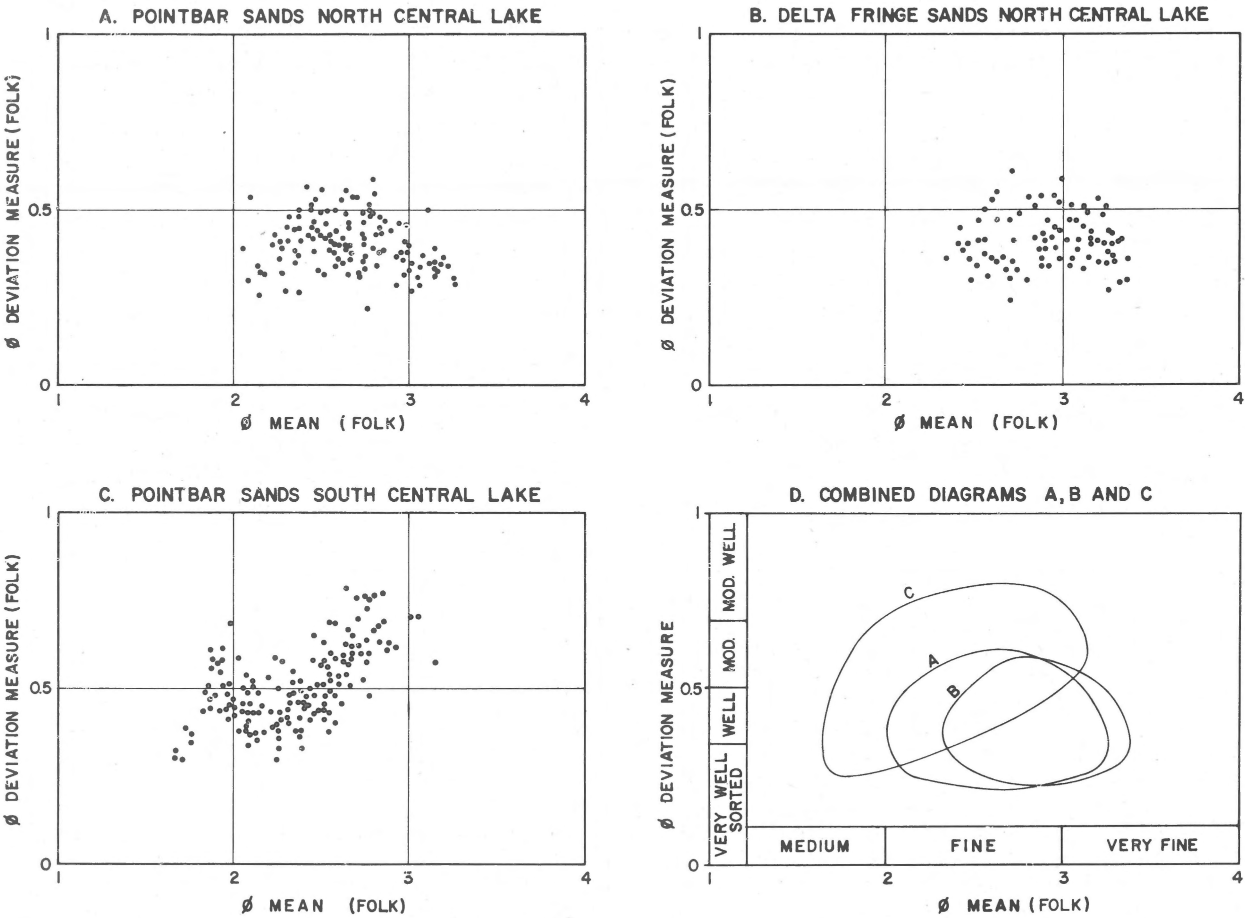


Fig. 11
Textural characteristics of Misoa sands (C-Member) in Lake Maracaibo.

