CARBONATE DEPOSITIONAL STYLES CONTROLLED BY SILICICLASTIC INFLUX AND RELATIVE SEA LEVEL CHANGES, LOWER CRETACEOUS, CENTRAL LAKE MARACAIBO, VENEZUELA.

APPROVED:

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BY

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THESIS

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ABSTRACT

CARBONATE DEPOSITIONAL STYLES CONTROLLED BY SILICICLASTIC INFLUX AND RELATIVE SEA LEVEL CHANGES, LOWER CRETACEOUS, CENTRAL LAKE MARACAIBO, VENEZUELA.

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Izaskun Azpiritxaga

Co-supervisors: Amos Salvador and Don G. Bebout

The Aptian-Albian Cogollo Group, in Blocks I and II, Maracaibo Basin, represents two major depositional styles; the Aptian-middle Albian (Apon and Lisure formations) is characterized by upward-fining cycles and the upper Albian (Maraca Formation), by upward-coarsening cycles. The upward-fining cycles consist of burrowed skeletal, orbitolinid, intraclast grainstones at the base that grade upward into shaly dolomites and skeletal, pellet wackestone. Hardgrounds occur in the wackestones at the top of several of these cycles. The upward-coarsening cycles

consist of skeletal wackestones at the base that grade upward into laminated and cross-bedded ooid and skeletal grainstones .

All carbonates of the Cogollo Group were deposited in shallow water. The upward-fining cycles resulted from deposition under subtidal conditions, in 2 to 15 m (5-50 ft) of water, in an open lagoon and associated with submarine sand-belts in shelf environments. The overlying upward-coarsening cycles represent open-water deposits, from 0 to 5 m (0-15 ft) of water, that accumulated as subtidal to intertidal shoal complexes.

A Fischer plot of this carbonate section suggests relative fall and rise of the sea during the deposition of the upward-fining cycles and a fall during the deposition of the upward-coarsening cycles. The upward-fining section is the thickest and is thought to be controlled by both sea-level changes and periodic influx of siliciclastics. During the Aptian (Apon Fm.) sea level fell and promoted the influx of siliciclastics. The siliciclastics inhibited carbonate production, and as a consequence upward-deeping cycles formed during an incipient drowning of the platform, despite the fall of sea level. Relative rise of sea level during deposition of the lower and middle Albian (Lisure Fm.) resulted in retrogradational events over a large incipient drowned platform. During the late Albian (Maraca Fm.), thin, upward-coarsening cycles were deposited during relative fall of sea level and represented upward-shallowing cycles. These upward-coarsening cycles represent a brief return to shallow-water conditions prior to abrupt deepening of the sea and the subsequent deposition of the overlying Upper Cretaceous La Luna pelagic carbonates.

No significant amount of matrix porosity was observed in the rocks. The average of matrix porosity is 2 percent and is more likely to be found in the Apon and Maraca formations. Porosity in the Apon Formation is intercrystalline in dolomites and interparticle in the orbitolinid grainstones. The porosity in Maraca Formation is moldic in mollusk grainstones.

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1. INTRODUCTION

The Maracaibo Basin, Western Venezuela, (Fig. 1) is host to many large oil fields ranging in age from Cretaceous to Miocene (Gonzalez de Juana and others, 1980). The high potential production of light oil and condensate from Cretaceous reservoirs has increased the interest in their study.

Cretaceous reservoirs in the Maracaibo Basin are mostly represented by the Cogollo Group, a shallow-water carbonate sequence. Oil is thought to be produced from fractured carbonates with low matrix porosity and permeability. The initial production from these fields is generally by natural flow because the Cretaceous reservoirs are highly overpressured. The oil gravity varies from 27°to 43°API (Reijers and Bartok, 1985).

The area of this study includes two Maraven S.A concessions, Block I and Block II (Fig. 1), located in the central part of Lake Maracaibo.

Block I, which has an area of 200 sq km is crossed by the Icotea Fault, a north-northeast-striking normal fault that divides the block into the west down-dropped flank and the east or horst flank (Fig. 2). Ten wells have been drilled on the west flank, and three of these are active wells with oil production of 7200 b p d. The estimated original oil in place (OOIP), for this block, is 706.35 MM bls, and the proved reserves are 101.0 MM bls. The recovery factor is 14.3 percent. By June, 1988, 27.58

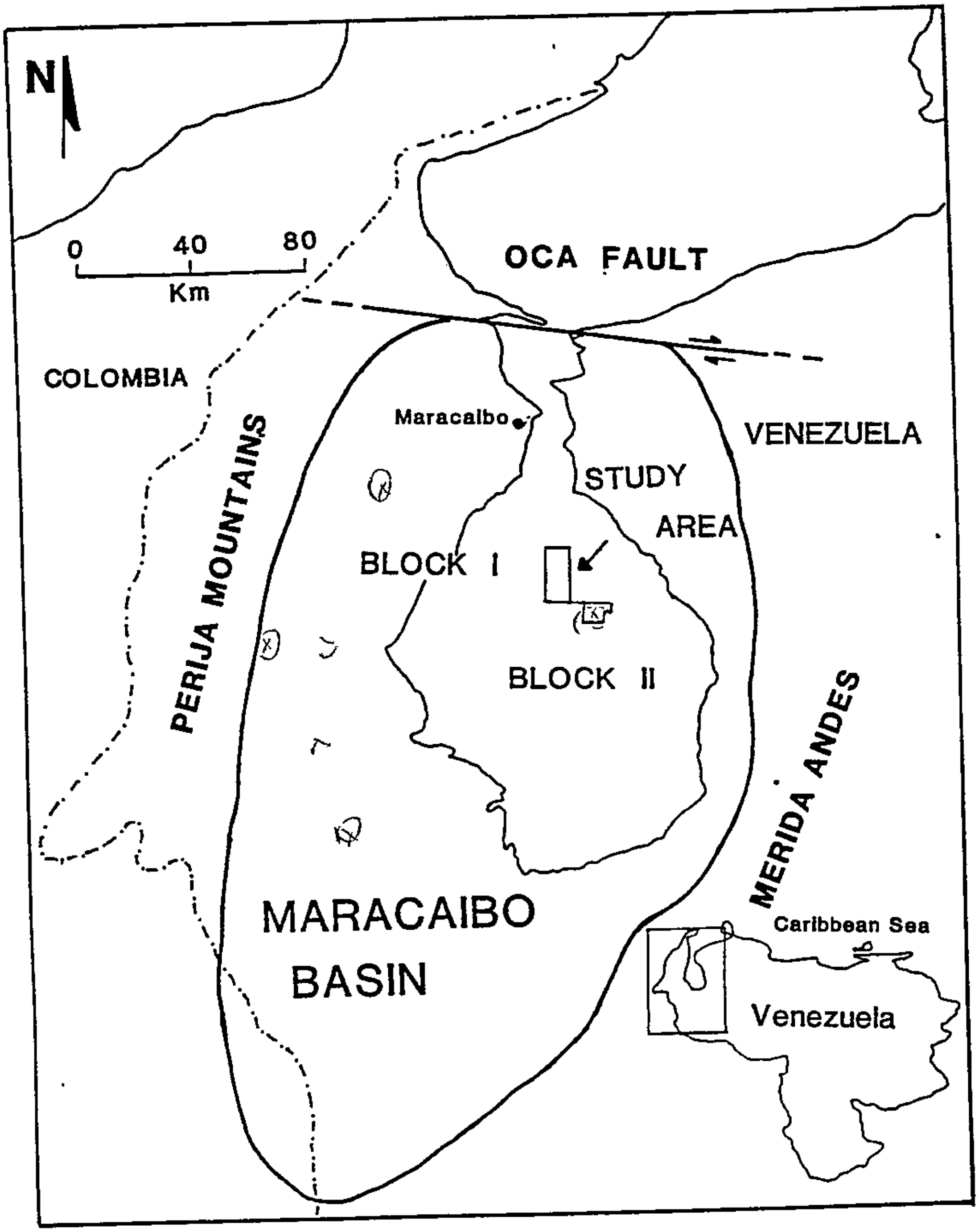


Fig. 1. Location map showing the present-day Maracaibo Basin and study area.

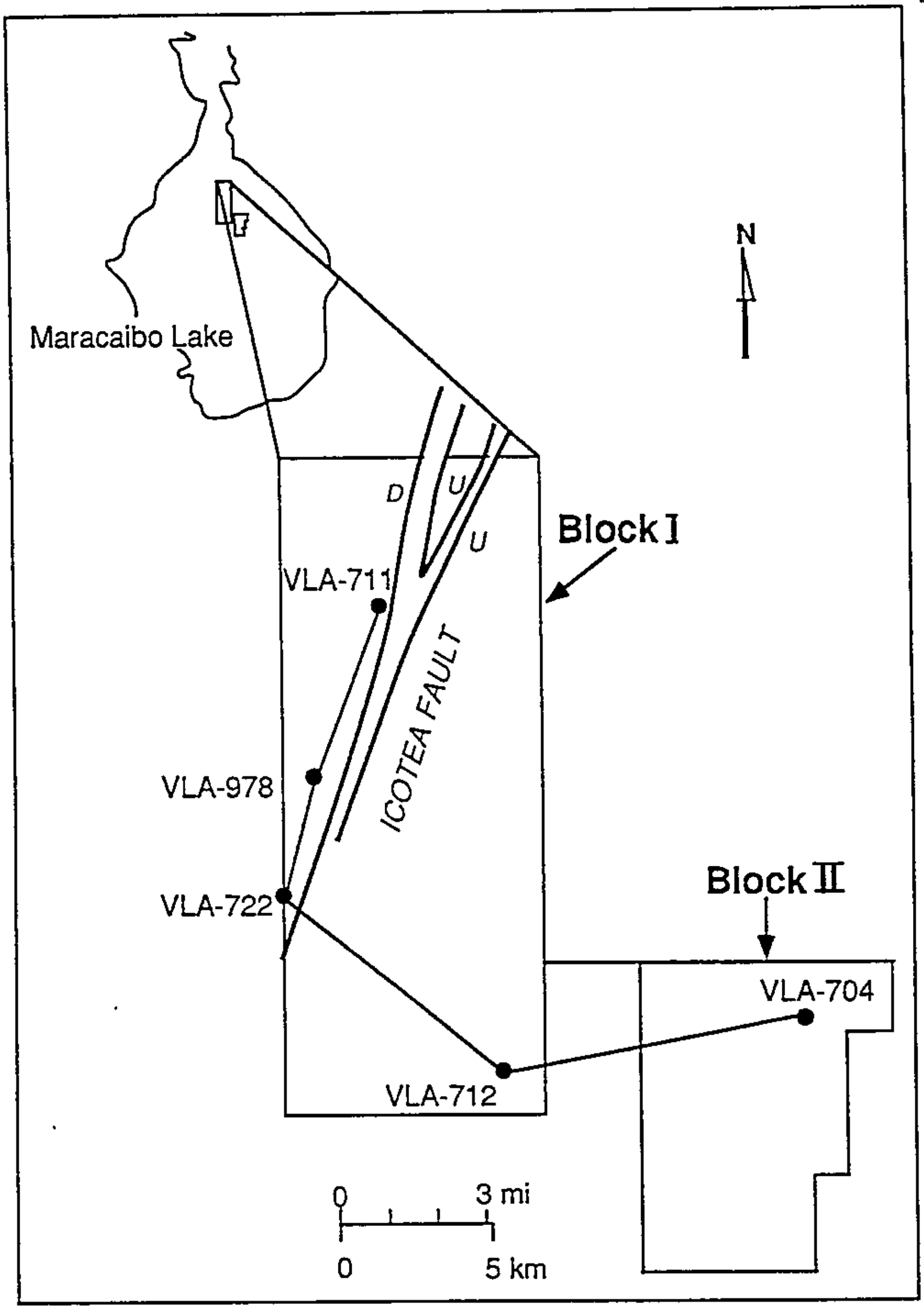


Fig. 2.- Map showing the location of the cores in Block I and Block II.

MM bls had been recovered and 73.42 MM bls remained, which represents 10 percent of the OOIP (Slavione and others, 1988). On the east flank of Block I, five wells have been drilled; no oil has been produced from these wells, and the area was abandoned in 1976 (Slavione and others, 1988).

Block II has an area of 80 sq km, and only one well (VLB-704) has penetrated the Cretaceous section. This well did not produce and was abandoned in 1975. The estimate of unproven reserves is 2.0 MM bls. of oil and 2.1 Bcf of gas (Slavione and others, 1988).

1.1 OBJECTIVES

The general objectives of this study were to examine all available cores in the area of study to identify matrix porosity, to analyze the depositional setting of the Lower Cretaceous Cogollo Group, and to establish what factors controlled the depositional model.

It was hoped that establishing the depositional framework would contribute to better understand the Lower Cretaceous reservoirs in the area.

1.2 METHODOLOGY

The study focused on the detailed description of Lower Cretaceous cores from 5 wells: VLA-711, VLA-978, VLA-722, VLA-712, and VLB-704 (Fig.2). A total of 975 m (3,200 ft) of core were described. The description was made by macroscopic observation, following the methodology of Bebout and Loucks (1984), and microscopic observation by the description of thin sections from selected intervals. Geophysical logs (gamma ray-resistivity) were correlated with the core description.

Facies were defined by grouping together units with common characteristics. Cyclic patterns were observed in the vertical sequence of facies. The cycles were well defined based on specific facies assemblages and on the nature of the contacts between facies (sharp, hard grounds). The different cycles were correlated laterally through all the cores. The recognition of the vertical distribution of the cycles led to identify styles of deposition. The depositional environment for the different styles was defined based on the components of the facies and on facies association.

In order to aid in understanding of the mechanism that controlled the cyclic sequence and depositional styles a Fischer plot was constructed. The Fischer diagram plots the cumulative thickness of the cycles of the Cogollo Group in meters against their time of deposition in millions of years. The horizontal axis represents time, and individual cycles are spaced evenly along the axis on the assumption that all cycles were deposited during equal intervals of time; the duration of these intervals was determined by dividing the total geological time of the deposition of the entire section by the number of cycles (AVERG. TIME = TIME/N CYCLES). The determination of geological time (Aptian-Albian) for the Cogollo Group was established by paleontological data. *Choffatella decipiens*, the index fossil of the lower Aptian, and *Orbitolina texana*, the index fossil of the upper Aptian and lower Albian, were used to provide geological time. The top of the Albian was defined by the overlying Cenomanian La Luna Formation. In this study the Aptian-Albian time duration was considered to be 15 m.y. based in Haq and others (1987).

The vertical axis is a composite (none of the wells have core through the entire Cogollo section), non decompacted, cumulative thickness of the total number of cycles. The straight line that connects the base of the stratigraphic section to time zero is the mean subsidence vector that is also constant and is the obtained relation between the thickness and time (SUBSIDENCE RATE = TOTAL THICKNESS/TIME) (Fischer, 1964). The individual cycles are plotted at their proper stratigraphic elevation above this vector and any slope (+ , -) reflects deviation from the mean subsidence and hence changes in relative sea level (Goldhammer and others, 1987).

2. REGIONAL GEOLOGICAL SETTING

2.1 REGIONAL GEOLOGY

The Maracaibo Basin, located in northwestern Venezuela, is delimited by the Oca fault to the north, the Perija Mountains to the west, the Merida Andes to the south and southeast, and the low relief region of Falcon-Lara to the east (Fig. 1). At present, the basin covers an area of 50,000 sq km within the drainage region of Lake Maracaibo. The Maracaibo Basin was part of a larger pericratonic basin that extended from Venezuela to Peru along the western margin of the Guyana and Brazilian Shields and became completely isolated during the late Cenozoic Andean orogeny (Figs. 3 and 4) (Macellari, 1988).

The oldest Mesozoic sedimentary rocks in the basin are the Jurassic La Quinta Formation (Maze, 1984) composed of continental red sandstones and conglomerates associated with pyroclastic and calcalkaline felsic to mafic igneous rocks. The terrigenous sediments were deposited within extensional half-grabens, which trend north-northwest (Bot and Perdomo, 1986) following the present upper Magdalena River Valley-the Cesar Valley-Perija Mountains trend (Fig. 4). The La Quinta Formation also is present in the Merida Andes area (Juliver 1968, according to Bartok and others, 1981). This association of graben-related non-marine beds together with acidic and alkaline

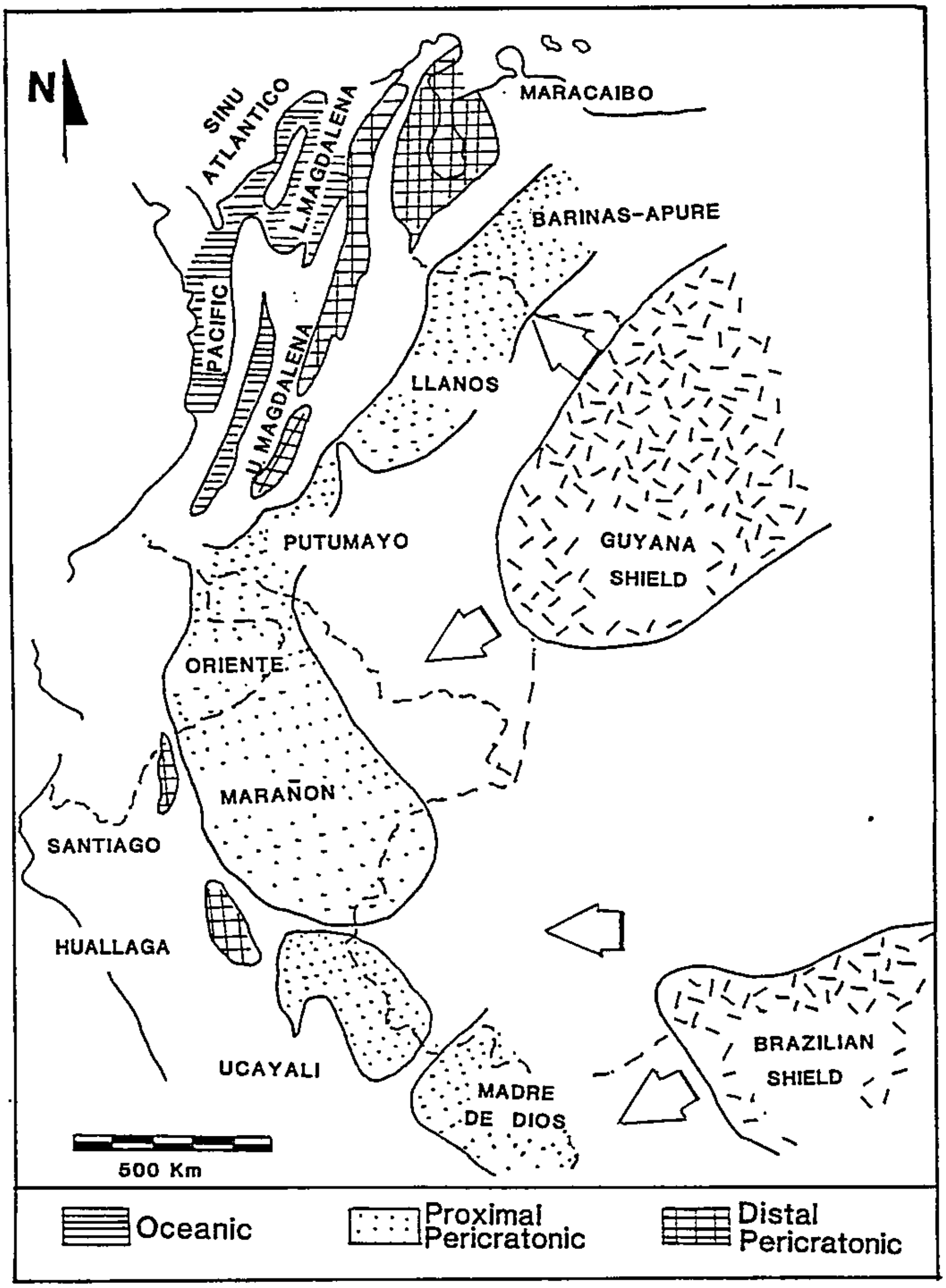


Fig. 3 Northern South America map showing the present-day major sedimentary basins on the basis of Cretaceous rocks present (modified from Macellari, 1988)

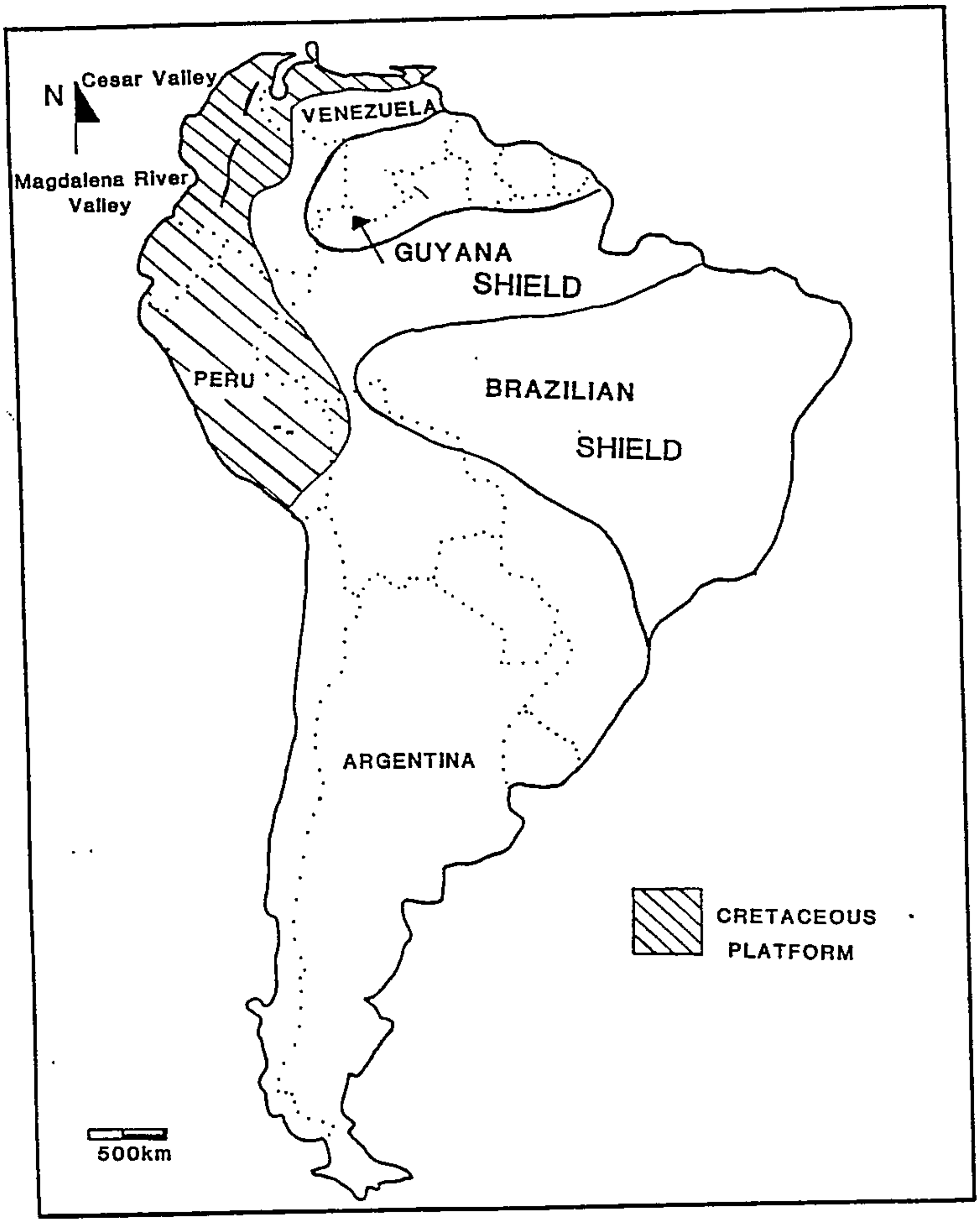


Fig.4. Extensive Cretaceous platform covering the Northern part of South America (modified from Macellari, 1988).

igneous rocks is typical of the early rifting phase in the development of an "Atlantic type" or passive continental margin (Eva and others, 1989). After the deposition of the La Quinta Formation, an erosional stage took place that almost completely flattened the Paleozoic and Mezosoic deposits.