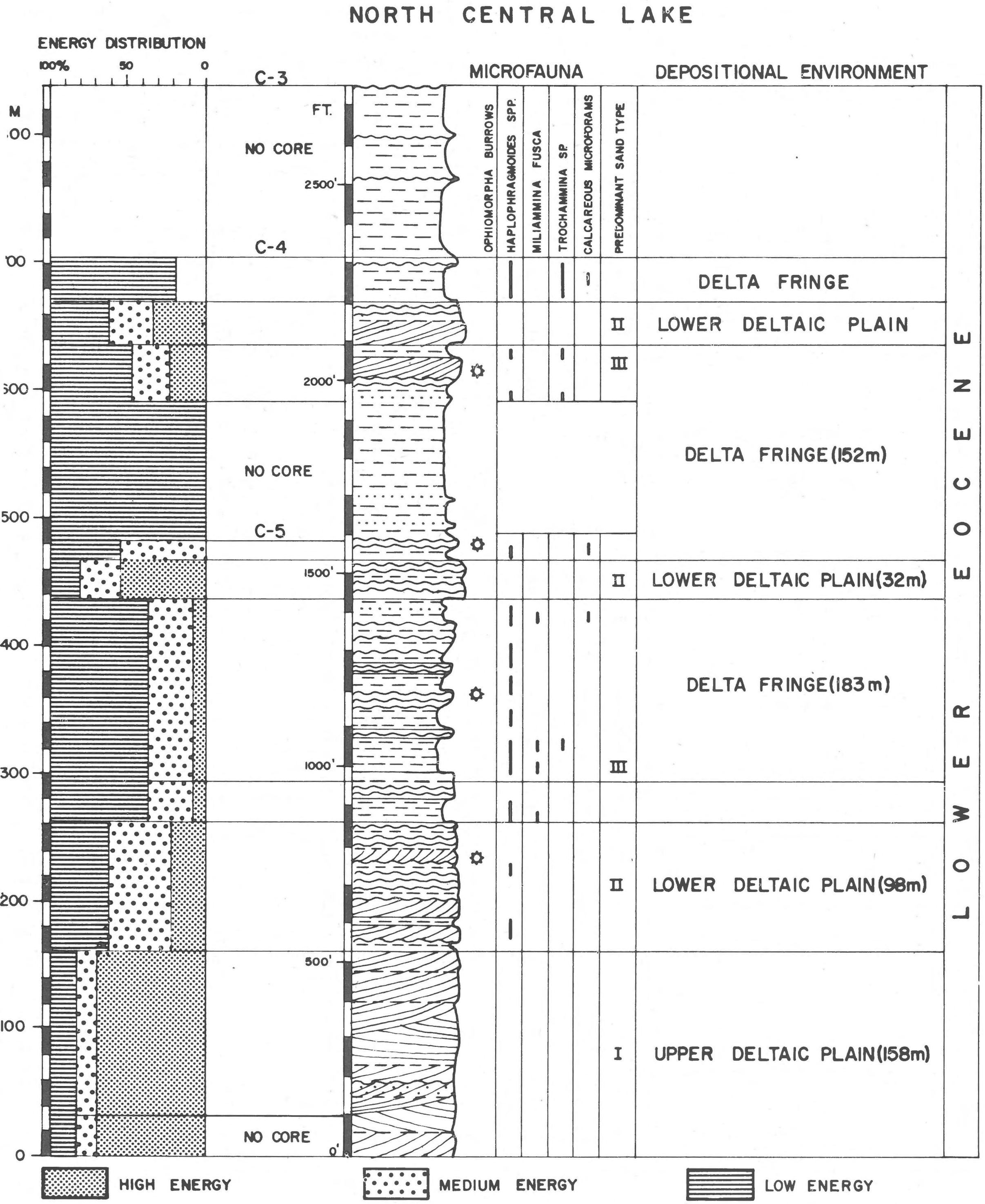
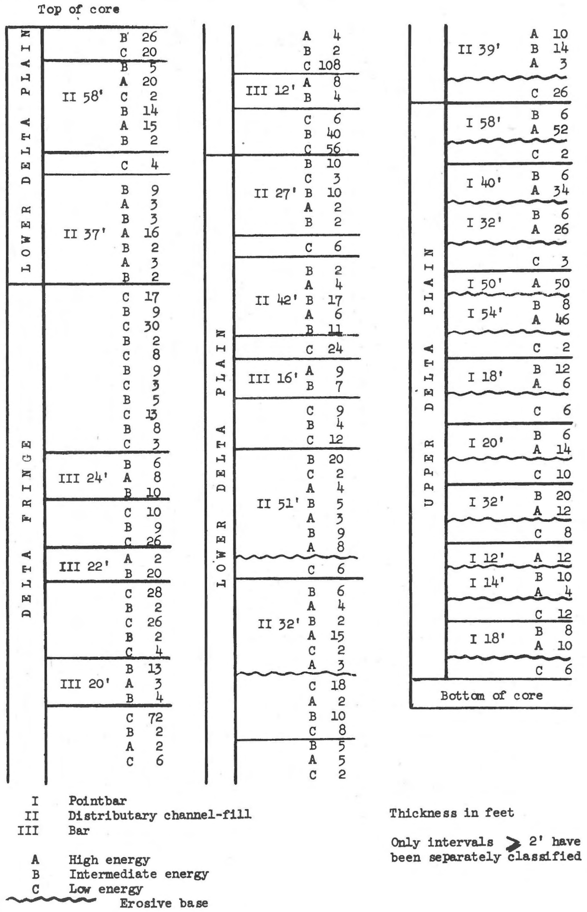


Fig. 12
Depositional environments in North Central Lake well.