During the Cretaceous the Maracaibo Basin was part of an extensive platform that was encroached by a series of marine advances. The Cretaceous platform covered parts of Peru, Ecuador, Colombia, and Venezuela and surrounded the Precambrian Guyana and Brazilian Shields (Fig. 4). It is important to mention that this extended platform probably was complex (Fig. 3), and individual subbasins were separated by structural highs, islands, or positive areas (Gallango and others, 1984).

The Lower Cretaceous in the Maracaibo Basin is represented by the Rio Negro Formation (Barremian) and Cogollo Group (Aptian-Albian) (Fig. 5). The Upper Cretaceous is represented by the La Luna Formation (Cenomanian-Santonian) and Colon Formation (Campanian-Maastrichtian) (Fig. 5) (Gonzalez de Juana and others 1980 ; Gallango and others 1984).

The distribution of the Lower Cretaceous sediments was controlled by a series of the northeast-trending troughs (Uribante, Machiques, and Barquisimeto) and the northwest-trending paleohigh (Merida Arch) (Fig. 6). The depositional troughs were formed as a consequence of rapid subsidence in the area, resulting in the grabens filled with the La Quinta Formation (Macellari, 1988).

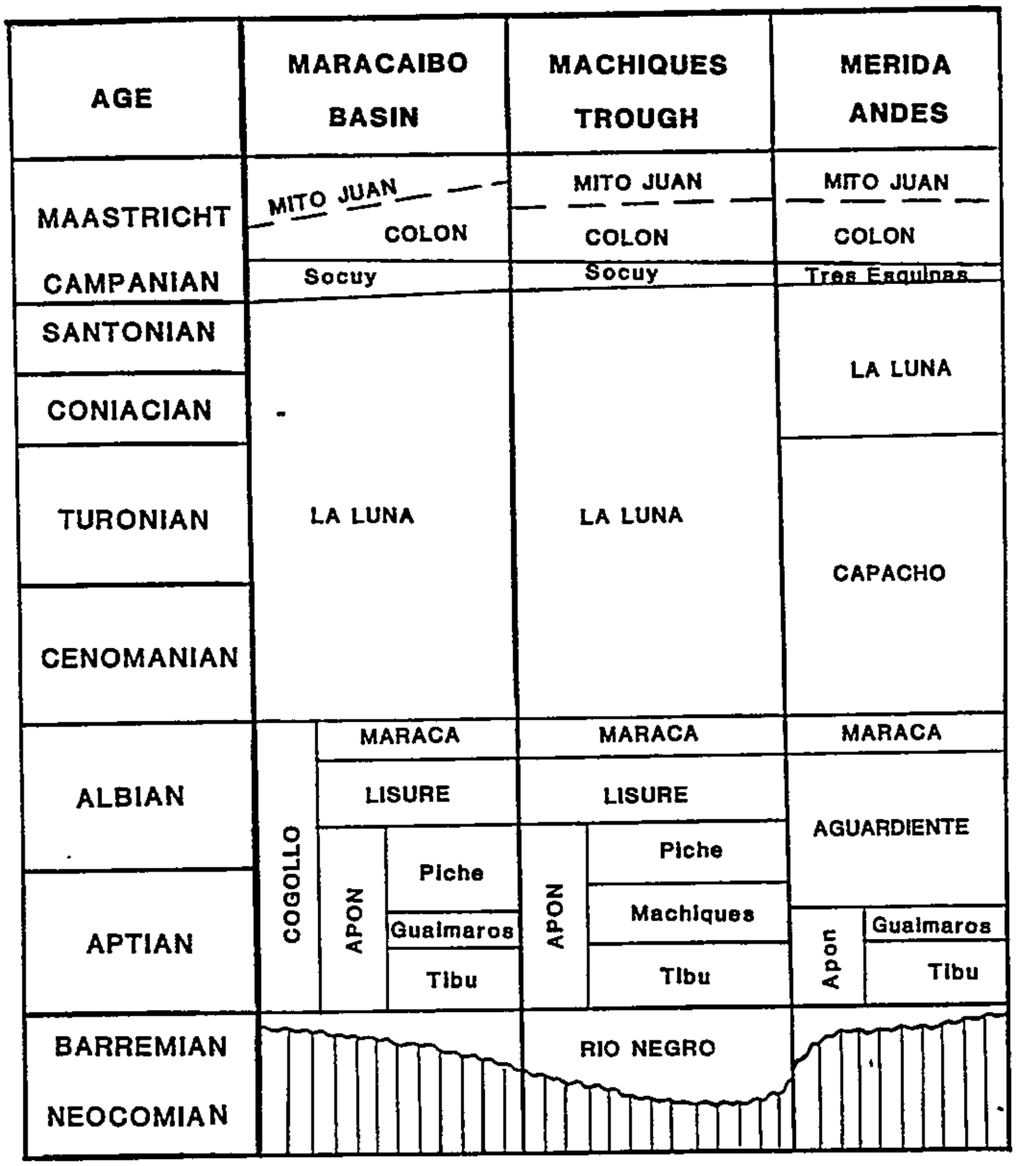


Fig. 5. Cretaceous lithoestratigraphic units in the Maracaibo Basin (Gonzalez de Juana and others, 1980).

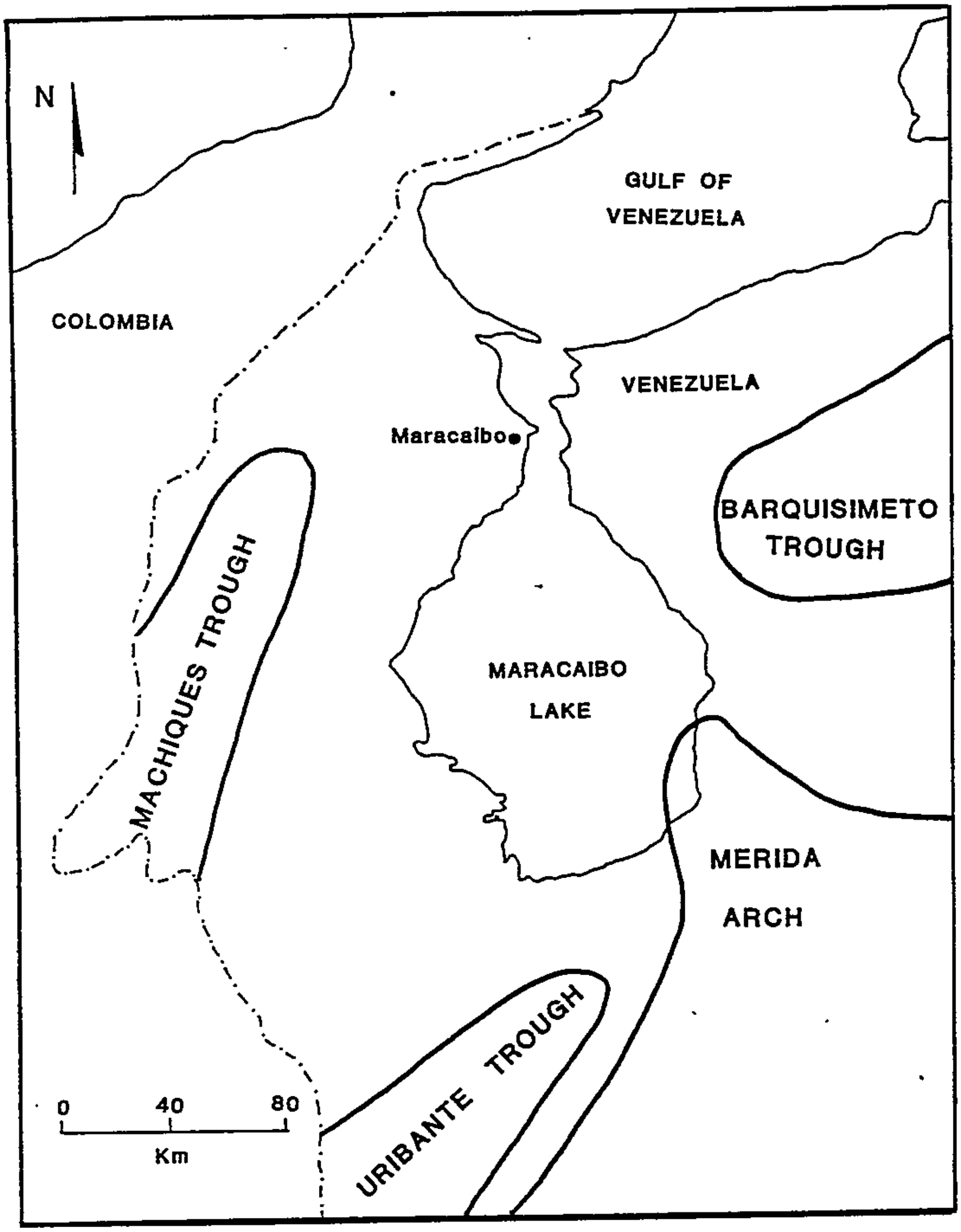


Fig. 6. Map showing the structural features that controlled the Cretaceous sedimentation in the Maracaibo Basin (Zambrano and others, 1969).

During the Barremian the Rio Negro fluvial sediments were deposited over the platform and in the trough areas, where they are thicker (1,200 to 1,500 m in the Machiques trough, Corpoven S.A, 1982). The Rio Negro Formation pinches out against the borders of the positive Merida Arch and Santander Massif (Fig. 7) (Gonzalez de Juana and others, 1980 ; Macellari, 1988).

The Cogollo Group was deposited throughout the basin during the Aptian-Albian (Gonzalez de Juana and others, 1980) and ranges in thickness from 244 m (800 ft) on the east to 366 m (1200 ft) on the west. In structural lows the Cogollo Group is 610 m (2,000 ft) thick (Bartok and others, 1981). Rod and Maync (1954) subdivided the Cogollo Group into three formations, from bottom to top: Apon, Lisure, and Maraca (Fig. 5).

The Apon Formation is characterized by light-gray, massive, and fossiliferous limestone. Renz (1954) subdivided the Apon Formation into three members: Tibu, Machiques, and Piche from bottom to top. The Tibu Member is composed of shallow-water fossiliferous limestones. The Machiques Member represents pelagic shaly carbonates of euxinic nature and is restricted to the Machiques area. In the subsurface of Maracaibo Lake and in the Merida Andes area, an equivalent member shaly dolomite has been recognized as a very persistent regional marker called the Guaimaros Member. The Guaimaros Member (Maracaibo Area) and the Machiques Member (Perija area) are overlain by the Piche Member that is characterized by fossiliferous limestone deposited in more normal-marine waters.

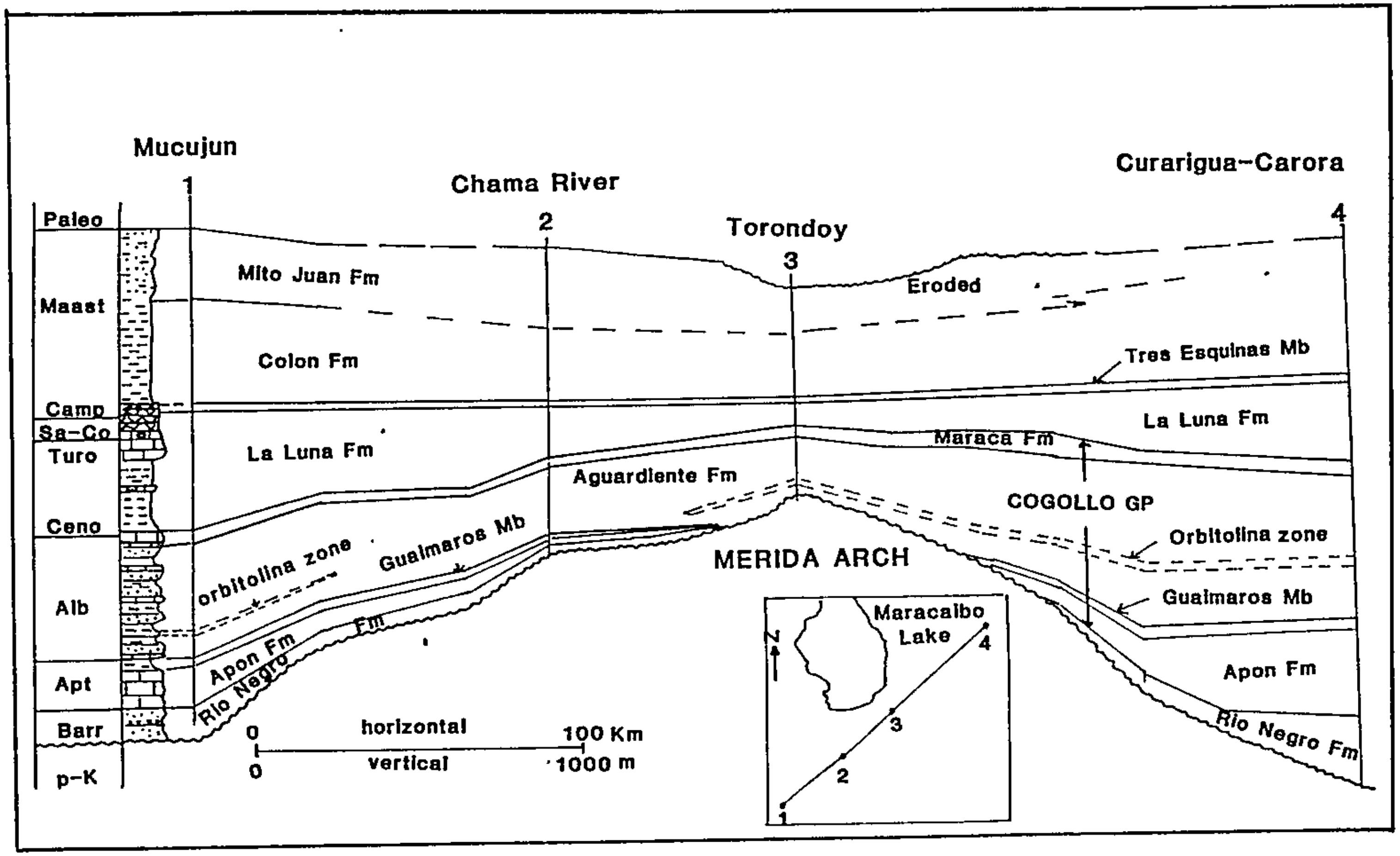


Fig. 7. Merida Andes area section showing the control of the Merida Arch over the Cretaceous sedimentation (modified from Gonzalez de Juana and others, 1980).

The Lisure Formation is characterized by fossiliferous limestone, intercalated with calcareous, glauconitic sandstone layers. This formation is recognized in the Perija Range and Maracaibo Basin. In the Merida Andes area, to the south, the Lisure Formation grades laterally into the sandstones of the Aguardiente Formation (Smith 1951).

The Maraca Formation, a good stratigraphic marker in the Maracaibo Basin, is a thin but widespread fossiliferous limestone that completely covered the Merida Arch. The Maraca thickness varies from 45 to 60 m (148-197 ft) in the Maracaibo Lake and is 20 m (66 ft)in the Merida Andes area. Compaction and subsidence on both flanks of the Merida Arch permitted thicker accumulation of the Maraca on the flanks (Fig.7).

The Maraca Formation is transitionally overlaid by the La Luna Formation, which is characterized by black, laminated, pelagic limestones. The La Luna Formation was deposited during the maximum expansion of the Cretaceous seas in northwestern South America, and indicates deposition in a predominantly anoxic environment (Macellari and De Vries, 1987). The La Luna Formation is the most important source rock of petroleum in the Maracaibo Basin.

Following deposition of La Luna, a period of slow, condensed sedimentation occurred (Campanian) before the subsequent regression. The lithological intervals that represents this period of slow sedimentation are the Tres Esquinas (glauconitic and phosphatic sandstones) and Socuy (glauconitic limestones) members of the Colon Formation.

The Colon Formation overlies the La Luna Formation; it was deposited under regressive conditions. In the Lake Maracaibo area, the Colon is composed of marine, grey to black, pyritic, glauconitic shales and represents the seal of the Cretaceous reservoirs in the Maracaibo Basin.

2.2 TECTONIC FRAMEWORK

Three principal deformation periods are responsible for the present structural configuration of the Maracaibo Basin (Fig. 8). The first period of deformation was a minor epirogenic uplift, which took place during the late Cretaceous and Paleocene. This period of deformation was responsible for the formation of small anticlines and north-northeast-trending normal faults (Icotea, Sibucara, Sol, Pueblo Viejo) (Gonzalez de Juana and others, 1980). Gallango and others (1984) believe the deformation was the consequence of the relative movement between the South American and Pacific-Caribbean plates.

A second period of deformation occurred during the late Eocene and Oligocene. This deformation is characterized by an intensive compressional stress in a northwest direction that resulted in important north-northeast structural relief (Sibucara Urdaneta, Lama, and Centro

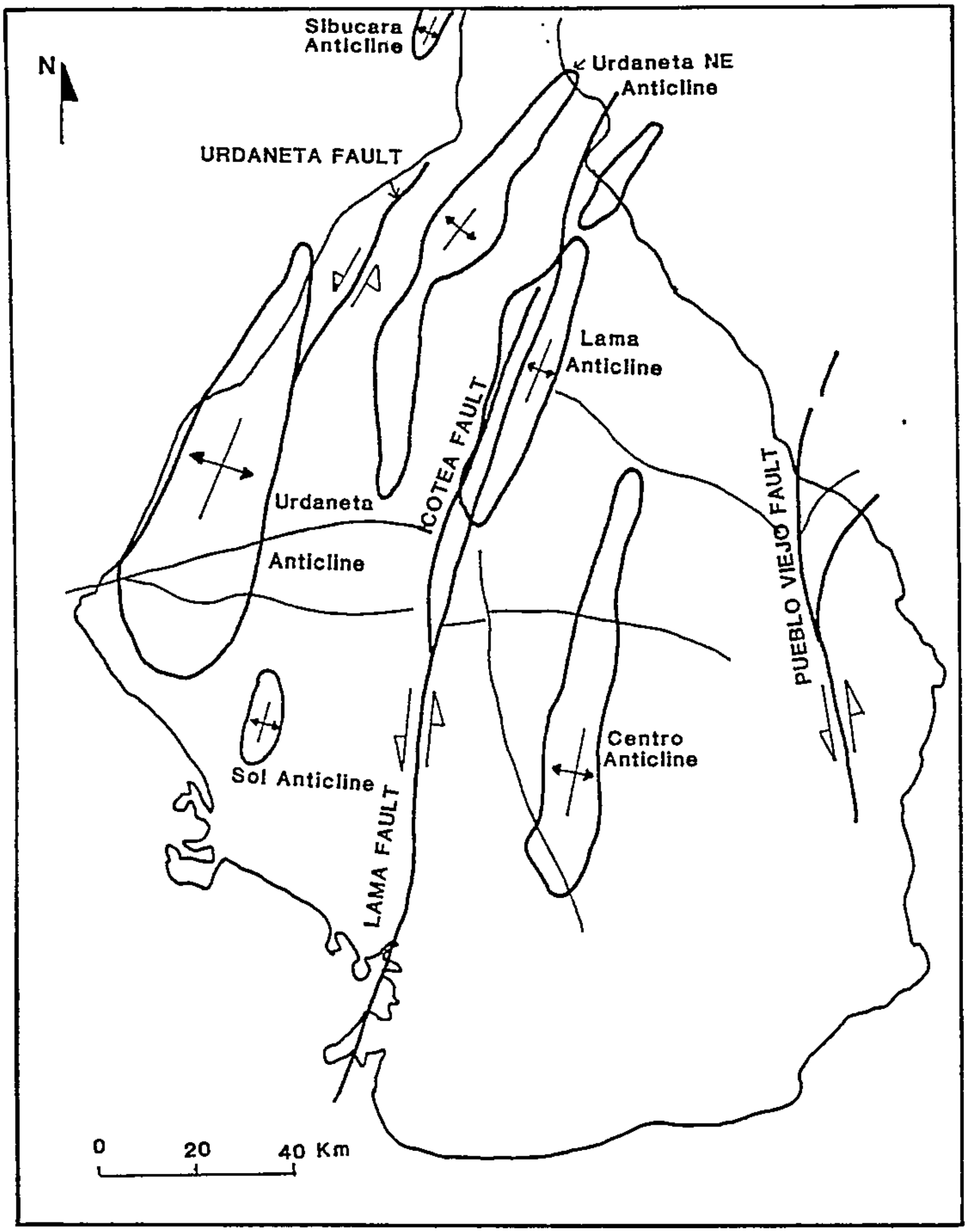


Fig. 8. Structural features of Maracaibo Lake showing anticlenes and faults formed during the late Eocene-Oligocene and the Late Cretaceous-Paleocene tectonic periods.

anticlines). Additionally, transverse northwest-trending faults were developed, and a first phase of fracturing occurred, producing a set of sub-vertical fractures and sub-horizontal stylolites (Keir and others, 1989). This second deformation event enhanced the anticlines and faults that were initiated during the Cretaceous and also generated east-west faults (Gallango and others, 1984). In contrast to the Gallango and others (1984) opinion, Lugo (personal communication) suggests that these faults are Late Jurassic reactivated features and that the normal faulting is attributed to the plate separation between northwestern South America and southern North America.

The third tectonic period occurred from the late Miocene to present. The most intense tectonic events occurred during the Miocene-Pliocene and resulted in causing uplift of the Merida Andes and Perija Mountains. Uplift at this time also caused folds and faults in the post-Eocene sediments and reactivation of pre-existing faults and structures (Gallango and others, 1984). This third tectonic period is responsible for the second phase of fracturing in the Cretaceous carbonates, which created a set of sub-horizontal / oblique fractures and sub-vertical stylolites (Keir and others, 1988).

3. SEDIMENTOLOGY

3.1 FACIES OF THE COGOLLO GROUP

3.1.1 Skeletal Grainstones

Three types of skeletal grainstones have been identified based on the analyses of cores: 1) mollusk grainstone, 2) echinoid-mollusk grainstone, and 3) arenaceous foraminifer-red-algae grainstone.