TABLE III
Sequence of sand units and energy classes in North Central Lake well.



covered. The shales contain a foraminiferal assemblage consisting of *Haplophragmoides, Trochammina* and a single *Discorbis* sp. and represent marginal marine sediments.

The entire above-described core section has, on palynological evidence, been dated as Lower Eocene. In this particular North Central Lake well post-Eocene erosion has removed the Middle and Upper Eocene.

SOUTH CENTRAL LAKE

Moving about 50 km to the south, another continuously cored well was available of which a short description will be given. 2130 ft (705 m) of the subsurface Misoa Formation is preserved in this well, of which 2070 ft (630 m) belong to the C Member and the uppermost 240 ft (73 m) to the B Member of which, however, no core is available. These Middle Eocene sediments are unconformably overlain by Oligo-Miocene sediments. The palynological boundary between the Lower and Middle Eocene was found at 1450 ft (440 m) above the base. It can thus be seen that the Lower Eocene is reduced in thickness from 2750 ft (840 m) in the North Central Lake to 1450 ft (440 m) in the South Central Lake. In the latter well 870 ft (265 m) of Middle Eocene sediments have been preserved (fig. 8)..

The lowermost 705 ft (214 m) of the section has a sand percentage of 90% (fig. 13). The fining-upward sequence of sand type I is characteristic for this interval. A cyclical development of high- and low-energy sediments can again be distinguished (Table V and fig. 14) and it is concluded that the depositional environment was the upper deltaic plain. The mean grain size of the point-bar sandstones in slightly bigger than that of the corresponding upper deltaic plain sandstones in the previously discussed North Central Lake Well (Table IV and fig. 11C).

TABLE IV
Comparison of point-bar grain-sizes in North and South Central Lake Cores

	North Central Lake			South Central Lake		
	Number of samples	Av. mean size (Folk)	Av. % $<125\mu$	Av. mean size	Av. % $<125\mu$	Number of samples
high-energy sands	104	2.40 ϕ fine upper	14%	2.13 ϕ fine upper	7%	268
intermediate energy sands	33	2.90 ϕ fine lower	37%	2.60 ϕ fine lower	23%	172