Mollusk grainstone

This facies is brown in color, and occurs in 0.6 to 1.2 m (2-4 ft) thick limestone beds; pelecypods and gastropods are the common assemblage of mollusks in this facies. The mollusks are pervasively cemented by calcite and outlined by micritic envelopes (Fig. 9). In rare cases, they occur as molds creating interparticle and moldic porosity (Fig. 10).

In rudist grainstones, rudist chambers are filled with internal sediment and calcite cement, forming geopetal structures, and the walls of the fossils have been highly cemented by calcite.

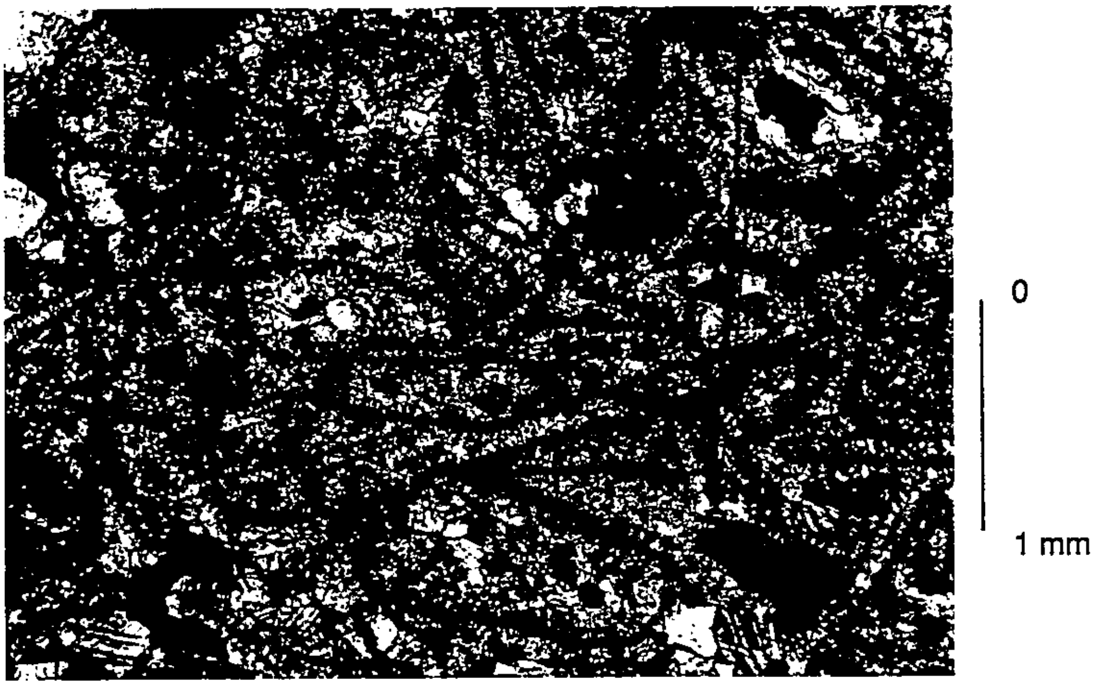


Fig. 9. Mollusk Grainstone. Rounded pelecypod fragments are outlined by micritic envelopes and highly replaced by calcite. Intergranular pores are filled with equigranular cement. (VLA-711--14,125 ft; cross polarized light).

Fig. 10. Porous Mollusk Grainstone with moldic and interparticle porosity. (VLA-978--13,427 ft; plane polarized light).

Mollusk-Echinoid grainstone

This grainstone occurs in beds 0.3 to 0.9 m (1-3 ft) thick. The mollusks represent 70 percent and the echinoids 30 percent of the facies (Fig. 11).

The mollusks are principally pelecypods. The pelecypods have micritic envelopes over which rims of bladed calcite have grown, and the chambers are filled with equigranular calcite. Oyster fragments, present in minor amounts, are the only mollusk conserving the original shell composition. The echinoid fragments are 1 to 0.75 mm in size. The intra-fossil voids are filled with syntaxial calcite overgrowths on echinoid fragments and equigranular calcite cement.

Arenaceous foraminifer-red-algae grainstone

This facies is brown in color and occurs in beds 3.3 to 5 m (10-15 ft) thick. Cross-stratification occurs, especially at the top of the beds.

The agglutinated foraminifers range from 1.5 to 0.5 mm in size. They constitute 30 to 50 percent of the rock. The red-algae fragments are 1 to 0.25 mm in size and compose 50 to 80 percent of the facies. Less than 10 percent of the allochems are echinoids, mollusks, and bryozoans (Fig. 12).

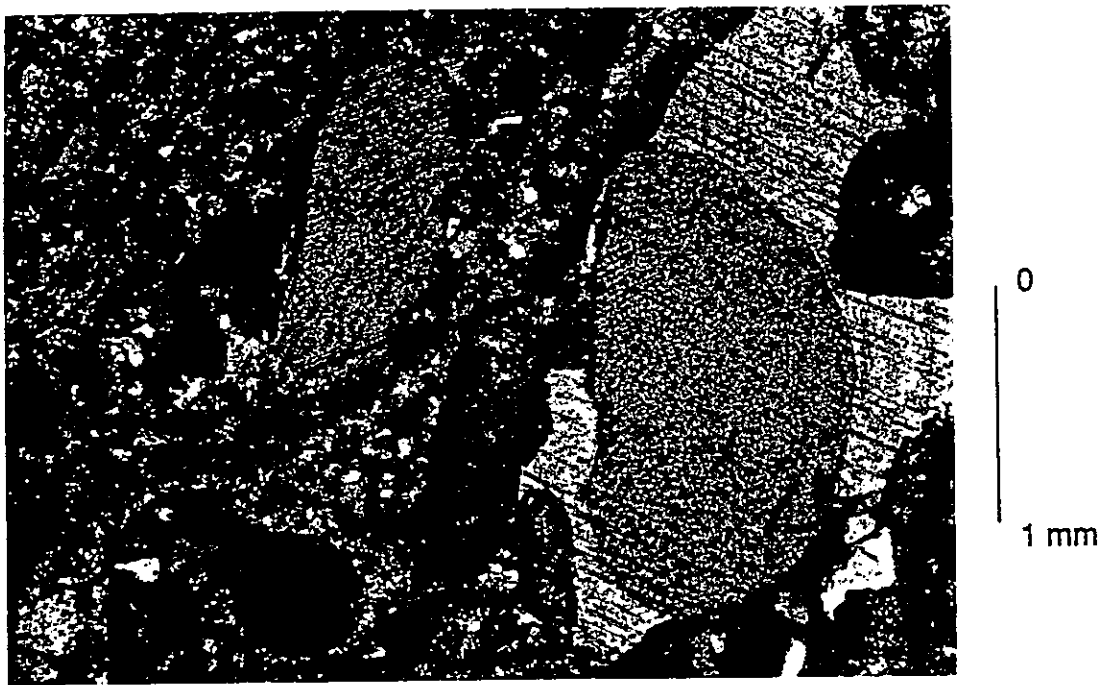


Fig. 11. Mollusk-Echinoid Grainstone. Mollusks are principally pelecypods, few oysters and gastropods presenting micrite envelopes. Echinoid plates are overgrown by syntaxial cement. (VLA-711--14,357 ft; cross polarized light).

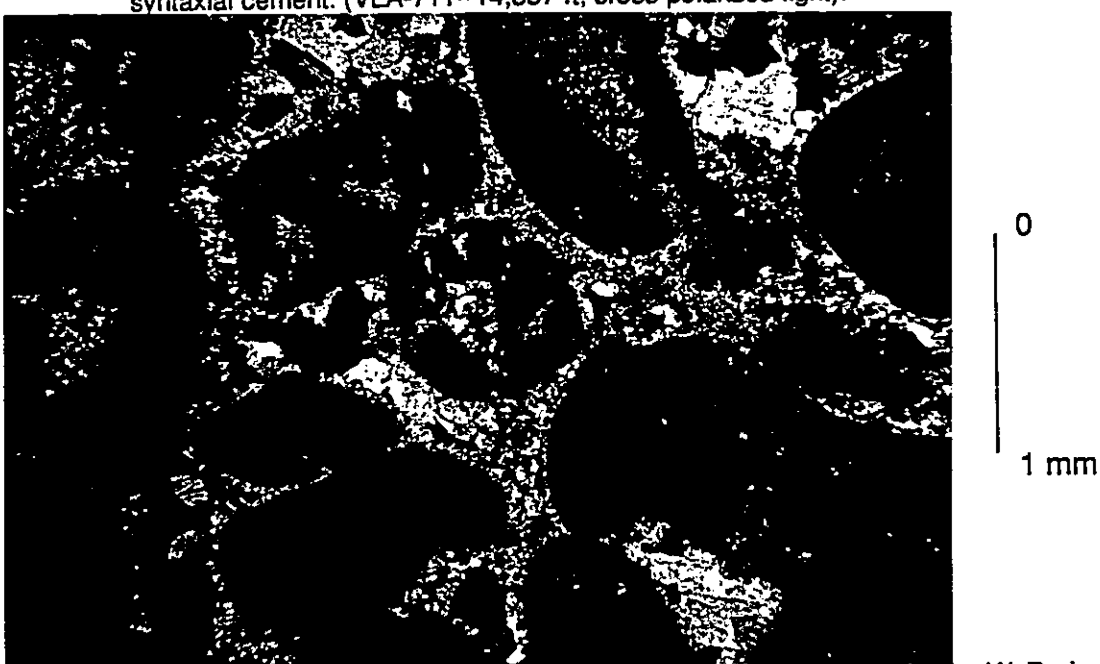


Fig. 12. Arenaceous foraminifer-red-algae grainstone. Arenaceous Foraminifer (A)-Red algae (B). Bladed crusts of calcite cement overgrow skeletal grains, and the interparticle spaces are filled by equigranular calcite cement. The arenaceous foraminifer shown consists of chambers composed of agglutinated individual micritized grains. (VLA-711--14,043 ft; cross polarized light).

Most grains are surrounded by bladed calcite cement, whereas syntaxial cement grows over echinoid fragments, and equigranular calcite cement fills interparticle spaces.

3.1.2 Oolite Grainstone

This facies is characterized by a gray color and occurs in beds 1 to 2 m (3-7 ft) thick. The ooids consist of multiple tangencial layers of carbonate around a nucleus. The nuclei are mostly skeletal and micritic grains. The ooids are moderately sorted and range from 0.5 mm to 0.25 mm in diameter (Fig. 13). The ooids make up 90 percent of the rock; the other 10 percent are fragments of mollusks and echinoids. Cross-bedding stratification is the most characteristic sedimentary structure. Hard grounds were observed at the top of some beds (VLA-711-14090' 4" and 14021') (Fig. 14) .

The oolites are held together by rims of bladed calcite, and equigranular calcite fills the interstices between the ooids.

3.1.3 Intraclast-Skeletal Grainstone

This facies (Fig. 15), which occurs in layers 3.3 to 9 m (10-30 ft) thick, is a dark brown in color, with a very mottled aspect.

Two types of intraclasts make up 60 to 80 percent of this facies: aggregate grains and peloids. Also, two types of aggregate grains occur 1) skeletal and micritized-grain aggregate; and 2) ooid grapestone (Fig.

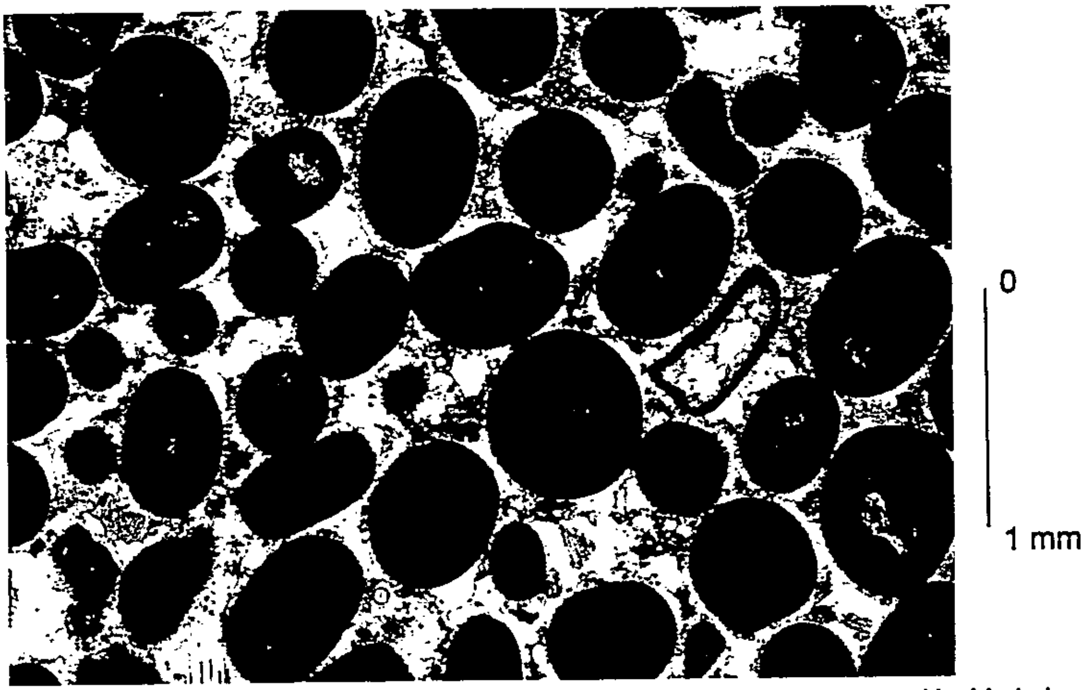


Fig. 13. Oolite Grainstone. The moderately sorted ooid grains are cemented by bladed calcite rims. The remaining pore spaces are filled by equigranular calcite. (VLA-711--14,015 ft; cross polarized light).

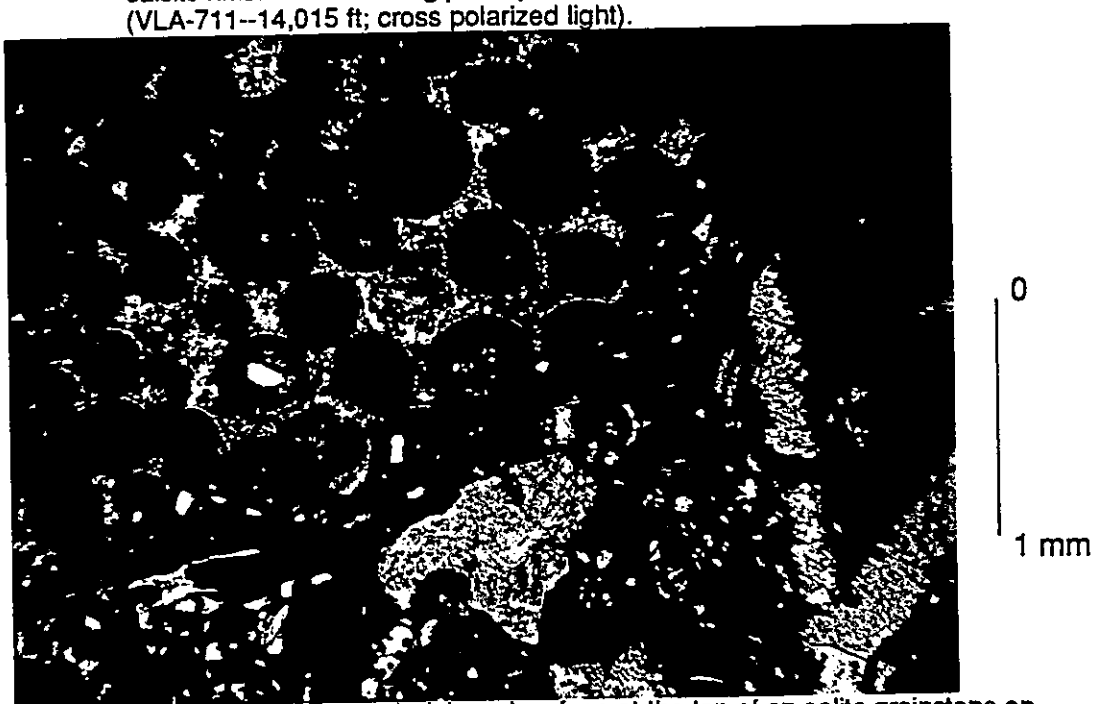


Fig. 14. Hard Ground. Cemented, bored surface at the top of an oolite grainstone on which a stylolite is superimposed. (VLA-711--14,021 ft; cross polarized light).

16). The subrounded aggregate grains are moderately sorted and range in size from 1.5 to 0.5 mm. The peloids are moderately sorted, spherical, and between 0.25 and 0.5 mm in size. The skeletal grains are mollusks, echinoids, and green and red algae. The skeletal grains are well preserved and represent 20 to 40 percent of the rock.

The grains are rounded and rimmed with bladed calcite. The remain pore space is filled with.equigranular and syntaxial cement.

Other components are siliciclastic sand and silt-sized grains; they are subrounded and well to moderately sorted and represent 5 percent of the facies.

Fractures and stylolites are common in this facies.

3.1.4 Pellet-Skeletal Grainstone/Packstone

This facies is a light brown, burrowed limestone that occurs in beds 3.3 to 5 m (10-15 ft) thick; skeletal fragments (30 to 50 percent) and pellets (50 to 70 percent) are the grains (Fig. 17).

The pellets are micritized grains, that range in size between 0.05 and 0.025 mm. The pellets are rounded and well sorted. The skeletal grains are echinoids, mollusks, foraminifers and green algae (Halimeda). In some cases an specific taxon characterizes the facies.

3.1.5 Skeletal (Orbitolinid) Grainstone/Packstone

This facies is characterized by dark brown limestone that occurs in

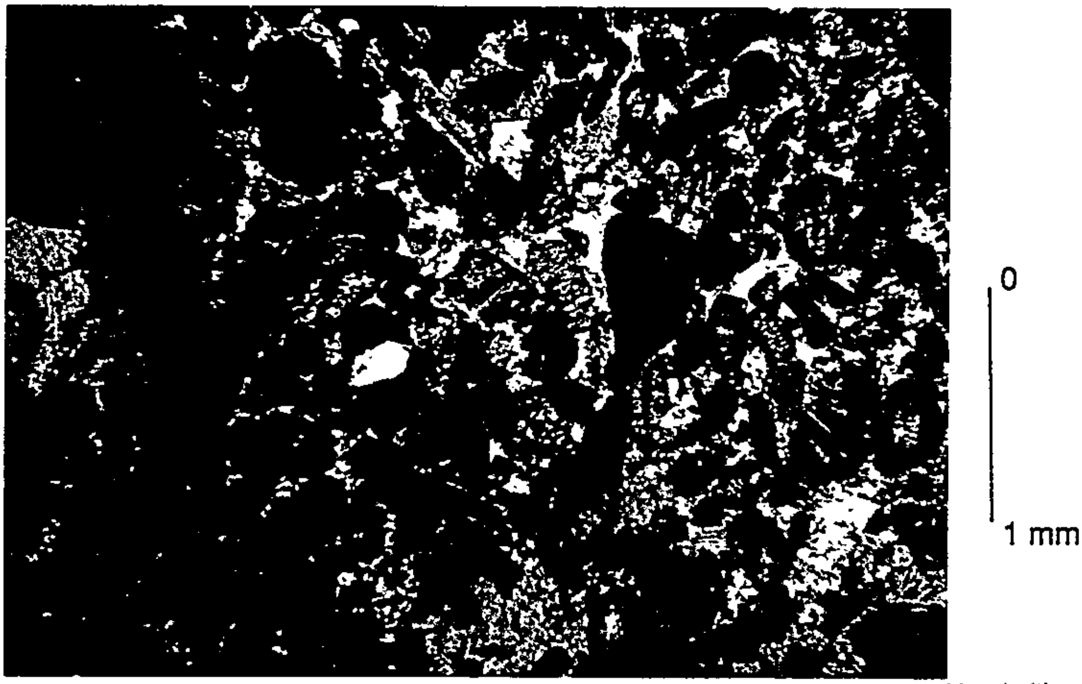


Fig. 15. Intraclast-Skeletal Grainstone. Skeletal grains are mollusk fragments with micritic envelopes. Intraclasts are made up of micritized grains (A) and aggregate grains (B). (VLA-978--13,838 ft; crossed polarized light).

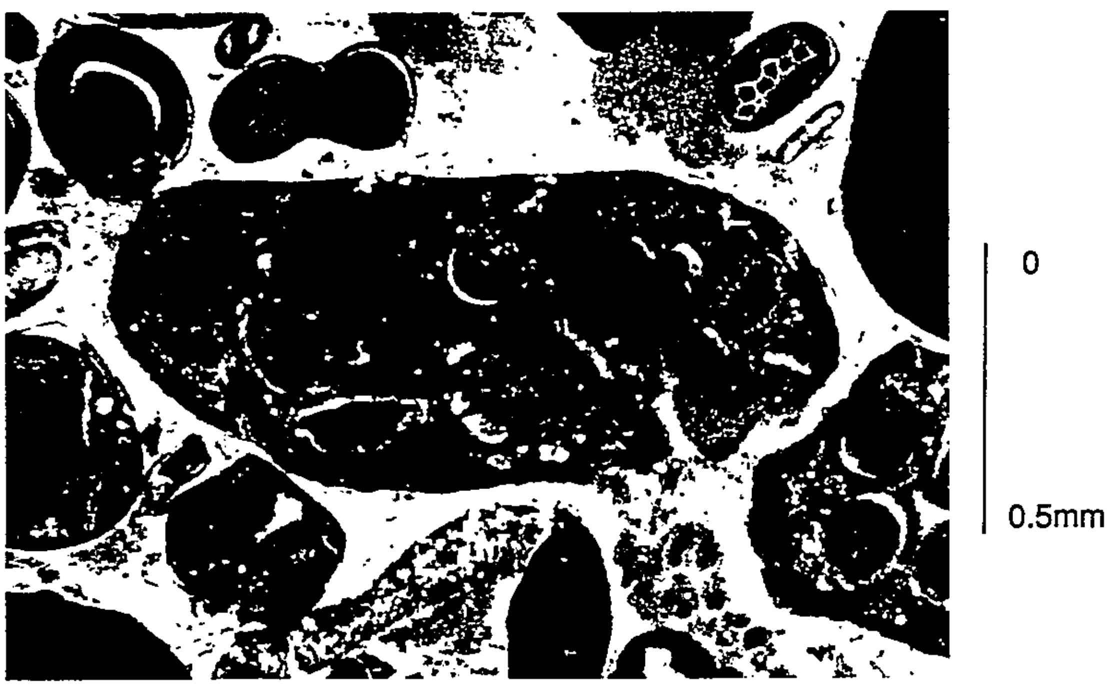


Fig. 16. Ooid grapestone. (VLA-978--13,487 ft, cross polarized light).

beds 3.3 to 12 m (10-40 ft) thick. This facies is characterized by beds upward-coarsening beds, burrows, and stylolites.

Orbitolinids are the predominant skeletal grains in this facies. They constitute 60 to 90 percent of the rock. The size of the orbitolinids ranges between 5 to 3 mm and in most of the cases are very well preserved (Fig. 18). Green algae (Halimeda), mollusks, and echinoids range in abundance from 10 to 40 percent. Up to 10 percent of intraclasts and peloids also occur .

The matrix, in most cases, is microcrystalline calcite (micrite). Nevertheless, in well VLA-978, the matrix of the orbitolinid packstone has been replaced by equigranular calcite. The calcite was later replaced by dolomite. The dolomite crystals are 0.25 mm in size and have a dirty appearance. They make up 5 percent of the facies. Interparticle porosity was observed in these samples. Bladed calcite rims surround the orbitolinids.

3.1.6 Oncolite Packstone

Oncolite packstones are dark brown in color and occur in beds 1.2 to 2.4 m (4-8 ft) thick. Stylolites are common (Fig.19).

The size of the oncolite grains ranges between 0.25 mm to 1 cm. The nuclei are skeletal fragments, which consist mostly of mollusks. Layers of blue-green algae surround the nuclei generating the oncolites. The oncolites make up 70 percent of the rock; skeletal grains (30

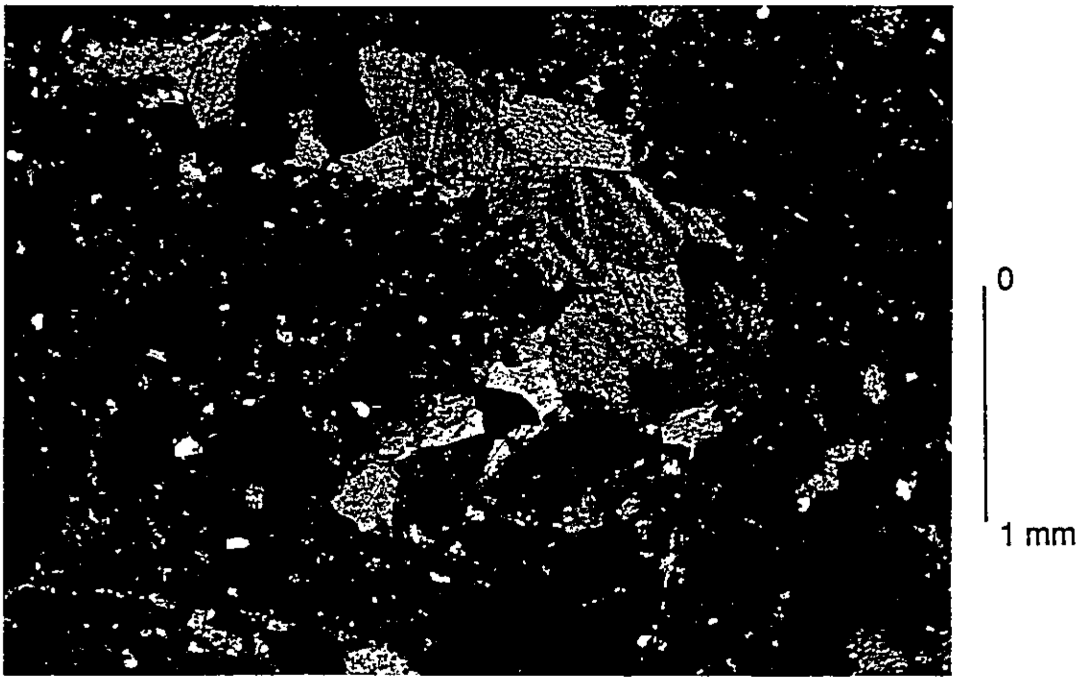


Fig. 17 Pellet-Skeletal Grainstone/Packstone. Cemented fragments of mollusk are scattered in pellet matrix. (VLA-711--14,385 ft; cross polarized light).

Fig. 18. Orbitolinid Grainstone/Packstone. Section of *Orbitolina texana* foraminifera. (VLA-978--14,064 ft; cross polarized light).

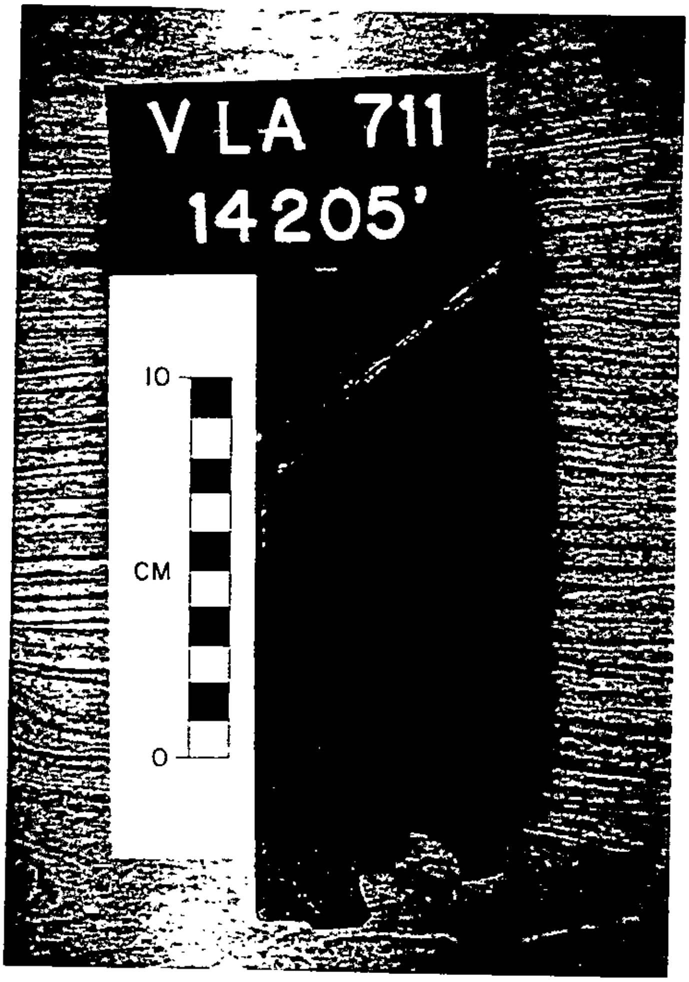


Fig. 19. Oncolite Packstone. Oncolites are approximately 1 cm in size and are surrounded by stylolites.

percent) also occur in the micritic matrix. The skeletal grains are echinoids and fragments of red algae.

3.1.7 Skeletal (Oyster) Packstone

This limestone facies is black to dark brown in color and occurs in beds 0.6 to 1.8 m (2-6 ft) thick. The oyster fragments (80 percent), a shaly - micritic matrix (20 percent) and traces of serpulid worm tubes are the principal textural constituents. The oyster fragments are 2 to 5 cm in size. The matrix is a mixture of shaly and microcrystalline calcite with trace of organic matter. The organic matter provides the dark color to the facies (Fig. 20).

Dolomite crystals are present floating in the matrix and represent 10 percent of the facies. The dolomite crystals are 0.1 to 0.05 mm in size. Silica cement (chalcedony) partially replaces the calcite walls of some oysters .

The sedimentary structures present are burrows filled with calcite, and stylolites.

3.1.8 Skeletal (Miliolid) Packstone/Wackestone

Very well preserved miliolid foraminifers scattered in a micritic matrix are characteristic of this facies. The bed thickness range between 0.6 and 1.2 m (2-4 ft).

The wackestone contains up to 10 percent miliolids and the packstone, up to 50 percent. The miliolids, which range in size from

Fig. 20. Oyster Packstone photomicrograph. The large oyster fragment is partially replaced by calcedony. Clean dolomite rhombus occur in the organic-rich micritic matrix. (VLA-978--14,226; cross polarized light).

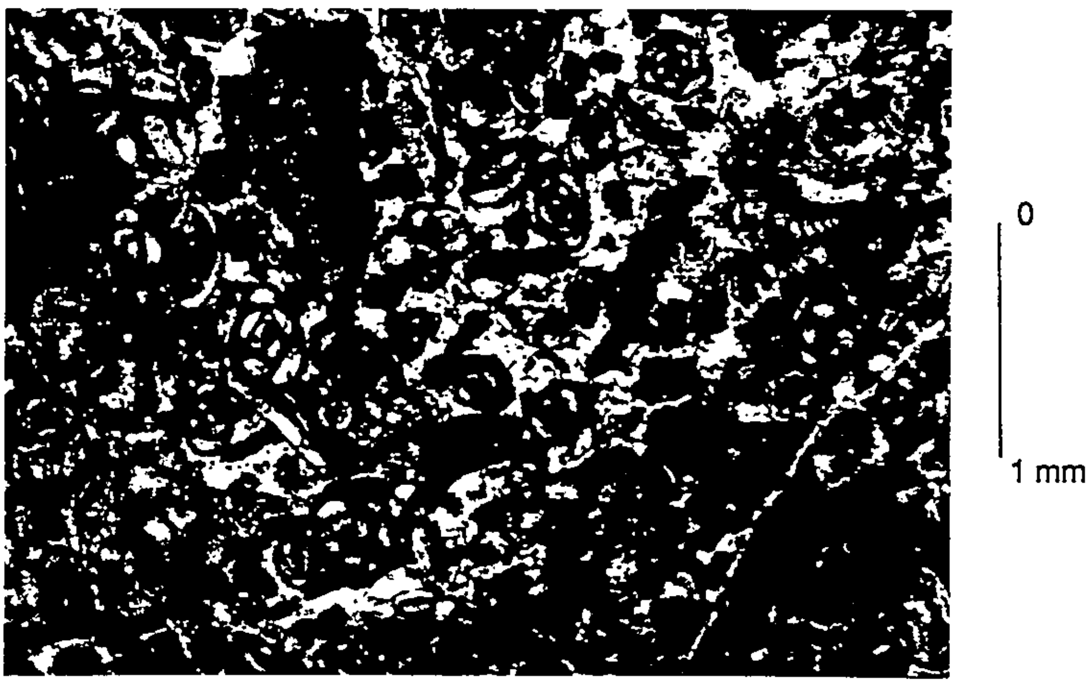


Fig. 21. Miliolid Packstone/Wackestone. Miliolid foraminifers with micritized walls and chambers filled with calcite. Mollusk chambers filled with internal sediments and equigranular calcite (geopetal structure). (VLA-722--14,334 ft; plane polarized).

0.125 to 0.5 mm, have micritic envelopes, and the chambers are filled with calcite (Fig. 21). Others skeletal fragments are textularid foraminifers and mollusk fragments.

The wackestone matrix is microcrystalline calcite (micrite), and the packstone matrix contains micrite and up to 20 percent peloids.

3.1.9 Skeletal Wackestone

This brown skeletal, burrowed, and stylolitize wackestone occurs in beds 3.3 to 5 m (10-15 ft) thick. The skeletal grains (echinoids and mollusks) represent 15 percent of the facies. The echinoid fragments are 0.5 mm in size, and the mollusk fragments, especially those of gastropods, are 0.75 mm in size. The other 80 percent of the rock is composed of micritic matrix (Fig. 22).

Up to 5 percent of dolomite crystals fill burrows and are scattered through the matrix.

A variety of this facies is silty-skeletal wackestone in which up to 10 percent siliciclastic silt occurs.

3.1.10 Pellet-Silty Wackestone

This light-brown limestone is characterized by 1-cm-thick interlaminations of pellets and siliciclastic silt. The beds are 5 to 6.2 m (15-20 ft) thick.

The pellets are well rounded and their size ranges between 0.05 and 0.15 mm. They represent 60 percent of the rock. The silt grains are

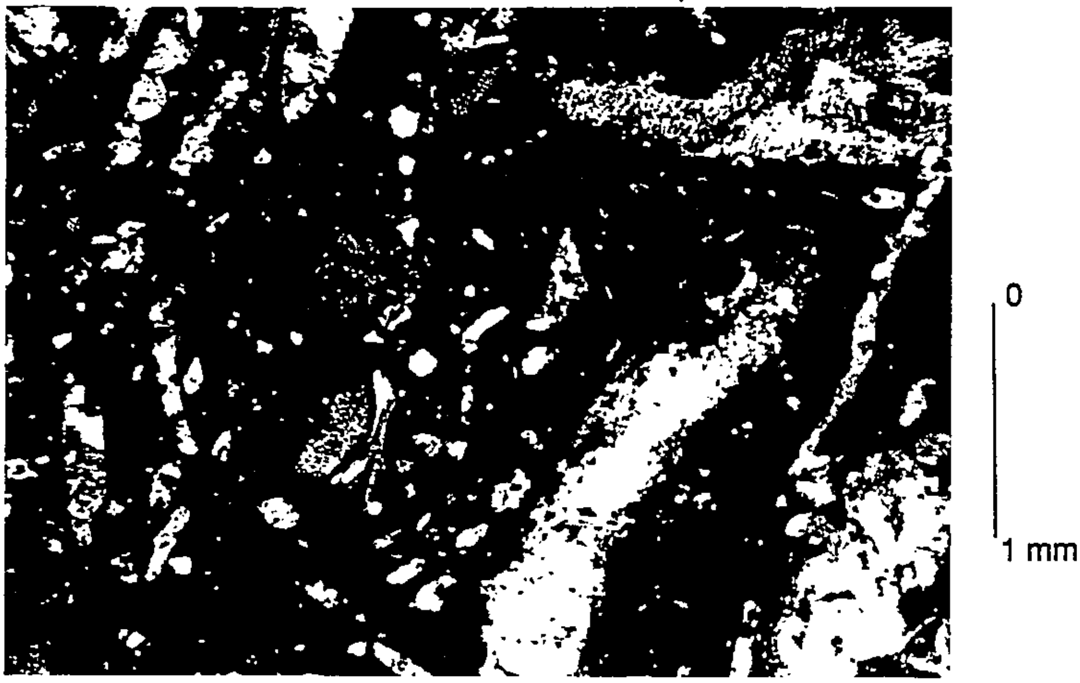


Fig. 22. Skeletal Wackestone. Echinoid and mollusk fragments scattered in a micritic matrix. (VLA-7978--13,898 ft; cross polarized light).

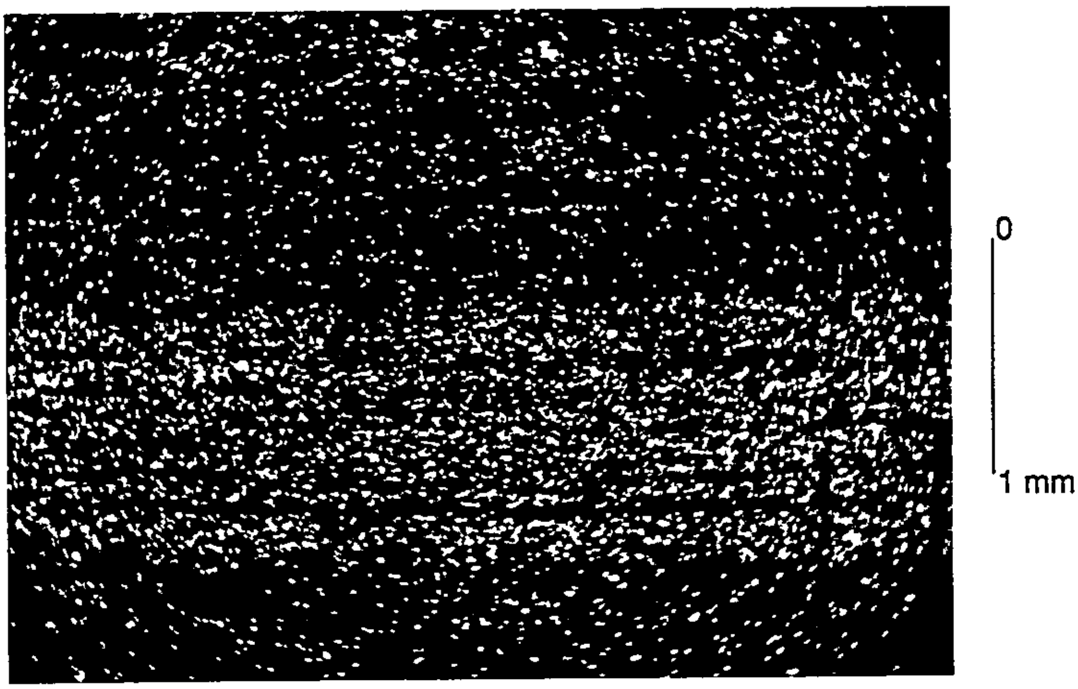


Fig. 23. Pellet-silty wackestone showing the fine interlamination that characterizes this facies. (VLB-704--14,156 ft plane polarized light).

angular to subangular 0.0625-0.025 mm in size and represent 40 percent of the facies (FIG. 23). Textularid foraminifers and fragments of echinoids and mollusks are present in small amounts. Laminations and submarine hardgrounds are characteristic of this facies.

3.1.11 Shaly Dolomite

The shaly dolomite is characterized by black color, 1.2 to 3.3 m (4-10 ft) beds. This facies contains dolomite crystals that range between 0.15 and 0.05 mm in size and make up 80 percent of the rock. The remaining 20 percent is argillaceous material. The finest dolomite crystals are generally scattered in a matrix rich in organic material (Fig. 24). Irregular lamination and stylolites are the most common sedimentary structures in this facies.

3.1.12 Dolomite

The dolomite is characterized by light-brown, 2 to 2.4 m (5-8-ft) thick beds. The crystals are clear and range from 0.025 to 0.25 mm in size. The intercrystal spaces are filled with clay material. Intercrystalline porosity has been observed in this facies (Fig. 25).

* Isotopic analysis for the dolomites are shown in Appendix D

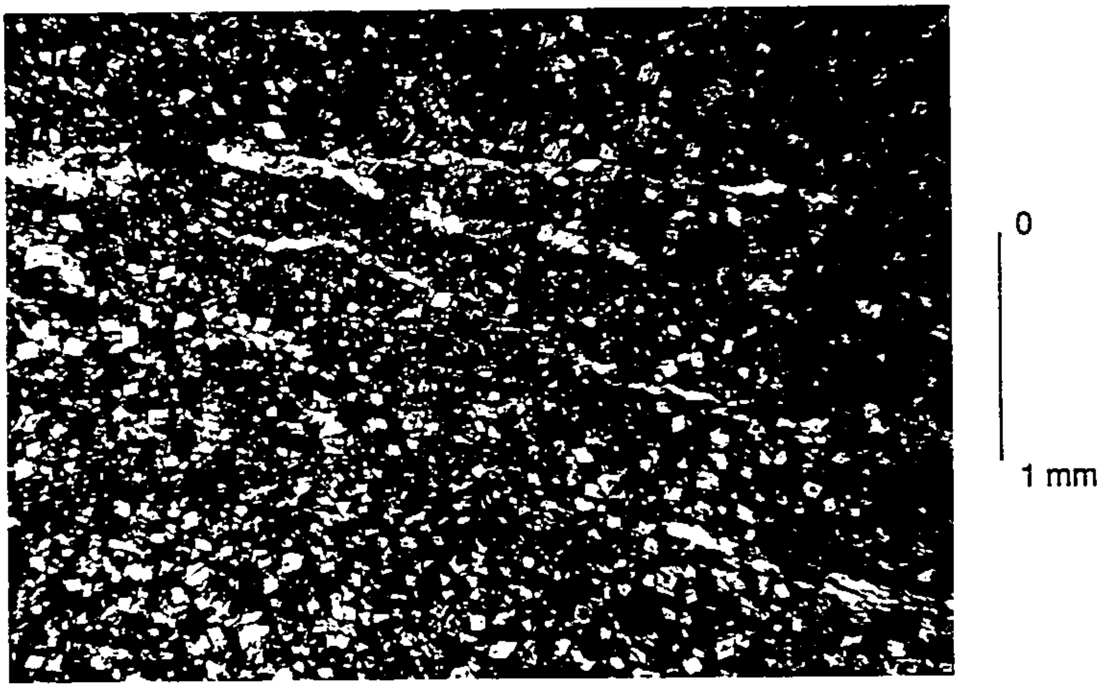


Fig. 24. Shaly Dolomite. The small dolomite crystals float in a laminated organic shaly matrix. (VLA-978--13,884 ft; cross polarized light).

Fig. 25. Dolomite . Dolomite rhombic crystals and intercrystalline porosity. The intercrystal spaces are fill with clay material. (VLA- 722--14,396 ft; plane polarized light).

3.2 DEPOSITIONAL STYLES OF THE COGOLLO GROUP

The facies of the Cogollo Group occur in cyclical pattern. The cycles are characterized by specific assemblages of facies with a repetitive vertical distribution and limited by specific contacts.

Hardgrounds are a very important type of contact (Fig. 26). The observed hargrounds are readily recognized by presence of 1) bored surfaces, commonly pre-cemented and 2) bored encrusting organisms attached to the surface of the bed. These signs show the existence of a hard floor that was lithified prior to the deposition of the overlying sediment and represents periods of non deposition (Bathurst, 1977). The lithification of the hardground surfaces observed in the cores is believed to take place under submarine conditions because 1) submarine cements are cut by borings and 2) truncation of early borings by later borings in which the early borings were cemented or filled with internal sediments before penetration of the later borings (Fig. 14). Thus cementation proceeded while boring organisms were active, indicating submarine cementation. This is the reason why the presence of hardgrounds is an excellent feature for the definition of the cycles.

Another type of contact that helped to establish the limits between cycles was sharp boundaries between muddier and grainier facies that represent abrupt changes in levels of energy, representing the initiation of new cycles.

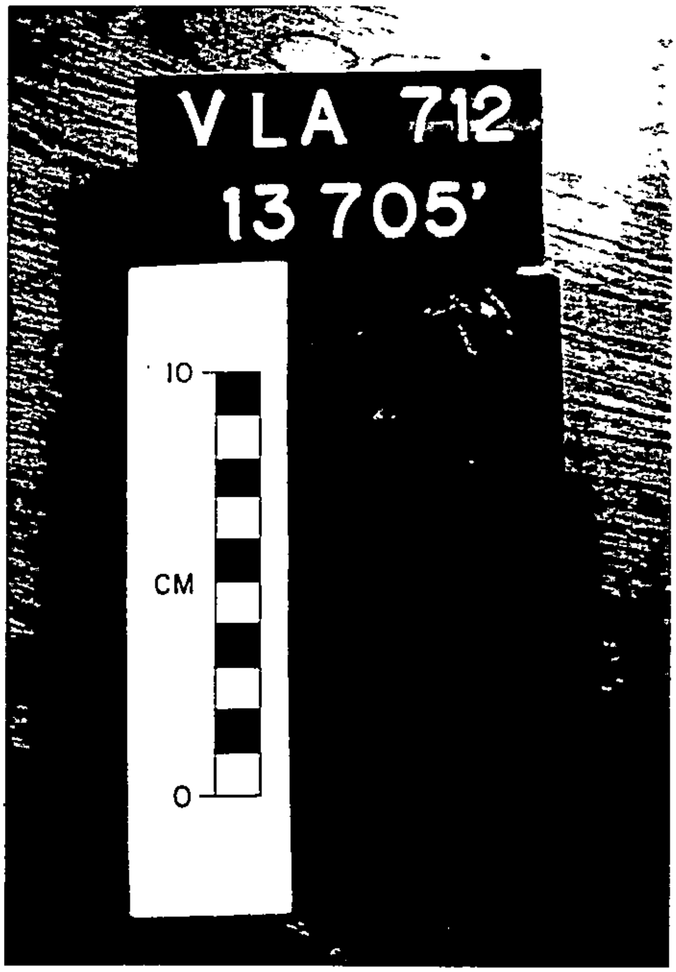


Fig.26. Submarine hardground slab. Observed at the top of an upward-fining cycle.