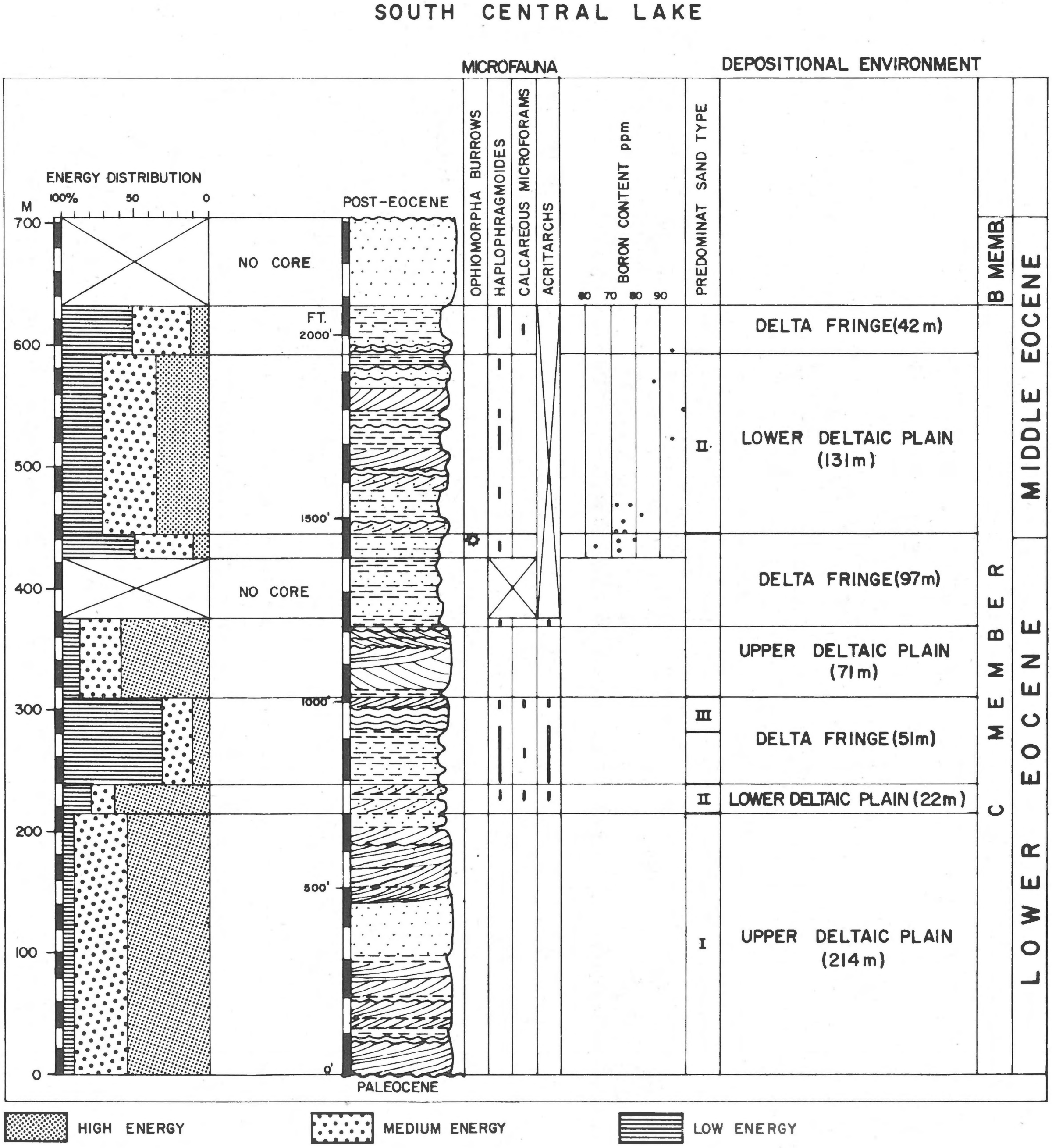


Fig. 13
Depositional environments in South Central Lake well.

In the next 71 ft (22 m) of section two sand bodies of type II can be recognised, which are indicative of the lower deltaic plain. The shales of this interval contain a microfauna consisting of *Haplophragmoides* spp., *Trochammina* spp., *Miliammina* sp. cf. *fusca*, *Gyroidinoides* spp., *Ammobaculites* spp., *Lenticulina* spp., *Pulsiphonina* spp. and *Heterolepa* spp. Palynological analysis revealed a significant amount of *Acritarchs* and of the chitinous inner linings of microforaminiferal tests, which both indi-

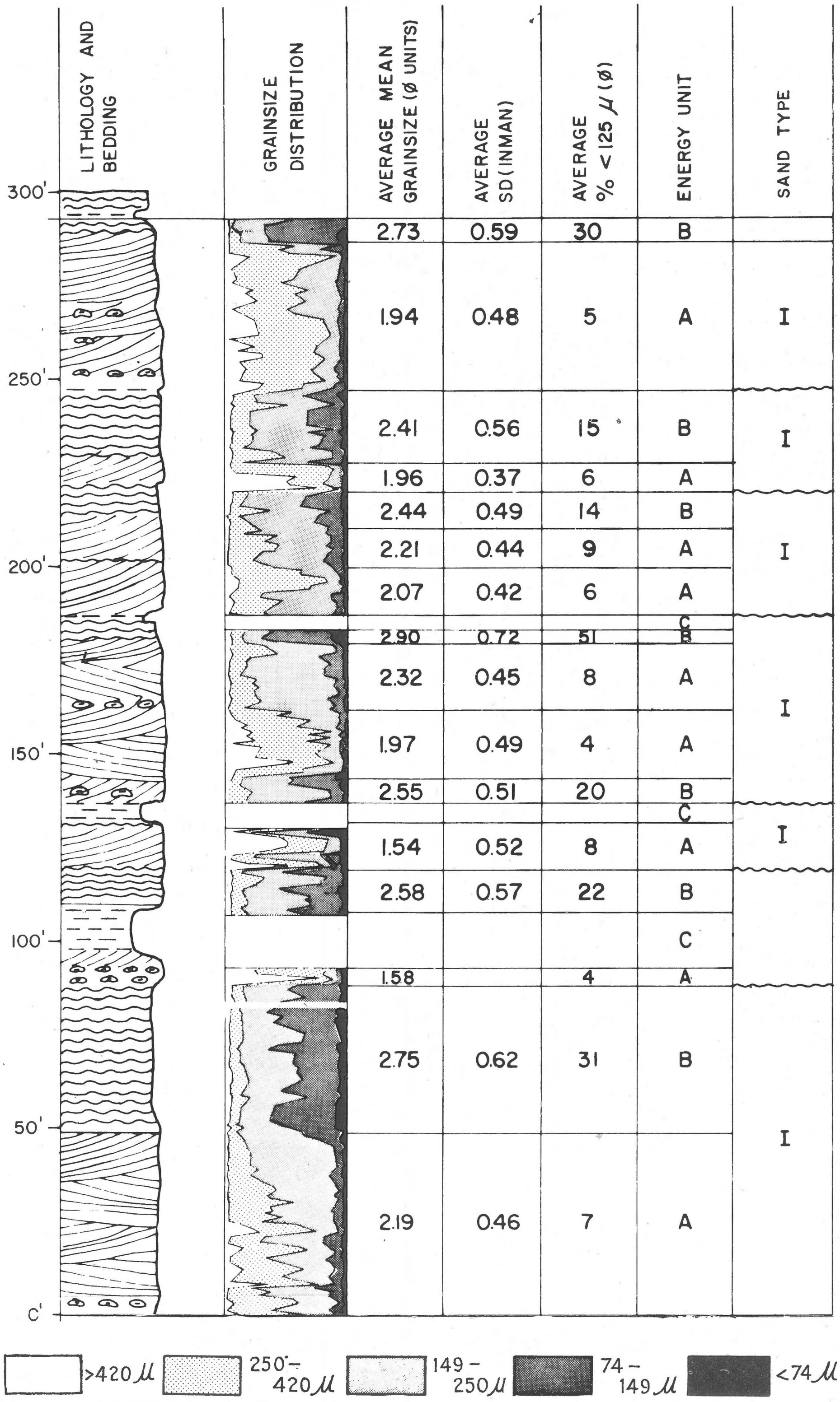


Fig. 14
Sequence of energy classes in lower part of South Central Lake well.

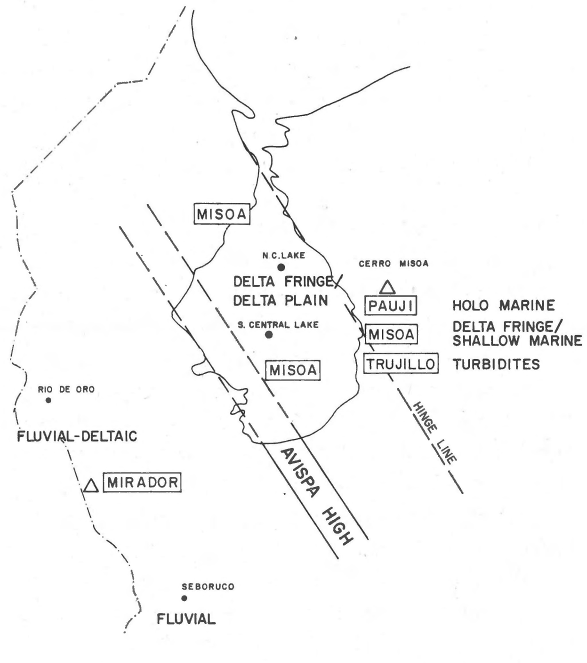
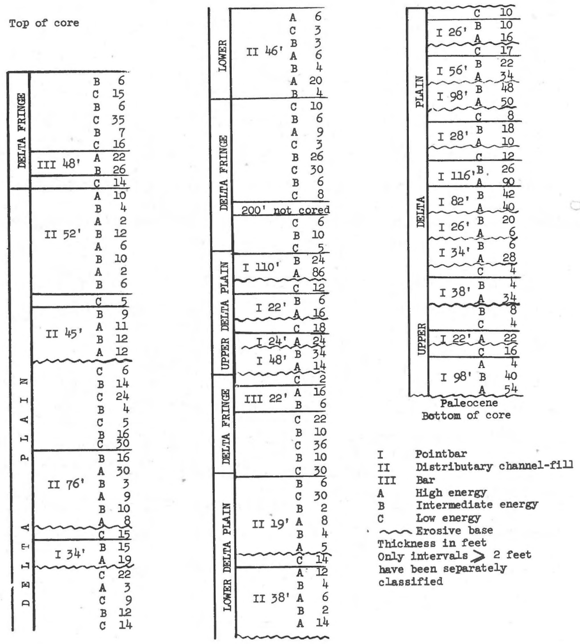


Fig. 15
Depostional environments of Lower-Middle Eocene formations in the Maracaibo Basin.