The 55 cycles defined in the Cogollo Group are divided into two types: upward-fining and upward-coarsening cycles. Each of the upward-fining cycles is characterized by a grainier carbonate facies at the bottom grading to a muddy carbonate facies at the top. An opposite trend characterizes the upward-coarsening cycles (Fig. 27) (Appendices A, and B). Hardgrounds were observed frequently in the upper part of the muddier carbonate facies at the top of the upward-finning cycles (Fig. 26). However, they have also been observed at the top of oolite grainstones in the upper-coarsening cycles (Fig. 14).

The defined cycles, upward-fining and upward-coarsening, represent upward-deeping and upward-shallowing depositional styles, respectively.

3.2.1 Upward-Fining Cycles

The upward-fining cycles represent 80 percent (approximated 230 m total thickness) of the Cogollo Group, and a total of 42 cycles were identified (Fig. 27). Four different types of upward-fining cycles have been recognized in the section, based on various types of grainstone to packstone facies at the bottom grading to various types of wackestone to mudstone facies at the top (Fig. 28).

Cycle A.- Cycle A consists of oyster packstone at the bottom and shaly dolomite or dolomite at the top. A variation of this cycle, named A', differs from the A cycle in that mudstone or skeletal wackestone are present at the top. The average thickness of this cycle is 3.3 m (10 ft).

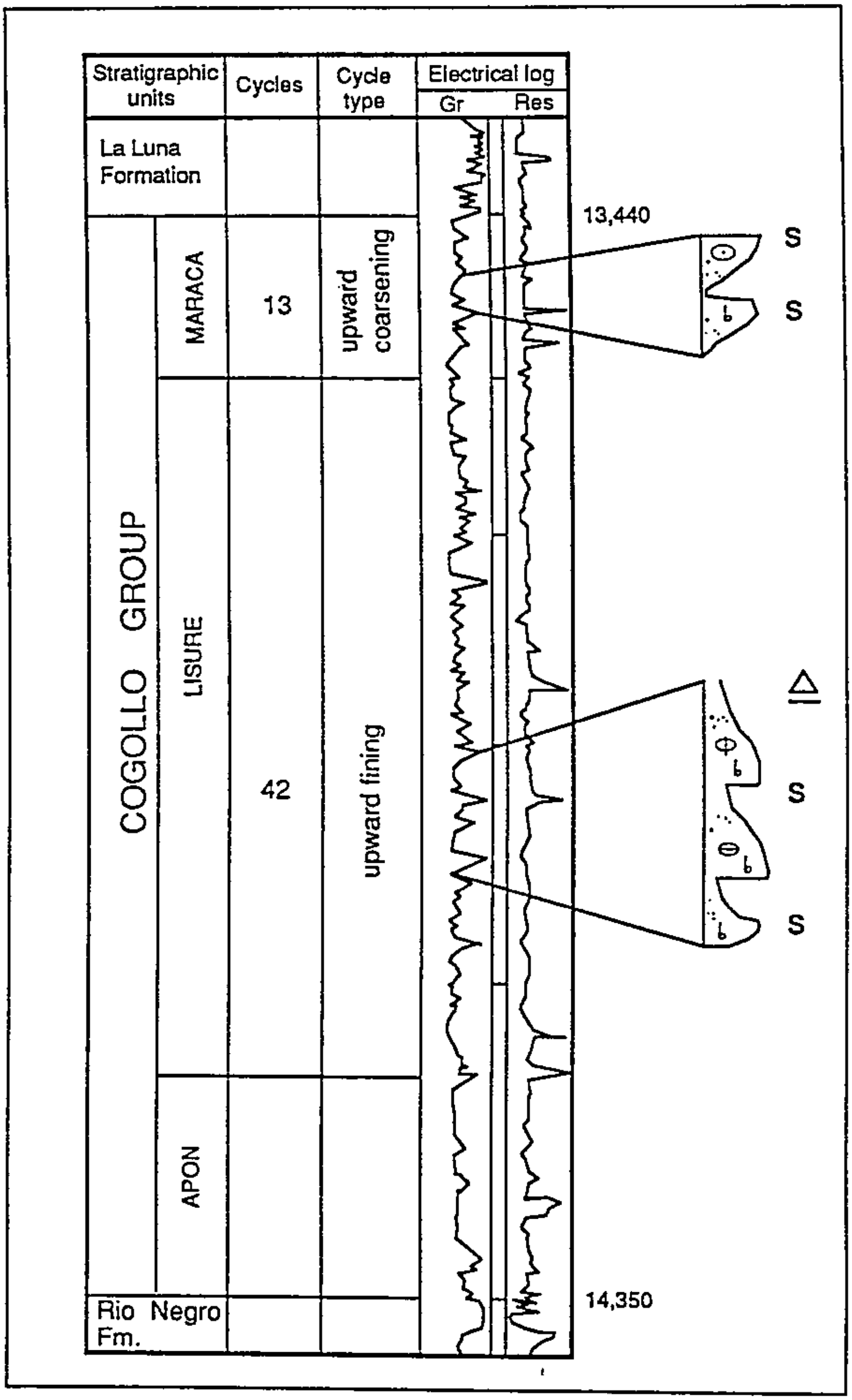


Fig. 27.- Distribution of the upward-fining and upward- coarsening cycles defined in the Cogollo Group. For symbols see Figure 28.

Cycle B.- *Orbitolina* grainstone occurs at the bottom of the Cycle B, followed transitionally by miliolid wackestone. This cycle presents an average thickness of 5 m (15 ft), although cycle 23 is 15 m (50 ft) thick.

Cycle C.- Cycle C is characterized by a skeletal-pellet grainstone facies at the bottom grading upward into laminated silty-pellet wackestone facies at the top. Submarine hardgrounds are common at the top (Fig. 26). The average thickness of the cycle is 8 m (25 ft).

Cycle D.- Cycle D is composed of mollusk-echinoid grainstone at the bottom grading upward into skeletal-intraclast grainstone and then oncolite packstone and skeletal wackestone. The intraclasts are composed of skeletal-micritic clasts. The average thickness of this cycle is 8 m (25 ft).

3.2.2 Upward-Coarsening Cycles

The upper 20 percent of the Cogollo Group consists of 13 upward-coarsening cycles. The average total thickness is 37m (120 ft) (Fig. 27).

Three different kinds of cycles have been distinguished. Each cycle has a specific facies assemblage and is always characterized by wackestone at the bottom, grading upward into grainstone (Fig.29).

Cycle E.- Cycle E consists of skeletal wackestone at the bottom that grades upward into oolite grainstone. The average thickness of this cycle is 3.3 m (10 ft).

Cycle F.- Cycle F consists of siliciclastic-skeletal wackestone at the bottom that grades up into an oncolite packstone, followed at the top by

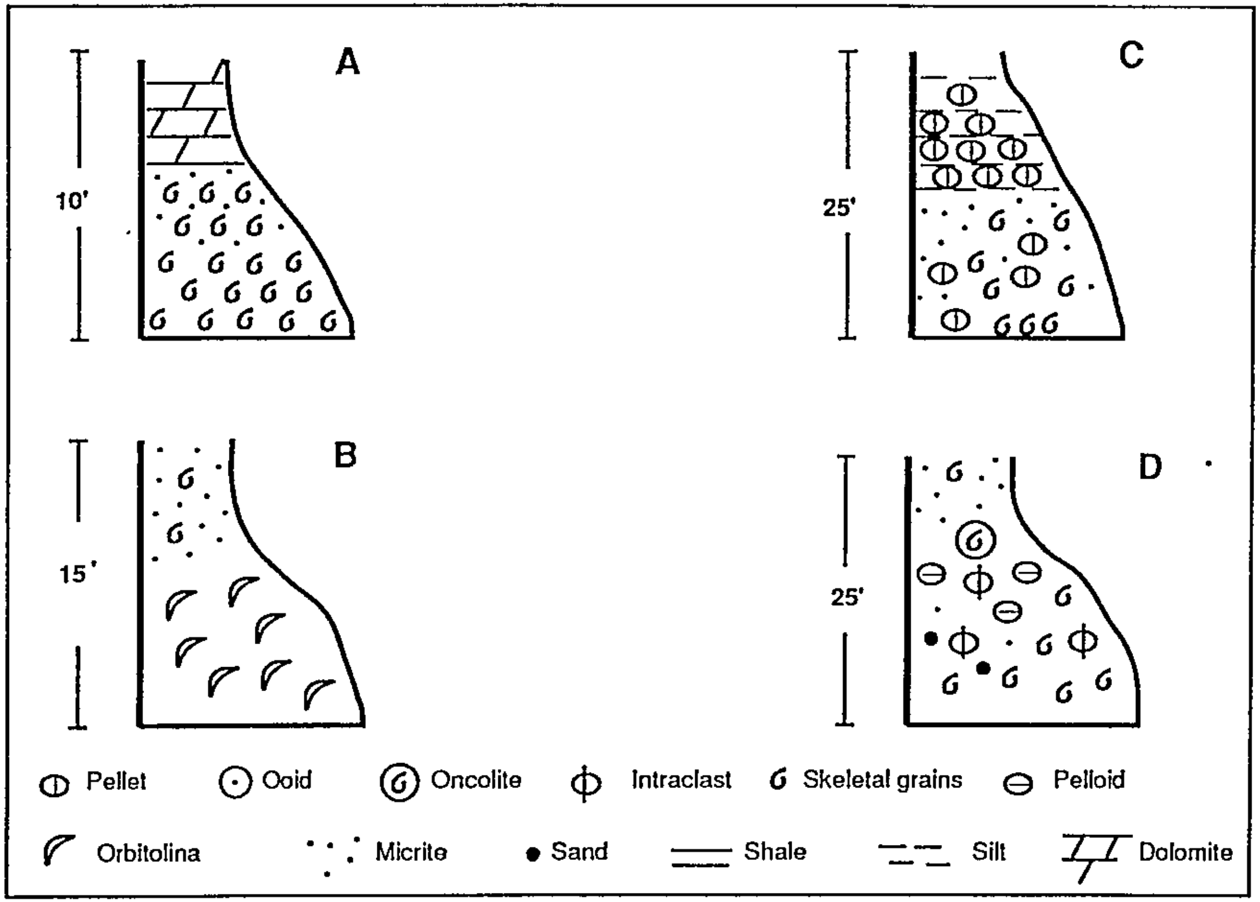


Fig. 28.- Types of upward-fining cycles defined in the Cogollo Group.

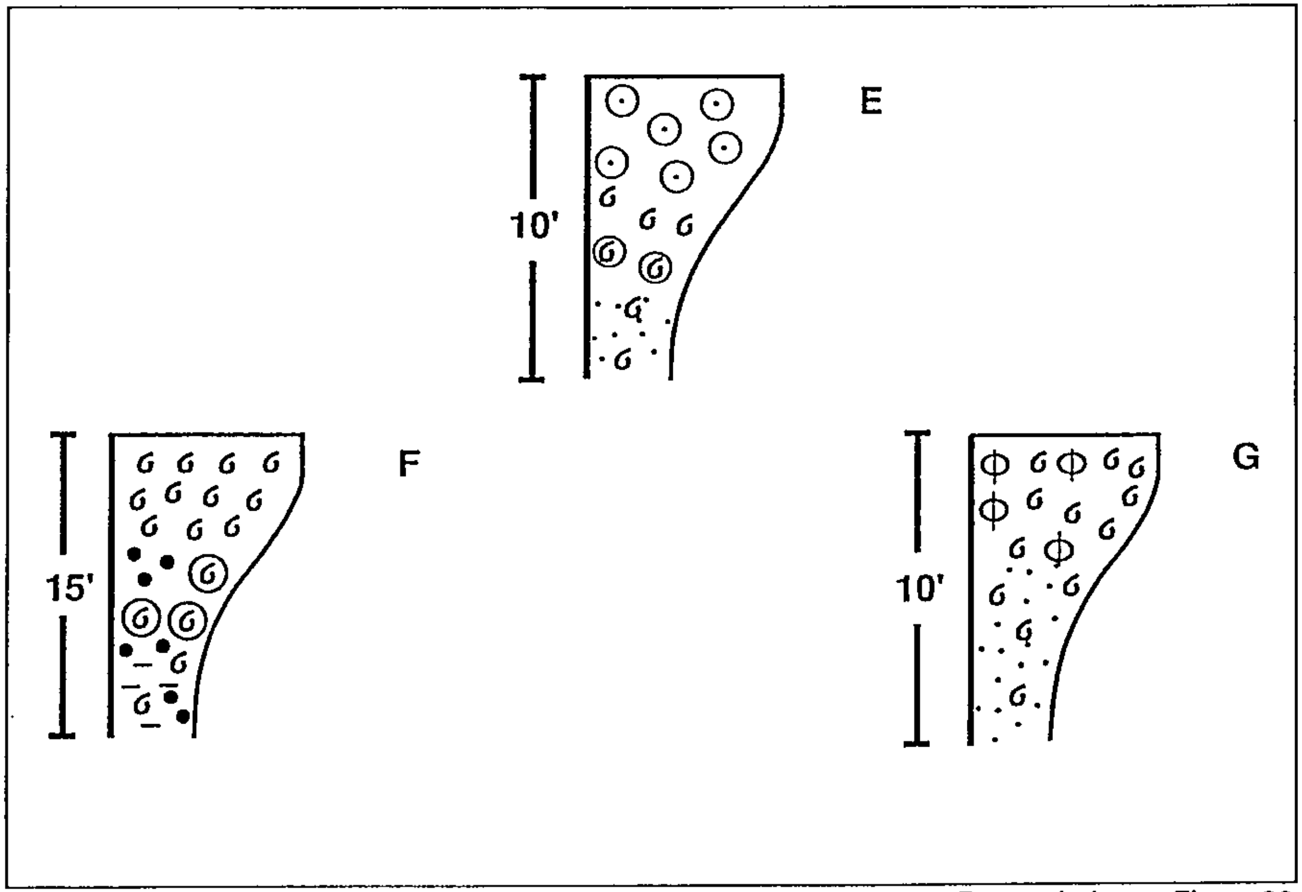


Fig. 29.- Types of upward-coarsening cycles defined in the Cogollo Group. For symbols see Figure 28.

skeletal grainstone (arenaceous-foraminifer, red-algae grainstone and mollusk grainstone). The average thickness of this cycle is 5 m (15 ft).

Cycle G.- Cycle G is characterized by skeletal wackestone at the bottom that grades upward into skeletal packstone in the middle part and skeletal-intraclast grainstone at the top. The intraclasts of the grainstone consist of ooid-grapestone (Fig. 16) and peloid grains. The cycles have an average thickness of 3.3 (10 ft).

3.3 VERTICAL AND LATERAL CYCLE DISTRIBUTION.

The defined cycles, upward-coarsening and upward-fining, represent two depositional styles. These styles of deposition have individual and specific patterns of vertical and lateral distribution.

The upward-fining cycles occur in a vertical pattern. The A and B cycles are restricted to the bottom third part of the section; the C and D cycles generally alternate, the D cycles following the C cycles (Fig. 30). A pattern to the occurrence of the various types of upward-coarsening cycles has not been determined (Fig. 31).

Laterally, the distance between wells makes it difficult to establish a detailed lateral distribution of individual cycles. Nevertheless, groups of upward-fining cycles are typically continuous and correlative (Fig. 32) but individually they may change laterally, e.g. cycle # 25 in VLA-978 and VLA-712 is a C cycle, while in VLA-711 it is a D cycle (Appendix B). The

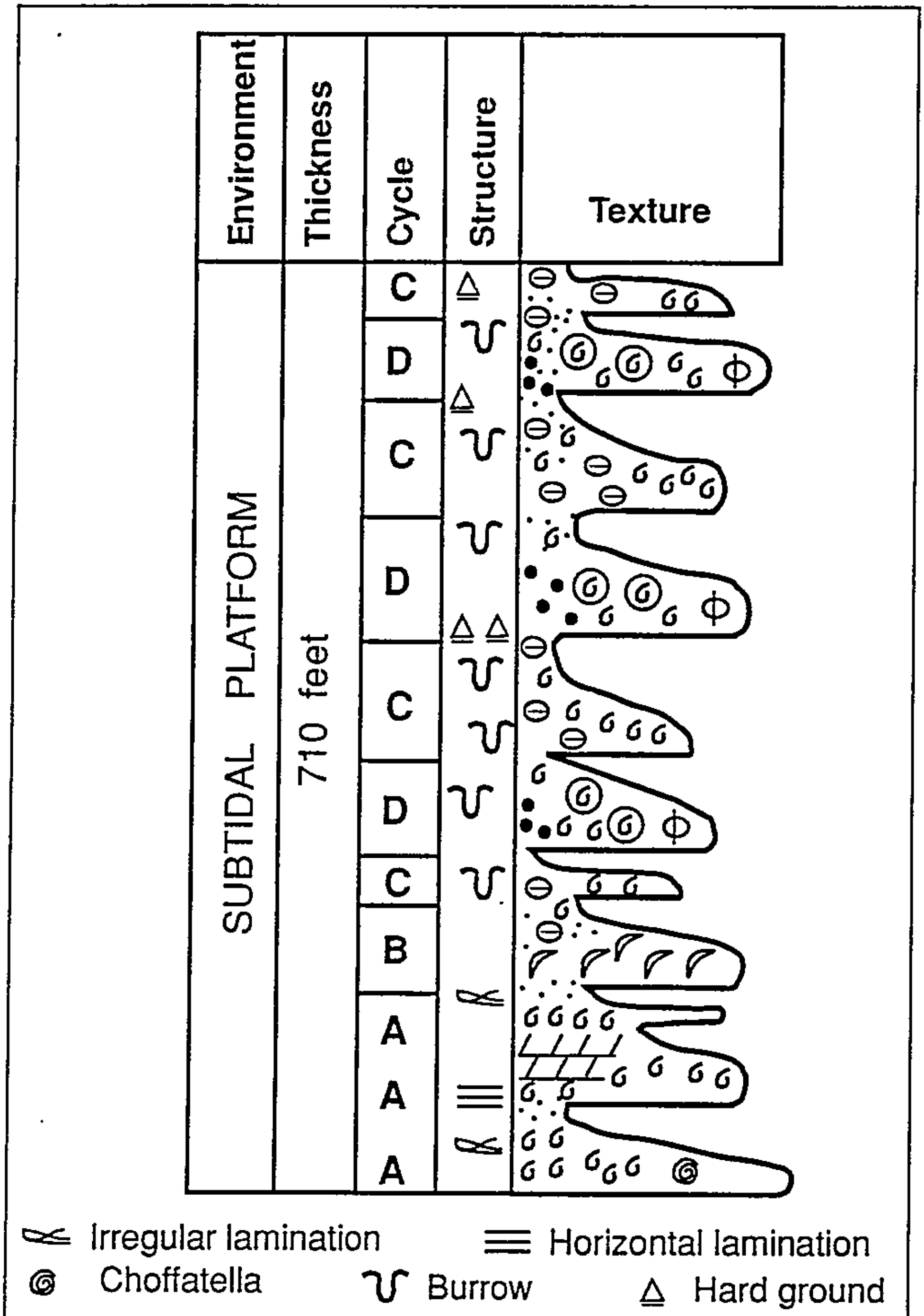


Fig. 30.- Schematic vertical distribution of upward-fining cycles. A general pattern is observed: A-B cycles are limited to the lower third of the section, and C-D cycles alternate in the upper part. For texture symbols see Figure 28.

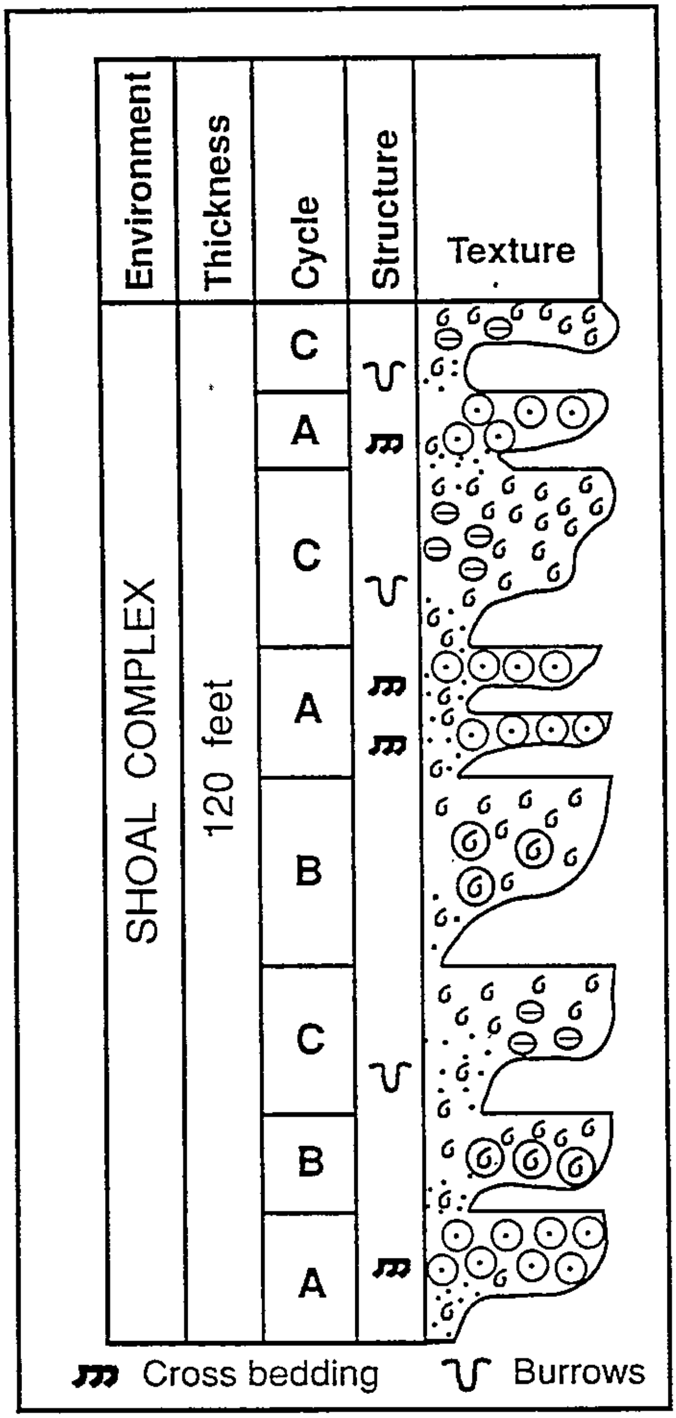


Fig. 31.- Schematic vertical distribution of upward-coarsening cycles. The cycles do not show a recognizable pattern. For texture symbols see Figure 28.