TABLE V
Sequence of sand units and energy classes in South Central Lake well.



cate marine influence.

The microfauna and *Acritarchs* persist in samples from the overlying 168 ft (51 m) dominantly shaly section, which is interpreted as pertaining to a delta fringe environment. In the subsequent 234 ft (71 m) predominantly sandy section, point-bar sequences form the bulk of the interval, indicating that renewed delta building took place. Microfauna is virtually absent in shales from this interval. The environment of deposition is likely to be an upper deltaic plain.

The major part of the overlying 320 ft (97 m) mainly shaly interval has not been cored. The lowermost shales contain *Haplophragmoides, Trochammina* and *Acritarchs*, whereas the uppermost sands contain *Ophiomorpha* burrows. A marginal marine environment is thus inferred for the entire section. An increase in sand percentage to 70% takes place in the following interval of 430 ft (131 m). The predominant sand unit is the distributary channel fill.

The topmost 140 ft (42 m) of the cored interval commences with a 48 ft (15 m) coarsening-upward unit followed by a mainly shaly interval. The high-energy part of the unit is a well developed, clean, well sorted sand of 22 ft (7 m), overlying a 26 ft (8 m)

TABLE VI
Thickness of sand units

	North Central Lake					South Central Lake				
	Range		Average		n*	Range		Average		n*
Genetic sand unit	Feet	Meters	Ft	M		Feet	Meters	Ft	M	
I Point bar	12-62	4-19	34	10	12	22-116	7-35	56	17	15
II Distributary channel-fill	27-58	8-18	41	13	8	19-76	6-23	46	14	6
III Bar	12-24	4- 7	19	6	5	22-48	7-15	35	11	2

* n = number of sand units

thick ripple-bedded sand with an increasing amount of shale intercalations downward. It is interpreted as a barrier beach.

An arenaceous microfauna mainly consisting of *Haplophragmoides* occurs throughout the upper cored section, but towards the top a more diversified fauna is found with *Trochammina, Ammobaculites, Protelphidium* and *Rhizammina*. This diversification goes together with an increase in boron content. The boron figures, obtained from 20 shale samples, range from 59 to 99 parts per million in the clay fraction (fig. 13). Boron determinations give an indication of relative salinities (P o r r e n g a, 1968) and in the present case can be interpreted as an increasing salinity of environment in an upward direction.

A tabulation of the vertical sequence of sand units, their energy classes and thickness for the entire cored section is presented in Table V. A comparison of thicknesses of the various sand units in the North and South Central Lake well is shown on Table VI. It can be seen that sands of all three types are on the average thicker in the South Central Lake than in the North Central Lake.

CONCLUSIONS

Three types of genetically distinct sandstone bodies were recognised in Lower to Middle Eocene sections in and around Lake Maracaibo, based on grain-size distribution trends and vertical sequence of sedimentary structures. The alluvial point bar is characteristic for the Mirador Formation which outcrops to the south and southwest of Lake Maracaibo. The off-shore bar or barrier beach is typical for the outcropping Misoa Formation to the east of the Lake. In the subsurface Misoa both point bars and off-shore bars or beaches were found together with distributary channel-fill deposits. It is interesting to note that when point bars of about equal thickness from the lower part of the Mirador and the lower part of the subsurface Misoa Formation are compared, a decrease in grain-size can be observed going from south to north over a distance of 225 km. Although over a large part of this distance (about 150 km) information is lacking, this decrease could well be explained as due to a dwonstream diminution in sediment size in one and the same river system (fig. 1). Similar grain-size distributions and decreases of the same order have been reported from the Mississippi River between upstream of Baton Rouge and New Orleans over a distance of about 200 km. (L e o p o l d et al., 1964, fig. 6-16). The thickness range of individual point bars in the Misoa (Table VI) also corresponds to those reported by F i s k (1944, 1947) from the Mississippi ("typically 40-60 ft thick, but in places over 80 ft").

There seem thus to be good reasons to assume that the Mirador and the time-equivalent Misoa formations were both deposited as parts of an alluvial and delta complex of Mississippi size, originating from a southwestern or southern source. During the Eocene, the Andean mountains which presently enclose the Maracaibo basin, had not yet emerged. There is therefore the possibility that a proto-Magdalena River provided the Mirador and Misoa sediments.

The thin development of the fluvaitile Mirador at Seboruco could, apart from possible later erosion, be explained by assuming an alluvial plane in equilibrium on a stable floor which acted as an area of sediment transit for most of the time. A stable floor would also account for the uniformity of the preserved sediments which consist almost entirely of high-energy sands (B e e r b o w e r, 1964, p. 34-35). To the northwest some subsidence took place as can be concluded from the greater thickness and more heterogeneous lithology. The outcropping Mirador thins from Seboruco to the northeast against the Avispa Massif, possibly mainly due to post-Eocene erosion which has also removed any evidence of a lateral transition zone from Mirador to Misoa, which presumably once existed across the high.

The thinning and facies change in the Mirador to the north of Río de Oro has led to the assumption that the Avispa high continues in the subsurface across Lake Maracaibo (B r o n d i j k, 1967b). The high may have acted as a threshold separating the stable shelf from the subsiding Maracaibo basin.

The deltaic sediments of the Misoa in Lake Maracaibo gradually thicken from south to north accompanied by a decreasing sand percentages and average grain size. Several phases of delta advance can be recognised, separated by tongues of clayey delta fringe and/or shallow-marine sediments. Marine influence which is limited to one or two thin intervals in the South Central Lake well becomes more important in North Central Lake and is likely to have prevailed over most of the outcropping Misoa to the east. The rapid increase in thickness of the Eocene across the basin hinge is accompanied by the deposition of turbidites of the Trujillo Formation. The Trujillo is, at least in part, time-equivalent to the deltaic Misoa sediments and these turbidites may have a deltaic source.

The Misoa constitutes overall a transgressive sequence with the interspersed delta plain sediments becoming thinner and less extensive during successive phases of delta building. Marine conditions finally prevailed over most of the area during Paují times, when holo-marine shales were deposited. The Paují Formation outcrops in the Misoa Hills with a thickness of 1200 m (4000 ft) and has been encountered in several Lake wells with thicknesses up to 800 m (2600 ft).

REFERENCES

Allen, J.R.L. (1965) – A review of the origin and characteristics of recent alluvial sediments: Sedimentology 5, p. 89-191.

Asociación Venezolana de Geología, Minería y Petróleo (1968) – La Estratigrafía del Eoceno en la Cuenca de Maracaibo, Publ. Especial No. 1, Caracas, 99 p.

Beerbower, J.R. (1964) – Cyclothems and cyclic depositional mechanisms in alluvial plain sedimentation, in: Merriam, D.F., ed., Symposium on cyclic sedimentation, Bull. 16, Vol. 1, p. 31-42. State Geol. Surv. of Kansas.

Bernard, H.A., R.J. LeBlanc, and C.F. Major (1962) – Recent and Pleistocene geology of Southeast Texas, in Geology of Gulf Coast and Central Texas, Guidebook of excursions: Houston Geol. Soc., p. 175-224.

Brondijk, J.F. (1967a) – Contributions of the A.V.G.M.P. Maracaibo Basin Eocene Nomenclature Committee: III. The Misoa and Trujillo formations. Bol. Informativo, Asoc. Venezolano de Geol., Min. y Petróleo, Vol. 10, No. 1, p. 3-19.

—— (1967b) – Contributions of the A.V.G.M.P. Maracaibo Basin Eocene Nomenclature Committee: V. "Eocene" formations in the southwestern part of the Maracaibo Basin. Bol. Informativo, A.V.G.M.P., Vol. 10, No. 2, p. 33-50.

Coleman, J.M., S.M. Gagliano and J.E. Webb (1964) – Minor sedimentary structures in a prograding distributary. Marine Geology, Vol. 1, p. 240-258.

Fisher, W.L., and J.H. McGowen (1969) – Depositional Systems in Wilcox Group (Eocene) of Texas and their relation to occurrence of oil and gas. Amm. Assoc. Petroleum Geologists, 53, p. 30-54.

Fisk, H.N. (1944) – Geological investigation of the alluvial valley of the lower Mississippi River. Mississippi River Commission, Vicksburg, Miss., 78 p.

—— (1947) – Fine grained alluvial deposits and their effects on Mississippi River activity. Mississippi River Commission, Vicksburg, Miss. 82 p.