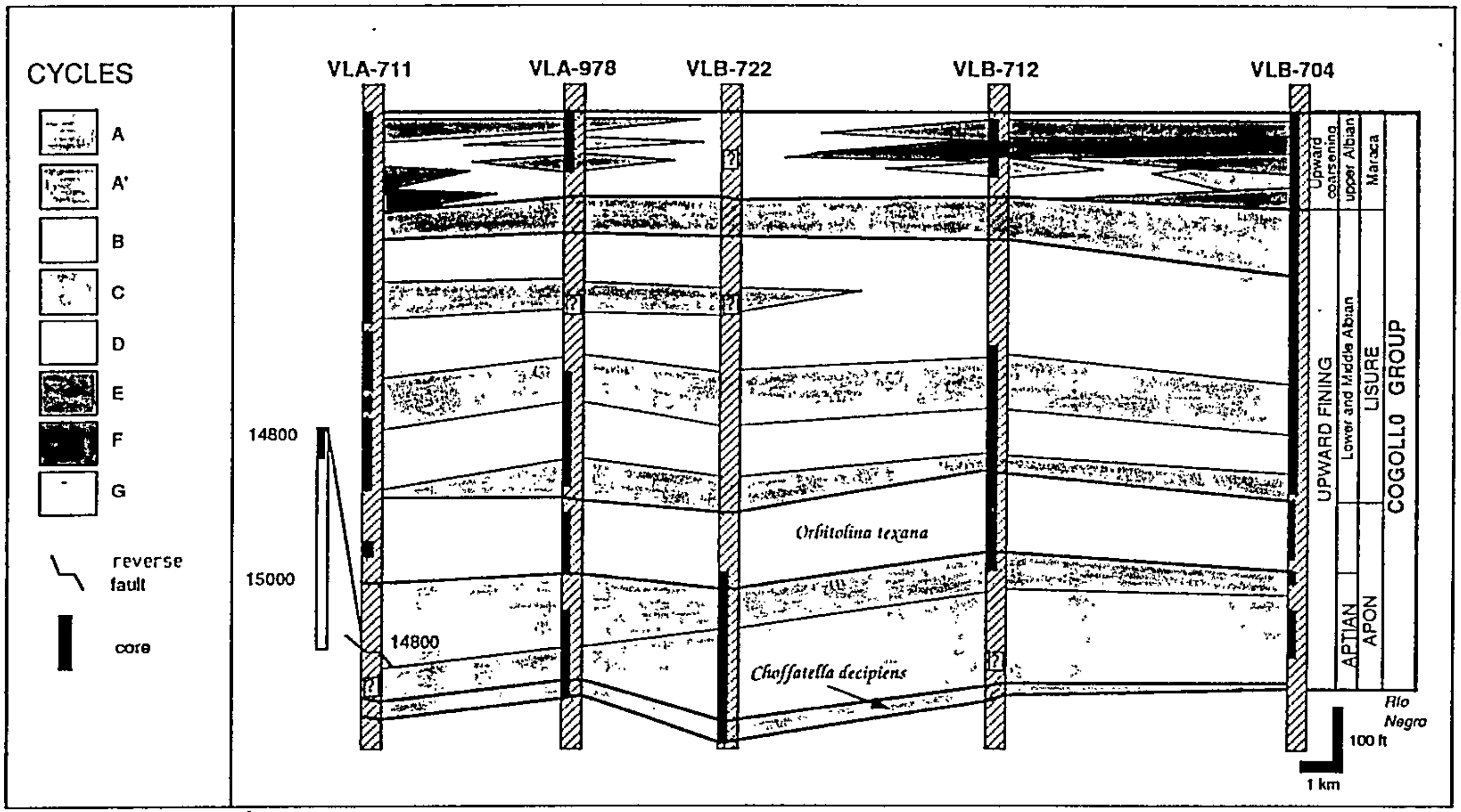


Fig. 32.- Schematic lateral and vertical distribution of the Cogollo Group cycles. The upward-fining cycles, which represent the Apon and Lisure Formation are laterally more continuous than the upward-coarsening cycles, which represent the Maraca Formation.

upward-coarsening cycles, on the other hand, grouped or even individually are more restricted laterally. The lateral distribution to the cycles is a direct response of the depositional environment in which these cycles were deposited

3.4 DEPOSITIONAL ENVIRONMENTS

The depositional environments were interpreted from the characteristics of the facies (fabric, texture, fauna, sedimentary structures) and the relationship to bounding facies. The development of the depositional model for this study was derived principally from vertical succession of these facies. The great distances between cores made establishment of detailed lateral distribution of the individual cycles difficult.

The carbonates of the Cogollo Group were deposited in shallow water. The upward-fining cycles resulted from deposition under subtidal dominantly low-energy conditions; the sediments are mud-dominated with the grainier base of cycles representing sand waves deposited in slightly high energy. The overlying upward-coarsening cycles represent open-water, high-energy deposits that accumulated as broad subtidal to intertidal shoal complexes.

3.4.1 Subtidal-Platform , Upward-Fining Cycles.

The upward-fining cycles were deposited on a subtidal platform (Fig. 33); no supratidal or even intertidal deposits have been observed in this section of the Cogollo Group. Cycles A and B were deposited in normal-marine water in low- to moderate-energy environments.

Cycle A consists at the base of oyster-bank deposits that formed in water 2 to 5 m (5-15 ft) deep on a moderate-energy platform; upward in the cycles the facies change to shale, which had a source in the southern Merida Arch area. The burrowed facies that characterize the B cycle (orbitolinid grainstone/packstone and miliolid wackestone) were deposited in a broad, open-lagoon environment in similar water depth (Fig. 33)

The C and D cycles represent deposition of submarine sand belts, which were deposited in deeper water than cycles A and B; the water depth ranges between 5 and 15 m (15-50 ft).

Cycle D is characterized by coarser grained facies consisting of cross-bedded intraclast-skeletal grainstone and skeletal grainstone, and is interpreted to represent elongated ridges that are formed in relative high-energy environments. The muddier sediments rich in pellets and green algae (Halimeda) skeletal grains of the C cycle represent deposition in low-to moderate-energy inter-ridge zones more protected from current action (Fig. 33).

A modern example of this environment is the submarine sand belt in the strait between Isla Mujeres and the mainland of the Yucatan Peninsula (Ward, 1977; 1985). The grainer sediments in this strait are formed by tide and storm-induced currents and by normal waves and are redistributed by long-shore currents as "mobile" submarine belts. These submarine belts at Isla Mujeres are blankets of fine-to-medium sand, 0.8

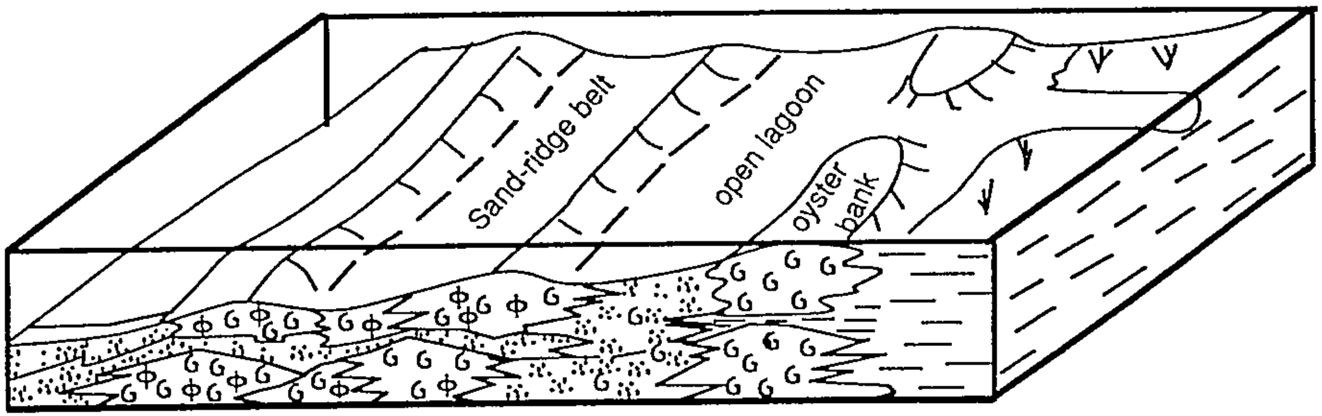


Fig. 33.- Block diagram showing interpreted subtidal platform environment of the upward-fining cycles. The A and B cycles were deposited in an open lagoon and oyster bank capped by siliciclastics. The C and D cycles were deposited in a sand-ridge belt environment. For symbols see Figure 28.

Fig. 34 Submarine sand belt in the strait between Isla Mujeres and the mainland of Yucatan Peninsula. Light colored bands (A) represent a sand-ridge, high-energy environment and the dark bands (B) represent the inter-ridge zone of lower energy. Aerial photograph from Halley and others (1983).

to 8 km wide and at least 45 km long. The alternating light-colored bands (Fig. 34) indicate active transport of sand (sand ridges, Cycle D). The dark bands are quiet-water flats stabilized by algae, and they are not active transport routes (Ward, 1977, 1985), (inter-ridge deposit, Cycle C).

3.4.2 Shoal-Complex , Upward-Coarsening Cycles

The upward-coarsening cycles represent a depositional style that was developed in a shallow-water, high-energy environment. Each individual cycle represents an upward-shallowing trend from subtidal skeletal wackestone to intertidal ooid and skeletal grainstones. They represent shoal-complex deposits formed on a very-shallow water platform (0-5 m) (Fig. 35). The active shoal bars are represented by cycles E and F. Cycle G, characterized by ooid grapestone and peloids, represents deposits of transitional areas between the agitated oolite active bars and a protected mud environment. Tucker and Wright (1990), suggested that the energy levels in this area were sufficient to remove mud and silt but not sand-sized particles. These cycle G sediments were deposited on a stabilized area, back of the shoal bars.

In the study area, not enough data are available to interpret the dimension and orientation of these bars. Nevertheless, Bartok and others (1981) show a paleogeographic setting for the uppermost part of the Cogollo Group, where the bars trend northwest (Fig. 36).

The dimension of this shoal-complex could be estimated based on modern analogs in the Bahamas. The Cat Cay ooid belt is up to 2 km wide and extends along the shelf margin for nearly 70 km (Purdy, 1961; Ball,1967). The Lily Bank area (Hine, 1977) is from 2 to 4 km wide and extends along the northern margin for 25 km. The Tongue of the Ocean ooid bar belt (Purdy, 1961) is 20 to 25 km wide and extends for 100 km in length; individual bars are 0.5 to 1 km wide and 8 km long. The Frazers Hog Cay ooid bar area is 0.5 km wide and 4 km long. The Joulters Cays ooid shoal sand flat covers 400 sq km in area, and the mobile fringe, intertidal portion is 1 to 2 km wide and 25 km long (Harris, 1979 and 1984). The active bars are approximately 0.9 km wide and 1.6 km long (Fig. 37) (D.G Bebout, personal communication). Using the dimensions of modern bars and established core correlation in which the oolite cycles (cycles E) have a restricted lateral distribution (Fig. 23). One could speculate that the dimensions of the active bars in the Cogollo Group may range between 0.5 km and 1 km in width and 1 km to 5 km in length, similar to those in the Frazers Hog Cay and the Joulters Cays (Fig. 37).

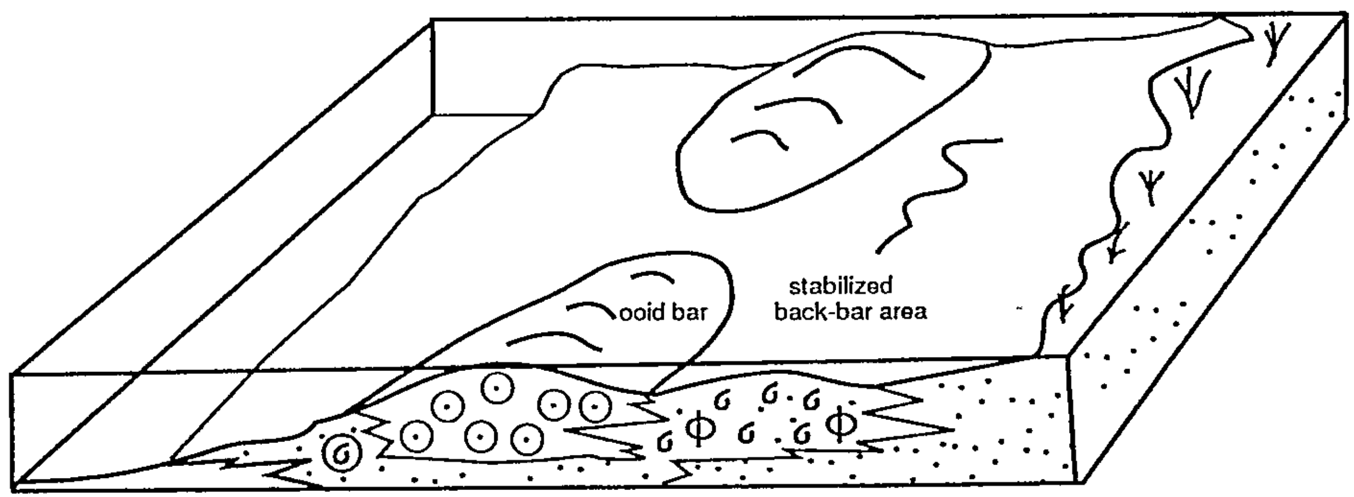


Fig. 35.- Block diagram showing the interpreted shoal-complex depositional environment of the upward-coarsening cycles. For symbols see Figure 28.

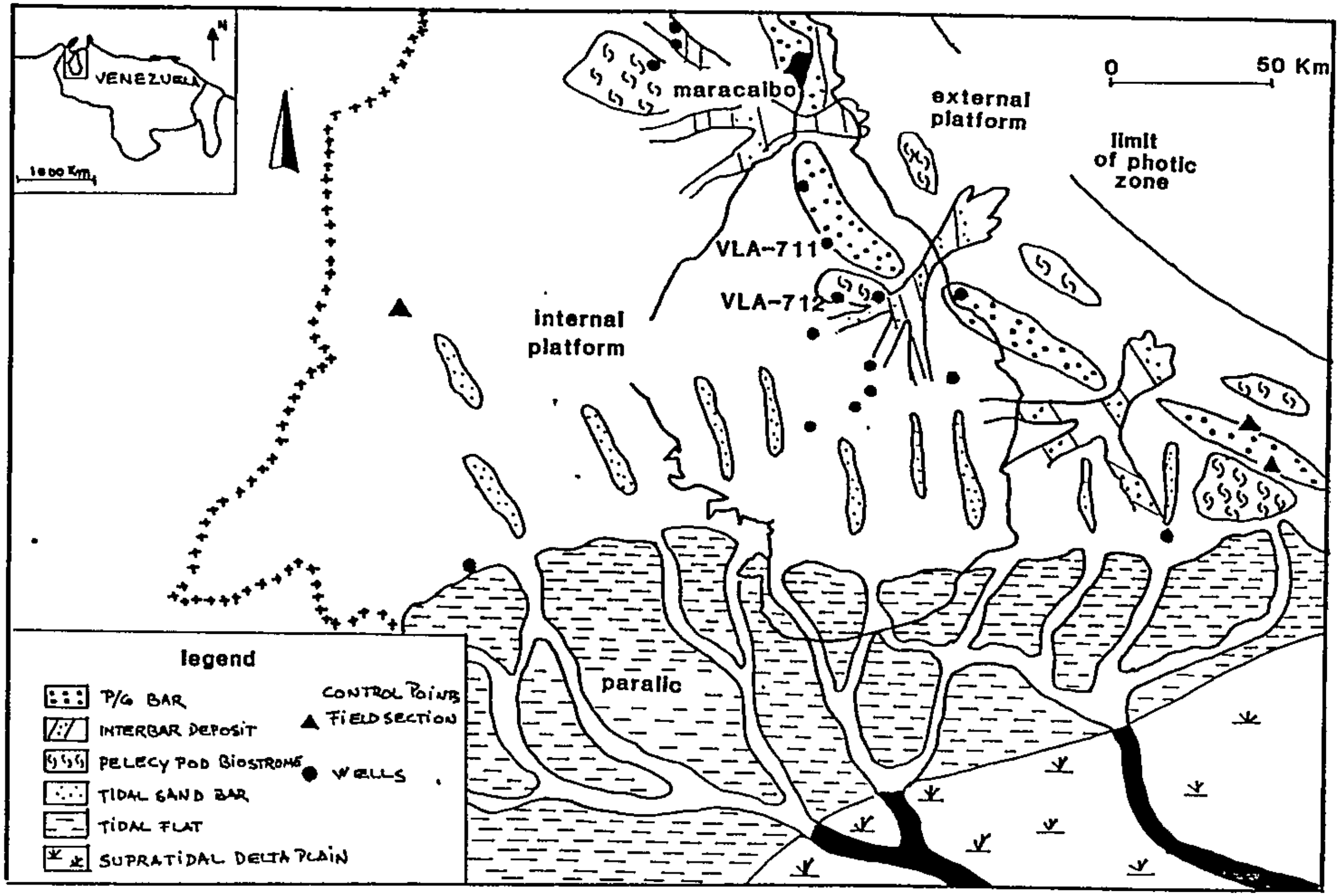


Fig. 36. Paleogeographic setting for uppermost Cogollo Group indicating principal environments of deposition and sediments associations during Late Albian. The bars are shown trending in a northwest direction (Bartok and others, 1981, Fig.7)

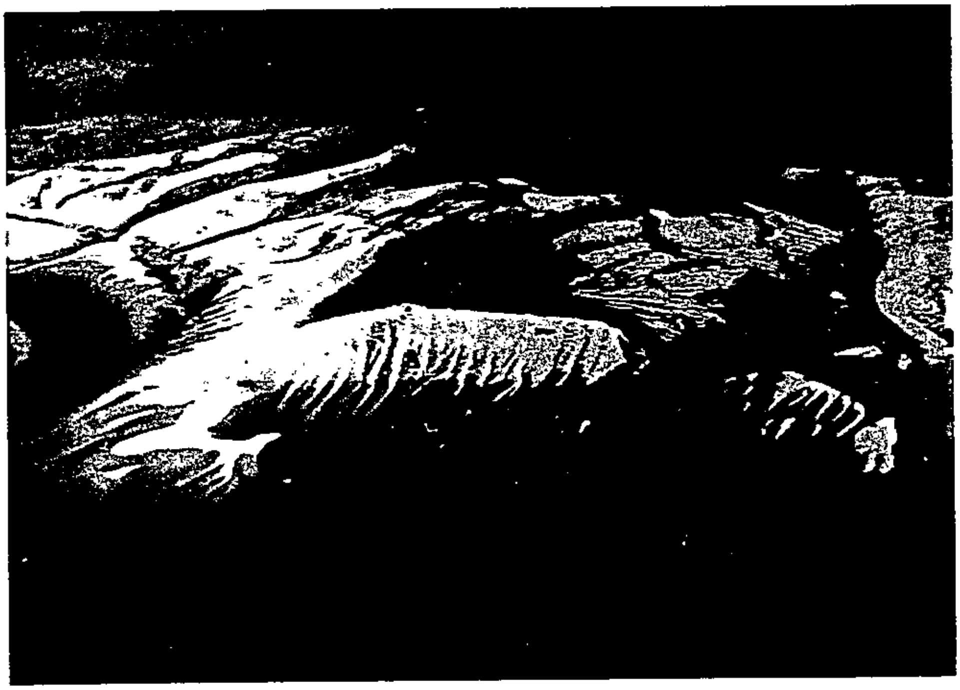


Fig. 37. Joulters Cays, Bahamas. Ooid active bar (A) and stabilized area (B).
(Photo courtesy of D.G Bebout).

4. LOCAL STRATIGRAPHY

In the Cogollo Group three good stratigraphic markers have been recognized; two of these markers are biostratigraphic; the *Choffatella decipiens* and the *Orbitolina texana* horizons.(Figs. 38 and 18, respectively). The other is a lithological marker at the contact between the upward-coarsening and upward- fining cycles.

The formations that constitute the Cogollo Group in the area of this study are subdivided using these biostratigraphic and lithological markers (Fig. 32 and Appendix C). From bottom to top, the Apon and Lisure Formations are constituted by upward-fining cycles, and the Maraca Formation, by upward-coarsening cycles.

The Apon Formation is restricted to the A and B cycles (Fig. 32), the bottom of the formation is defined by the base of a limestone located just above the sandstones of the Rio Negro Formation, which contains *Choffatella decipiens*; the top has been placed at the upper limit of *Orbitolina texana* zone.

The Lisure Formation is represented by C and D cycles (Fig. 32), included between the top of the *Orbitolina* zone (bottom) and the boundary between upward-fining and upper-coarsening cycles (top).

The Maraca Formation is represented by the upward-coarsening E, F, and G cycles, betwee the upward-fining cycles of the Lisure Formation below and the pelagic limestone of La Luna Formation above.

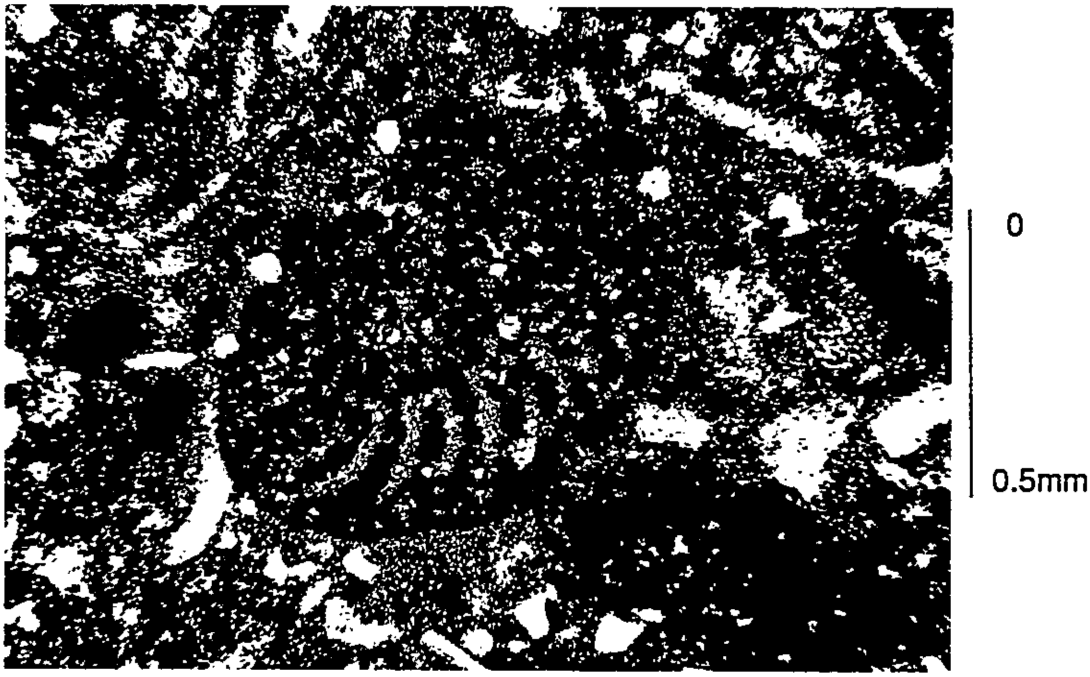


Fig. 38. Photomicrograph showing a longitudinal and transverse section of *Choffatella decipiens* . (VLA- 722--14,526 ft; plane polarized light).

There are some differences between the subdivision established in this study and the stratigraphic nomenclature of the region. In the stratigraphic nomenclature of the lake area in the Maracaibo Basin, the Apon Formation is subdivided in 3 Members (from bottom to top - Tibu, Guaimaros, and Piche members) based on lithostratigraphic characteristics. These members could not be recognized in the cores described in this study. The only possible correlation between the defined cycles and established members is that the A cycles (oyster packstone and shaly dolomite) could correspond to the Guaimaros Member defined as a shaly dolomite horizon. Being unable to define the members and having two biostratigraphic markers that help in defining better the Apon Formation, the biostratigraphic markers were used as boundaries of the Formation.

Another difference is a discrepancy between the log marker chosen by Maraven S.A to define the boundary between the Maraca and Lisure Formations and the lithological marker established in this study. The boundary between the upward-fining and upward-coarsening cycles as used in this study corresponds to a log marker that is approximately 9 m (30 ft) below the marker chosen by Maraven (Appendix C).

The markers (biostratigraphic and lithologic) that define the Apon, Lisure, and Maraca formations have been correlated by means of geophysical logs to other wells in the area and have been used in preparing an east-west regional cross section. The markers provide a good framework for correlation in the subsurface of the Maracaibo Basin

(Appendix C). This correlation should be used in future studies, because it is based on core and log correlation, and it is supported by both biostratigraphic and lithostratigraphic criteria.

4.1 VLA-711 REVERSE FAULT

Two repeated sections were observed in well VLA-711 that are the result of reverse faults.

The section from 14,460 to 14,790 ft (320 ft) is repeated from 14,790 to 15,110 ft (log depth). Another repeated 20 ft of section goes from 14,570 to 14,590 ft and from 14,590 to 14,610 (Appendix C).

The reverse faults have been cored discontinuously from 14,460 to 14,830 ft (core depth). The intervals from 14,460 to 14,488 ft and from 14,791 to 14,830 ft have been compared, and they correspond to the same rock section that has been repeated as a result of the reverse fault (Appendix B, VLA-711).

5. CONTROLS ON THE DEPOSITION OF THE COGOLLO GROUP

The primary factors that favor the deposition of most carbonate sediments are clear, warm, and shallow water (Wilson, 1975). Beside these factors, there are others that determine the nature of carbonate sedimentation: 1) geotectonic conditions, and 2) climate, and both together have a direct influence over the important sea-level variable (Tucker and Wright,1990; Scholle, 1989).

The geotectonic conditions determine the depositional setting and control the influx of siliciclastic material to the carbonate platform. There are five major depositional settings of carbonate sedimentation: shelf, ramp, epeiric platform, isolated platform, and drowned platform; each of which has a distinctive pattern of carbonate facies (Tucker and Wright, 1990). Siliciclastic influx, suspended clay in particular, can produce turbidity. Turbidity inhibits carbonate production by cutting down the amount of light reaching the sea floor and by affecting organisms feeding mechanisms; as a consequence, the growth of organisms is discouraged. Sand-sized siliciclastic particles do not produce this same problem for organisms. They are large and tend to settle more rapidly and do not interfere with carbonate production.

Climate, along with geotectonic conditions, is important in determining water-circulation patterns, temperature, salinity, nutrient supply, turbulence, storm-and tidal-current strengths, and wave activity. Climate is the major control over the type of sediments; rainfall and temperature are important to the distribution of carbonates and evaporites and to the amount of siliciclastic rocks deposited (Sarg, 1988).

Global sea-level position is a major factor in carbonate sedimentation. The sea-level position at different times is determined by ocean-basin volumes and ocean-water volumes, and both of them are controlled by geotectonic conditions and climate.

5.1 THE COGOLLO GROUP FISCHER PLOT.

Sea-level variation is one of the most important, if not the most important, of the controlling factors on carbonate deposition. The relative change of sea level creates the available space for accommodation of the sediments, which controls the depositional patterns and distribution of facies (Sarg, 1988).

In order to understand sea-level changes during the deposition of the Cogollo carbonate sequence, a Fischer plot was constructed to establish a sea-level curve based on the explanation given by Read and Goldhammer (1988. " the Fischer plots help to define relative sea-level curves if there is a long-term rise in sea level or an increase in subsidence, relatively thick cycles will develop as result of increase accommodation and water and sediment loading in excess of that due to linear subsidence. If there is a long-term fall, thin cycles will develop because the falling sea level (or decrease in subsidence rate) decreases the accommodation space expected from linear subsidence."

The Fischer plot of the Cogollo Group (Fig. 39) suggests relative fall and rise of the sea during the deposition of the upward-fining cycles and a fall during the deposition of the upward-coarsening cycles.

In the Aptian, the A and B upward-fining cycles, were deposited during a relative fall of the sea. During this sea-level fall, more land surface was exposed and there was a large influx of siliciclastic sediments into the Maracaibo Basin. The siliciclastic influx resulted in reduction in carbonate productivity and generated thin carbonate cycles.

During the early Albian and the middle Albian, a relative rise in the sea-level resulted in deposition of cycles C and D. The relative rise of sea level during the deposition of the C and D cycles was episodic: periods of deposition alternated with periods of slow or no deposition. The periods of slow or no deposition are defined by the presence of hardgrounds. The hardgrounds were formed immediately before the next rise of sea-level, representing what have been considered third (1-10 m.y.) (Vail and others, 1977) and fourth order cycles (0.1-1 my).

The upper Albian section, characterized by upward-coarsening cycles, was deposited during a relative sea-level fall and is represented by E, F, and G upward-shallowing cycles.

No supratidal deposits have been observed in the Cogollo Group sequence studied. For that reason, the Cogollo Fischer plot does not represent absolute sea-level rise or fall cycles, as it is also the case of the

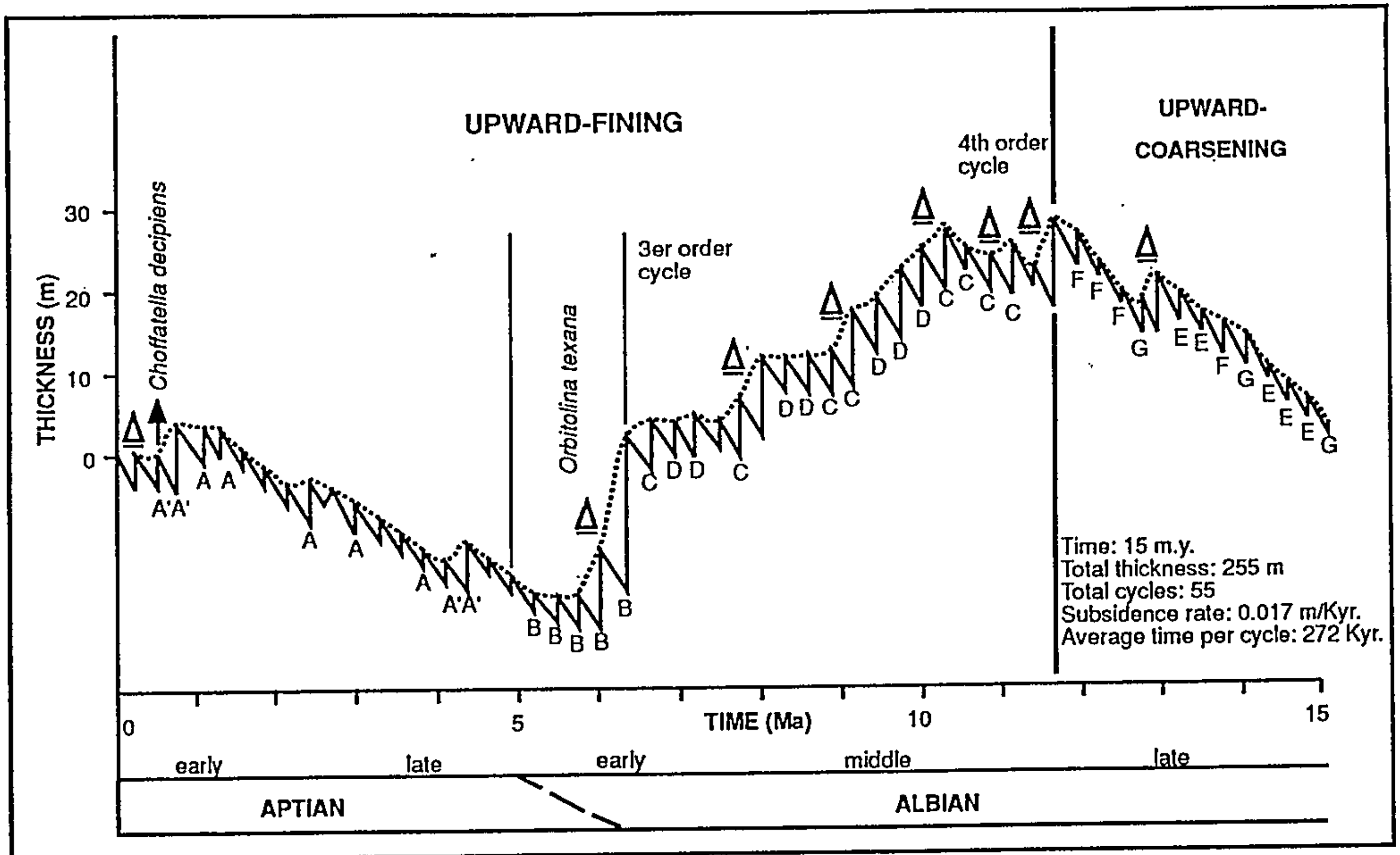


Fig. 39.- Cogollo Group Fisher Plot, Block I and II, Maracaibo Basin. The hardgrounds define third order cycles and fourth order cycle at the top of the upward-fining cycles.

global eustatic curve (Haq and others, 1987). Nevertheless, the plot does demonstrate relative sea-level change.

5.2 FACTORS.THAT CONTROLLED DEPOSITION OF THE COGOLLO GROUP

Two important factors controlled deposition of the carbonates of the Cogollo Group: sea-level changes and periodic influx of siliciclastics. These factors had a direct effect over the development of the shallow-water carbonate platform in which the Cogollo Group was deposited (Fig. 40).

During deposition of the upward-fining cycles (Aptian-lower and middle Albian) the Maracaibo Basin represented a drowned platform in an incipient stage. The water level, during the sea-level changes, did not reach depths beyond the photic zone, resulting in what Tucker and Wright (1990) call an incipient drowned platform because "the sea-level rise is not sufficient to terminate most benthic carbonate production." The estimated water depth for these deposit ranges between 2 and 15 m (5-50 ft).

The Aptian section was controlled by a relative fall of sea-level and periodic influxes of siliciclastics. As a result, upward-fining cycles developed. Siliciclastic shaly sediments cap subtidal carbonate deposits (Fig. 40 a).

The siliciclastics prograded over the carbonate deposits as a consequence of sea-level fall. The shaly material stresses the carbonate biological community inhibiting the growth of the carbonates, although sea level was falling, suggesting an apparent drowned platform. Thus, drowned platform result from environmental stress (Tucker and Wright, 1990). Such is the case in the Aptian section of the Cogollo Group.

The lower and middle Albian upward-fining cycles formed in response of episodic rise of sea level.

The individual upward-fining cycles represent upward-deepening cycles, with deep-water carbonate facies over shallow-water facies. No supratidal or even intertidal sediments have been observed in the cycles.

The sea-level rise created a retrogradational drowning episode over the platform (Fig. 40 b). The drowning periods are defined by the presence of submarine hardgrounds which are observed at the top of the deepest subtidal facies and correspond with the third- and fourth- order cycles observed in the Fischer plot.

After this period of sea-level rise, during the late Albian, represented by the uppermost part of the Cogollo group, shallow water (0-5 m) prevailed as a consequence of relative sea-level fall. During this time, upward-coarsening cycles were deposited in a high-energy progradational carbonate platform in which normal upward-shallowing cycles were formed (Fig. 40 c).

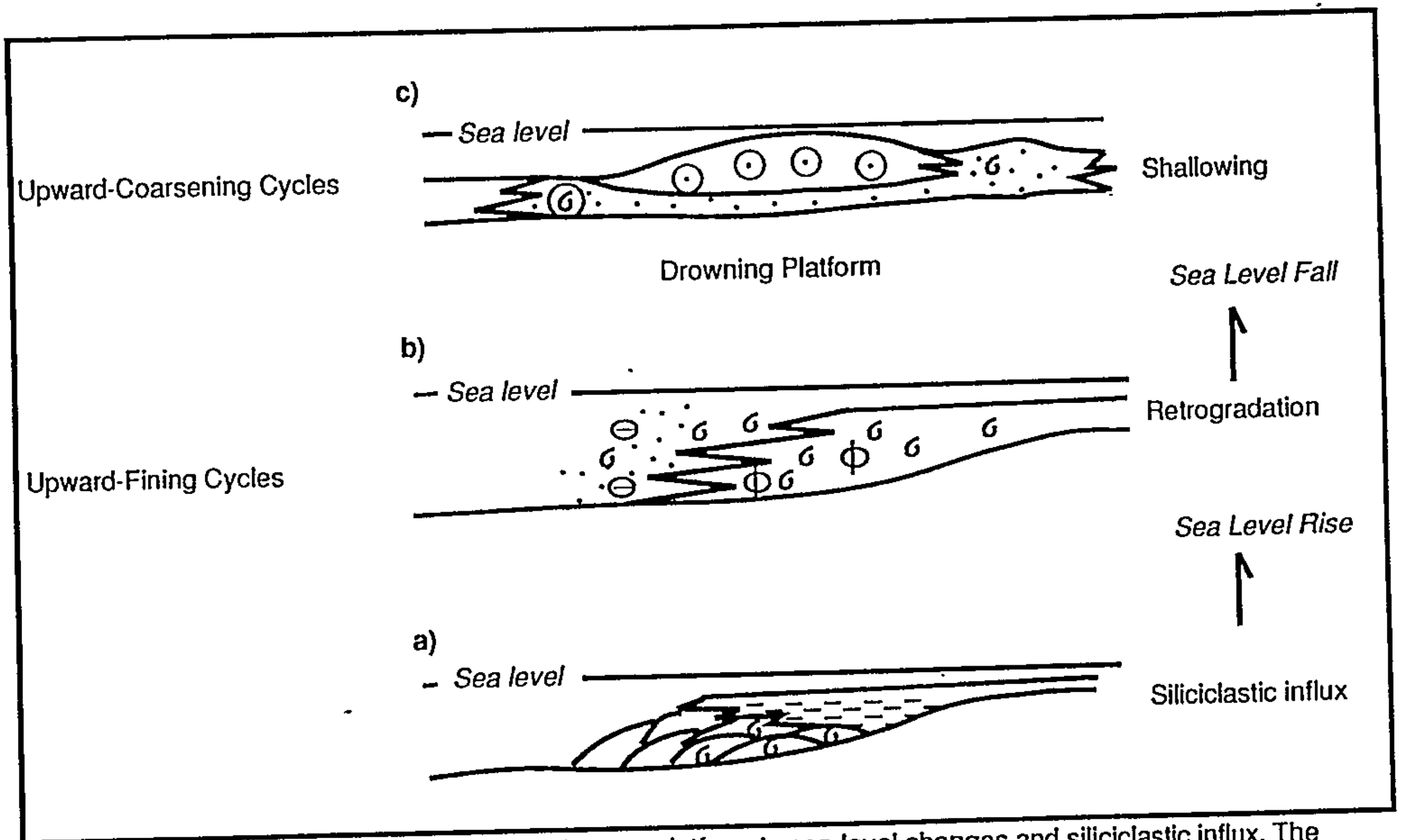


Fig. 40.- Response of the Cogollo Group carbonate platform to sea-level changes and siliciclastic influx. The upward-fining cycles were deposited over a drowning platform as a consequence of: a) the stress caused by the siliciclastics, and b) sea-level rise. The upward-coarsening cycles represent upward-shallowing in a progradational platform. For symbols see Figure 28.

5.3 COMPARATIVE CHART: COGOLLO SEA-LEVEL CURVE VERSUS GLOBAL EUSTATIC SEA LEVEL CURVE.

Sea-level changes are a consequence of eustasy and/or tectonic subsidence. In order to approach the effect that eustasy has on the deposition of the Cogollo Group, a comparative chart between the Cogollo Group sea-level curve (Fischer plot) and the global sea-level variations (Haq and others,1987) was prepared.(Fig. 41). This comparison reveals both similarities and differences between the curves.

The similarities are 1) there is a relative fall of the sea level at the Aptian-Albian boundary, 2) during the Albian a progressive relative sea-level rise is observed in both curves. The differences are that the two relative sea-level falls which are observed in the Cogollo Group sea-level curve during the Aptian and the late Albian, are not observed in the Global eustatic sea-level curve. The similarities and differences indicate that during the deposition of the Cogollo Group the sea-level changes were a consequence of the combination of eustasy and local differential subsidence.

Eustatic sea-level changes occur simultaneously worldwide. The cause of eustatic changes in sea level could be a consequence of: 1) changes in volume of sea water, due to melting and growth of ice sheets (Fairbridge, 1961: Donovan and Jones, 1979 in Gornitz and Lebedeff, 1987); and 2) changes in the volume of ocean basins as a consequence of seafloor spreading. Periods with rapid sea-floor spreading cause the

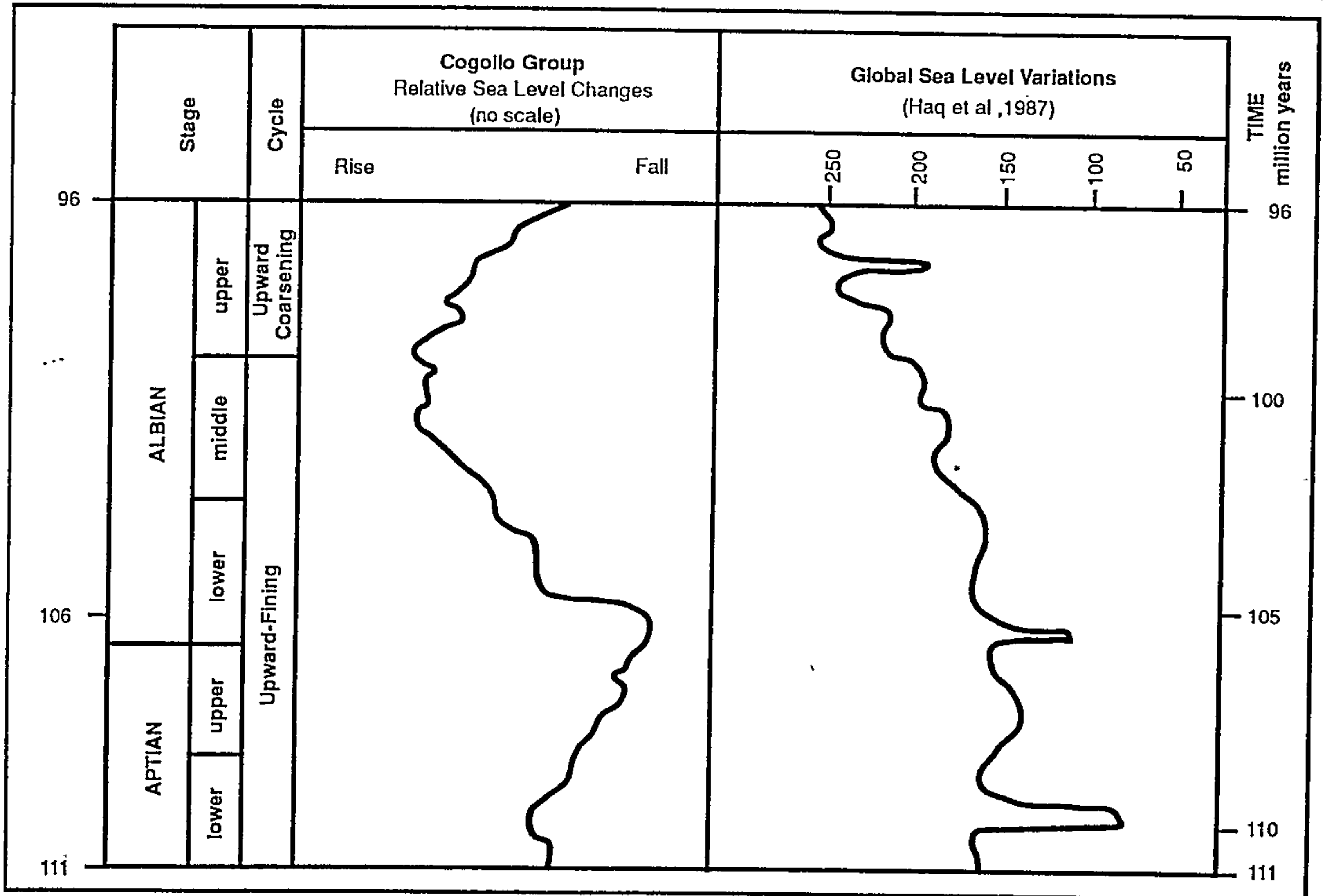


Fig. 41.- Comparative chart of the Cogollo Group sea-level curve (Fisher Plot) and Global Sea Level Variation (Haq and others, 1987).

volume of the ocean floor to expand and sea water will push farther into the continents, creating a transgression. If all seafloor spreading stopped, the sea floor would cool and contract, resulting in a regression (Bjorlykke,1989). Glacio-isostatic changes also affect the volume of the ocean basins due to adjustments of the earth's lithosphere to changes in ice and water loads (Clark and others,1978; Peltier, 1980, in Gornitz and Lebedeff, 1987).

The local differential subsidence, which is believed to be responsible for the differences observed in the Cogollo curve, is a direct response of the Arch of Merida. The Arch generated a greater stability at the southern part of the Maracaibo Basin. Major compaction and subsidence occurred on its flank and less on its crest, thus causing differential subsidence.