—— (1955) – Sand facies of Recent Mississippi delta deposits: 4th World Petroleum Cong. Proc., Sec. I/C, p. 377-398.

—— (1961) – Bar finger sands of Mississippi delta, in: Peterson J.A. and Osmond J.C., ed., Geometry of sandstone bodies, Am. Assoc. Petroleum Geologists, Tulsa, Okl. 240 p.

Folk, R.L. (1965) – Petrology of sedimentary rocks. Hemphill's, Austin, Texas 146 p.

Garner, A.H. (1926) – Suggested nomenclature and correlation of the geological formations in Venezuela. Am. Inst. Min. Metall. Eng., Trans. p. 667-684.

Germeraad, J.H., C.A. Hopping and J. Muller (1968) – Palynology of Tertiary sediments from tropical areas. Review of Paleobotany and Palynology 6, No. 3/4.

González Guzmán, A.E. (1967) – A palynological study on the Upper Los Cuervos and Mirador formations. Brill, Leiden, 68 p.

Kolb, C.R. and J.R. van Lopik (1966) – Depositional Environments of the Mississippi River Deltaic Plain – Southeastern Louisiana, in: Shirley, M.E., ed., Deltas in their geologic framework, Houston Geological Soc. 251 p.

Leopold, L.B., M.G. Wolman and J.P. Miller (1964) – Fluvial processes in Geomorphology. Freeman, San Francisco, 522 p.

MacKenzie, D.B. (1965) – Depositional environments of Muddy sandstone, Western Denver basin, Colorado, Am. Assoc. Petroleum Geologists, 49, p. 186-206.

Masters, C.D. (1967) – Use of sedimentary structures in determination of depositional environments, Mesaverde Formation, Williams Fork Mountains, Colorado, Am. Assoc. Petroleum Geologists, 51, p.2033-2043.

Miller, J.B., K.L. Edwards, P.P. Wolcott, H.W. Anisgard, R. Martin and H. Anderegg (1958) – Habitat of oil in the Maracaibo Basin, Venezuela, in: L.G. Weeks, ed. Habitat of Oil, Am. Assoc. Petroleum Geologists, Symposium p. 601-640.

Nanz, R.H. (1954) – Genesis of Oligocene sandstone reservoir, Seeligson Field Texas. Am. Assoc. Petroleum Geologists, 38, p. 97-117.

Pettijohn, F.J. and P.E. Potter (1964) – Atlas and glossary of primary sedimentary structures. Springer, Berlin, 370 p.

Pettijohn, F.J., P.E. Potter and R. Siever (1965) – Geology of sand and sandstone. Indiana University, Bloomington, 208 p.

Phleger, F.B. (1960) – Ecology and distribution of recent foraminifera John Hopkins Press., Baltimore.

Porrenga, D.H. (1967) – Clay mineralogy and geochemistry of recent marine sediments in tropical areas. Thesis University of Amsterdam, 145 p.

Potter, P.E. (1967) – Sand bodies and sedimentary environments: a review. Am. Assoc. Petroleum Geologists, 51, p. 337-365.

Schaub, H.P. (1948) – Outline of sedimentation in Maracaibo Basin, Venezuela. Am. Assoc. Petroleum Geologists, 32, p. 215-227.

Shelton, J.W. (1967) – Stratigraphic models and general criteria for recognition of alluvial, barrier-bar, and turbidity-current sand deposits. Am. Association Petroleum Geologists, 51, p.2441-2461.

Stapp, R.W. (1967) – Relationship of Lower Cretaceous depositional environment to oil accumulation, Northeastern Powder River basin, Wyoming. Am. Assoc. Petroleum Geologists Bull., 51, p. 2044-2055.

Visher, G.S. (1965a) – Fluvial processes as interpreted from ancient and recent fluvial deposists, in: Middleton, ed. Primary sedimentary structures and their hydrodynamic interpretation. Soc. Econ. Pal. and Min. Special Publ. 12, Tulsa, Okl.

—— (1965b) – Use of vertical profile in environmental reconstruction. Am. Assoc. Petroleum Geologists, 49, p. 41-61.

Walton, W.M. (1967) – Contributions of the A.V.G.M.P. Maracaibo Basin Eocene Nomenclature Committee IV. The informal units of the subsurface Eocene. Bol. Informativo, A.V.G.M.P., 10, p. 21-30.

Weimer, R.J. and J.H. Hoyt (1964) – Burrows of *Calianassa major* SAY, geologic indicators of litoral and shallow neritic environments. Journ. Pal., 38, p. 761-767.