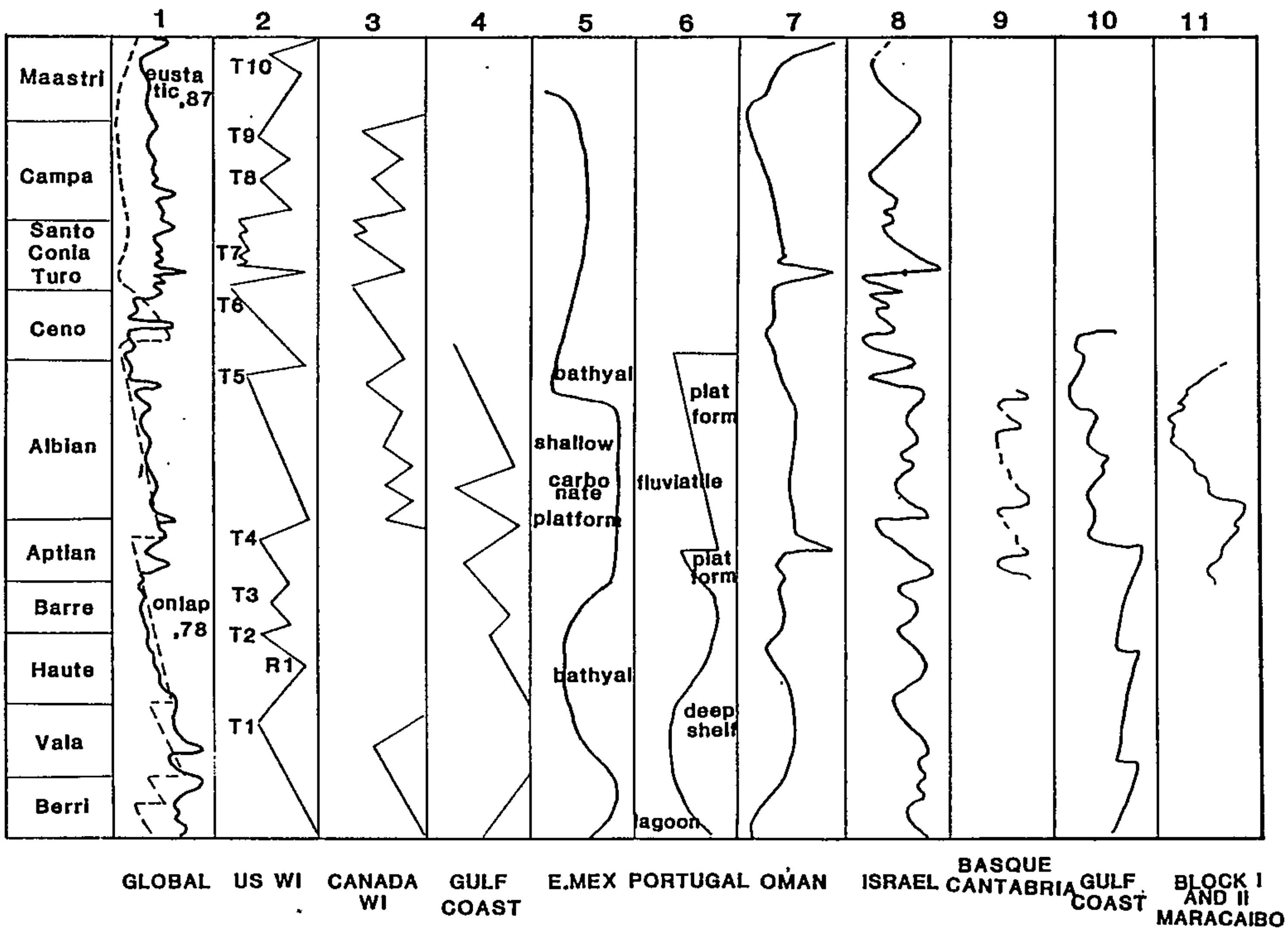
5.4 ANALYSIS OF CRETACEOUS SEA-LEVEL CURVES

Scott and others (1988) have compared the Cretaceous relative sea-level curves produced by several authors (Fig. 42), each using different criteria. Kauffman, (1977,1984) equated transgressive-regressive cycles with eustatic sea levels and periods of intense vulcanism in the western interior of United States (Fig. 42, column 2). The curves of Caldwell (1984) for the Canadian interior (Fig. 21, column 3) and McFarlan (1977) for the U.S. Gulf Coast are elaborated based on transgressive-regressive events (Fig. 42, column 4). Vail and others (1977), and Hag and others, (1987) used strata geometries and patterns of onlap, downlap, truncation, and basinward shifts of coastal onlap to interpret sea-level histories along various continental margins (Fig. 42, column 1). Other authors (Rey,1982; Harris and others,1984; Longoria,1984; Flexer and others,1986) based their curves on water depth, from which sea-level can be inferred. Scott and others (1988) established two paleobathymetric correlative curves, for the U.S. Gulf Coast and southeastern Arabia (Fig.42, columns 10 and 7), as possible eustatic sea-level rise events. Garcia-Mondejar, (1990) based the Aptian-Albian sea-level curve of the Basque-Cantabrian area (Fig. 42, column 9) on the definition of correlative depositional sequence boundaries by unconformities and correlative conformities over the area. In the present study the Fischer plot helped to define relative sea-level changes during the deposition of the Cogollo Group of the Blocks I and II in the Maracaibo Basin.(Fig. 42, column 11).

Observing the curves, it is evident than even though each one is based on different criteria and applies to different basins, the major features are correlative showing in a general way that changes in sea level seem to have been simultaneous all over the world.

I agree with Haq and others, 1987; Posamentier and others, 1988; and Read and Goldhammer,1988 that third-order cycles of sea-level changes are very much related to eustatic sea-level changes and that the differences observed among the curves are the consequence of the specific tectonic setting prevalent in each individual basin. Nevertheless, more work should be done to define the worldwide Cretaceous sea-level curve using the same criteria in all basins.

Fig. 42. Comparative chart of Cretaceous sea- level curves: 1- Vail and others, 1977; Haq and others, 1987, 2- Kauffman, 1977,1984; 3- Caldwell, 1984, 4- McFarlan, 1977, 5- Longoria, 1984, 6- Rey, 1982, 7- Harris and others, 1984, 8- Flexer and others, 1986, 9- Garcia-Mondejar, 1900, 10- Scott, 1990, 11- This study.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Maastri
Campa
Santo
Conia
Turo
Ceno
Albian
Aptian
Barre
Haute
Vala
Berri
eustatic .87
onlap .78
T10
T9
T8
T7
T6
T5
T4
T3
T2
R1
T1
bathyal
shallow
carbo nate
platform
bathyal
plat form
fluviatile
plat form
deep shelf
lagoon
GLOBAL
US WI
CANADA WI
GULF COAST
E.MEX
PORTUGAL
OMAN
ISRAEL
BASQUE CANTABRIA
GULF COAST
BLOCK I AND II MARACAIBO

6. RESERVOIR QUALITY

6.1 LITERATURE REVIEW

Because one of the objectives of this study was to identify matrix porosity and because very little matrix porosity was observed in the cores, a review of the literature discussing the reservoir quality of the Cogollo Group was undertaken in order to compare the observations made in this study with those in other areas of the Maracaibo Basin (Fig. 43).

Ever since 1945, when the first Cretaceous discovery occurred on the La Paz structure, the Cretaceous carbonate reservoirs in the Maracaibo Basin have been believed to produce from fracture porosity related to major structures. Several studies to better understand the production behavior of these reservoirs have focused on the belief that they do not produce only from fractures. Most of the studies reviewed (most of them proprietary, internal reports PDVSA (*)) try to define production or porosity zones throughout the Cogollo section by relating facies to type of porosity (matrix and fracture). They are summarized in the following paragraphs.

*Bebout (1972) studied cuttings samples from the Urdaneta, Centro, and La Paz areas (Fig. 43) and recognized four types of porosity: intercrystalline porosity is preserved in the calcite cement between the oolite grains (less than 3 percent), leached grains in the oolite and coated-grain facies (3 to 4 percent), leached matrix (small vugs), and small fractures. The type of oolite porosity is best develop in well CLA-73 A where it occurs in the upper 200 ft of the Cogollo section. Leached matrix porosity occurs in the upper 50 ft of the Cogollo Group, and other thin zones of leached matrix porosity also occur scattered through various parts of the Cogollo, some even below the *Orbitolina* zone. Small fractures occur scattered throughout the Cogollo.

*Burchette and Escalona (1984) in their study of the west Maracaibo Basin area (Fig. 43) conclude that the Cogollo Group limestones are effectively tight and possess little intrinsic reservoir potential. Thin intervals of biomoldic porosity are present, however, in the Maraca and Apon formations. These intervals are restricted to molluscan packstones and grainstones.

Reijers and Bartok (1985), in their study of the La Paz field (Fig. 43), established that only the grainstone/packstone bar and pelecypod biostrome facies contain a significant amount of porosity and permeability. They concluded that the matrix stores the oil and that the fractures enhance the production potential.

*Moldovanyi and Pinto-Auso (1987) concluded that the mechanism of production in the Alturitas Field (Fig. 43) is the result of fractures and vuggy porosity. The productive horizons are principally located at the top of the Apon Formation and consist of mollusk packstones with vuggy porosity.

Minor productive intervals are present in the Maraca Formation in fractured mollusk and algae packstones.

* Mercadier and others (1988) established five zones in Block I (Fig. 43), from top to bottom: a) a productive interval with open fractures at the La Luna/Maraca boundary, b) a tight interval in the Maraca and Lisure formations consisting of tight limestone with cemented fractures, c) a productive interval with open fractures and matrix porosity at the top of the Apon Formation, d) a tight interval in the Apon Formation, consisting of tight limestone with cemented fractures, e) a productive interval with matrix porosity in the lower part of the Apon Formation, consisting of streaks of porous sucrosic dolomite interbedded with tight dolomite and/or limestone layers.

Mendez (1989), in a regional study of the Maracaibo Basin, established that the occurrence of porosity depends on the facies. The biomoldic porosity is related to pelecypod biostromes in the Apon and the top of the Maraca Formation. Moldic porosity occurs in oolitic carbonates in the Lisure and Maraca formations in combination with interparticle porosity preserved in the oolites. Intercrytalline porosity occurs in dolomites particularly at the top of the Tibu Member of the Apon Formation.

Kummerow and Perez de Mejias (1989), in cores from Urdaneta, Sol Centro, Block II, and Bachaquero (Fig. 43), established that the diagenetic alterations suffered by the carbonates of the Cogollo Group, especially the pervasive

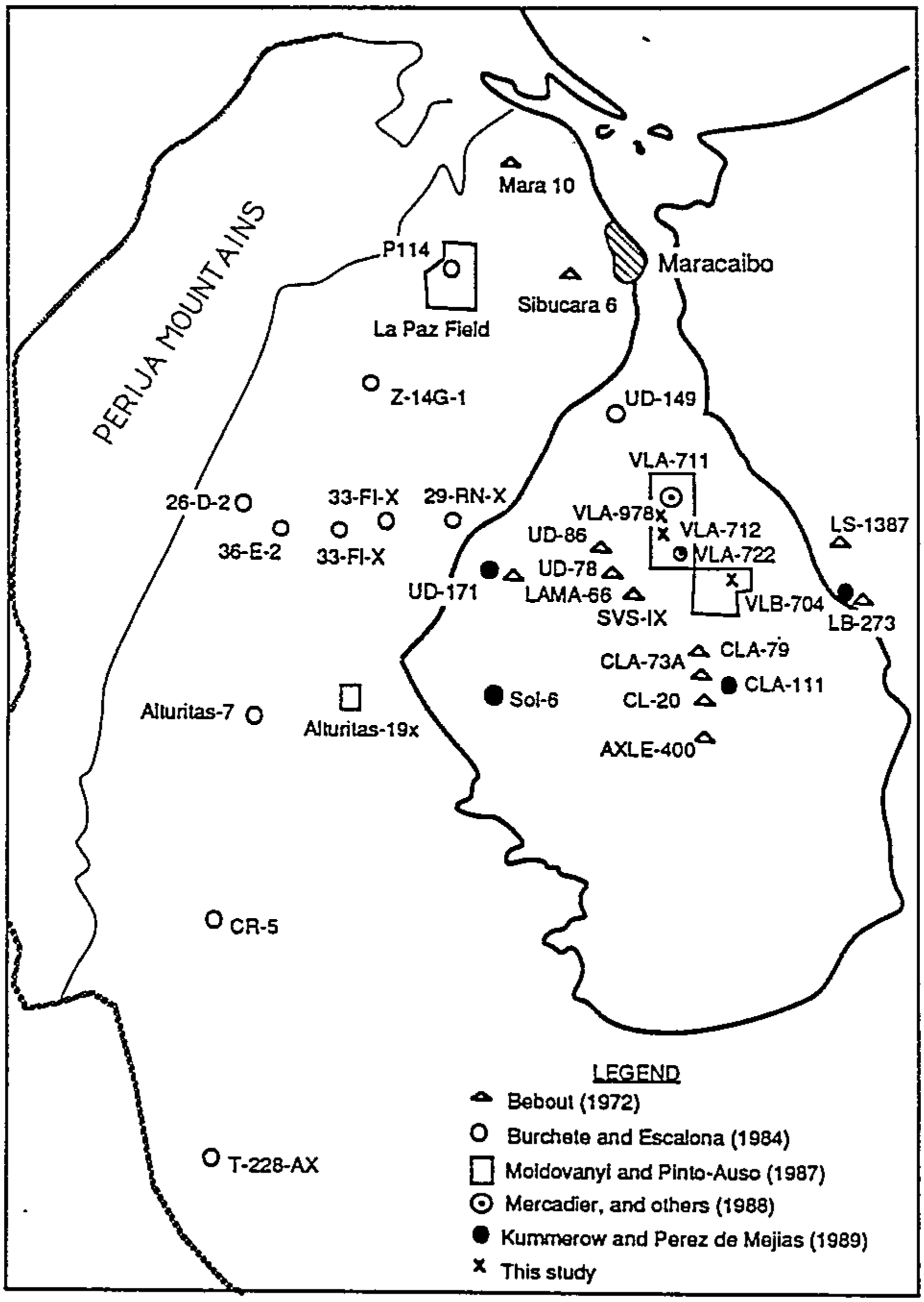


Fig. 43.- Location map showing the distribution of the areas reviewed in the literature.

> cementation, limited the properties of the rocks as reservoirs. Nevertheless, there are some intervals in the Maraca and Apon formations with preserved porosity in molds, ooidmolds, vugs and fractures.

From the above review, one can conclude that there are intervals in the Cogollo Group with porosity. Most of the authors have located them in the Maraca and Apon formations.

Bebout (1972), Burchette and Escalona (1984), and Mendez (1989) found moldic porosity in skeletal and oolite facies and vug porosity in nonspecific facies in the Maraca Formation . On the other hand, Moldovanyi and Pinto-Auso (1987) and Mercadier and others (1988) found fracture porosity in the Maraca Formation.

Most authors mention the presence of matrix porosity in the Apon Formation. Mercadier and others (1988), and Mendez (1989) observed matrix porosity in dolomites; Burchette and Escalona (1984) found biomoldic porosity and Moldovanyi and Pinto-Auso (1987) found vug porosity in mollusk packstone.

Although all the authors observed matrix porosity most of them did not believe that it was the principal contributor to the production.

According to:

*Bebout (1972): " The porosity in the samples studied is not high enough nor does it appear to be distributed over a thick enough section to account for the high production obtained from these Cretaceous wells. Unfortunately control is insufficient to estimate the contribution to the production from this porosity .".

•Burchette and Escalona (1984) said " Fractures form potentially the most important reservoir porosity and permeability in the West Maracaibo deep Cretaceous."

•Mercadier and others (1988) stated : " The reservoir potential of the matrix rock recovered in the cores is negligible except for some sucrose dolomite intervals. It is assumed that production comes from an open, natural fracture system."

Moldovanyi and Pinto-Auso (1987), as mention above, suggested that the production is a mixture of fracture and matrix porosity.

Mendez (1989)did not discuss fracture porosity.

6.2 POROSITY IN CORES DESCRIBED FROM THE COGOLLO GROUP

Neither significant amounts of matrix porosity nor fractures were found in the five cores described. The porosity (matrix and fracture) that is observed was located in the Maraca and Apon formations (Appendix A).

An average of 2 percent of moldic porosity was observed in thin sections of mollusk grainstone of the Maraca Formation. A maximum amount of this moldic porosity was 10 percent in a 33 cm (one-foot) zone (13,427 to 13,428 ft) in the core of VLA-978 (Fig. 10) (Appendix A). The open fractures in the Maraca Formation are mostly in the wackestone facies, and the average porosity is 2 percent (thin section) (Fig. 44).

The Apon Formation, presents intercrystalline porosity averaging 3 percent in the dolomites and moldic and interparticle porosity averaging 2 percent in *Orbitolina* grainstones/packstones (Fig. 45). Open fractures are observed in the dolomites, but never over 10 percent.

Only small amounts of matrix porosity were found in the Maraca and Apon formations. The question remains, how do the wells in Blocks I and II produce, and what determines their erratic production (one well produces up to 2,000 b/d (VLA-711) while another does not produce (VLA-704))?.

The data available do not allow a response to these questions. Nevertheless, in agreement with the publications reviewed, it seems that fractures play a major role in creating favorable reservoirs conditions in the Cogollo Group in the Maracaibo Basin.

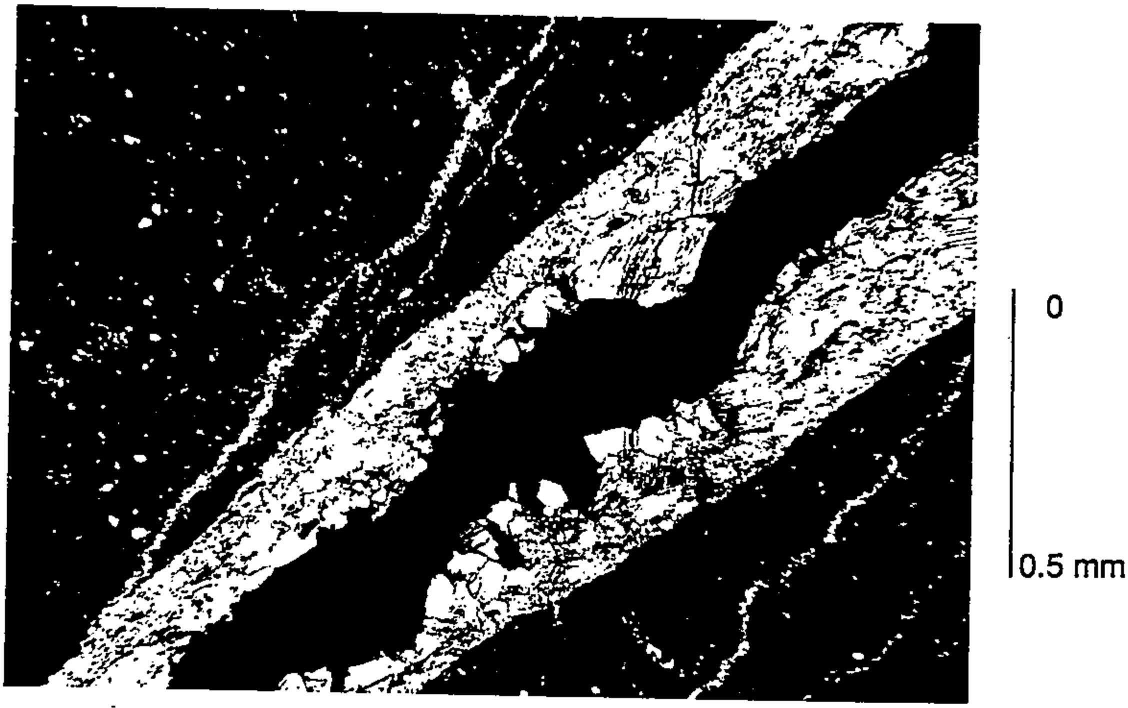


Fig. 44. Fracture porosity observed in a mudstone. Calcite cement filling the fracture has been dissolved generating the porosity. (VLA-711--14,2461 ft; plane polarized light).

Fig. 45. Interparticle porosity, in *Orbitolina* packstone, produced by dissolution of the micritic matrix. (VLA-978--14,073 ft; plane polarized light).

7. CONCLUSIONS

1) The carbonate Cogollo Group represents a cyclic sequence where two types of depositional styles have been defined - upward-fining cycles in the lower part and upward-coarsening cycles in the upper part. A total of 55 cycles were defined; 42 of them are upward-fining cycles and 13 are upward-coarsening.

2) Four types of cycles were recognized in the thick section containing the upward-fining cycles. Each cycle is characterized by grainier carbonate facies at the bottom and muddy carbonate facies at the top.. The A cycles are characterized by oyster packstone and shaly dolomite; the B cycles by *Orbitolina* grainstone and miliolid wackestone; the C cycles by skeletal-pellet grainstone and silty-pellet wackestone; and the D cycles by mollusk-echinoid grainstone, skeletal-intraclast grainstone, oncolite packstone and skeletal wackestone. The upward-fining cycles are continuous laterally and present a recognizable vertical pattern; the A and B cycles are restricted to the bottom of the section, and C and D are generally found alternating in the upper part of the section.

3) The thinner upper section of the Cogollo Group, contains three types of upward-coarsening cycles, all of them characterized by muddy carbonates at the bottom and grainer carbonates at the top. The E cycles

are distinguished by skeletal wackestone and oolite grainstone; the F cycles by skeletal-siliciclastic wackestone and skeletal grainstone; and the G cycles by skeletal wackestone and skeletal-intraclast grainstones. The upward-coarsening cycles are discontinuous laterally and do not present any specific vertical pattern.

4) In the Cogollo Group three stratigraphic markers have been defined. Two are biostratigraphic markers; the *Choffatella decipiens*, and *Orbitolina texana* markers. The third is a lithostratigraphic marker, the contact between the upward-fining and the upward-coarsening cycles. In the Aptian-Albian, Cogollo Group, the *Choffatella decipiens* is an index fossil of the lower Aptian, and *Orbitolina texana*, an index fossil for the upper Aptian -lower Albian boundary.

5) The Aptian-middle Albian section is characterized by upward-fining cycles. The Aptian (Apon Formation) is represented in this study by the A and B cycles and the lower and middle Albian (Lisure Formation) by the cycles C and D. The upper Albian (Maraca Formation) is characterized by the upward-coarsening E, F, and G cycles.

6) The upward-fining cycles were deposited on a subtidal platform in water depths varying from 2 to 15 m (5-50 ft) and represented upward-deeping cycles. The Albian upward-fining cycles A and B were deposited in a open-lagoon environment, where A cycles represent oyster banks

and B cycles represent extensive sheets of orbitolinids and miliolid deposited in water depths of 2 to 5 m (5-15 ft). These cycles were deposited during a relative fall of sea level and were affected by the influx of shaly siliciclastics. The mud influx inhibited the carbonate production keeping the platform drowned, although sea level was falling at that time. The lower and middle Albian upward-fining cycles C and D were deposited in a submarine sand belt in deeper water than the A and B cycles, 5 to 15 m (15-50 ft); D cycles represented sand ridges and C cycles inter-ridge zones. During the lower and middle Albian episodic rises of sea level occurred resulting in a series of retrogradational and episodic drowning events that were followed by periods of slow or no deposition represented by hardgrounds. A modern example of these submarine sand belts are the Holocene ridges that are forming between Isla Mujeres and the mainland on the Yucatan Peninsula in the Caribbean sea.

7) The upper Albian E, F, and G upward-coarsening cycles were deposited in a shoal complex in water depths up to 5 m (15 ft) during a relative fall of sea level on a progradational platform; they represent upward-shallowing cycles. The E and F cycles represent active oolitic and skeletal shoals, and the G cycles represent deposits of stabilized areas back of the shoals. A comparable modern analog is the shoal complex of the Joulters Cays in the Bahamas.

8) Deposition of the Cogollo Group in the Maracaibo Basin was controlled by sea-level changes and influx of siliciclastic sediments. The changes in sea level were a combination of eustacy and local differential subsidence. The Merida Arch played an important role during deposition of the Cogollo Group. The Merida Arch during the Aptian was a positive area that supplied the siliciclastic sediments that affected the deposition at that time. It also, represented a stable substratum that controlled the differential subsidence during the Aptian-Albian .

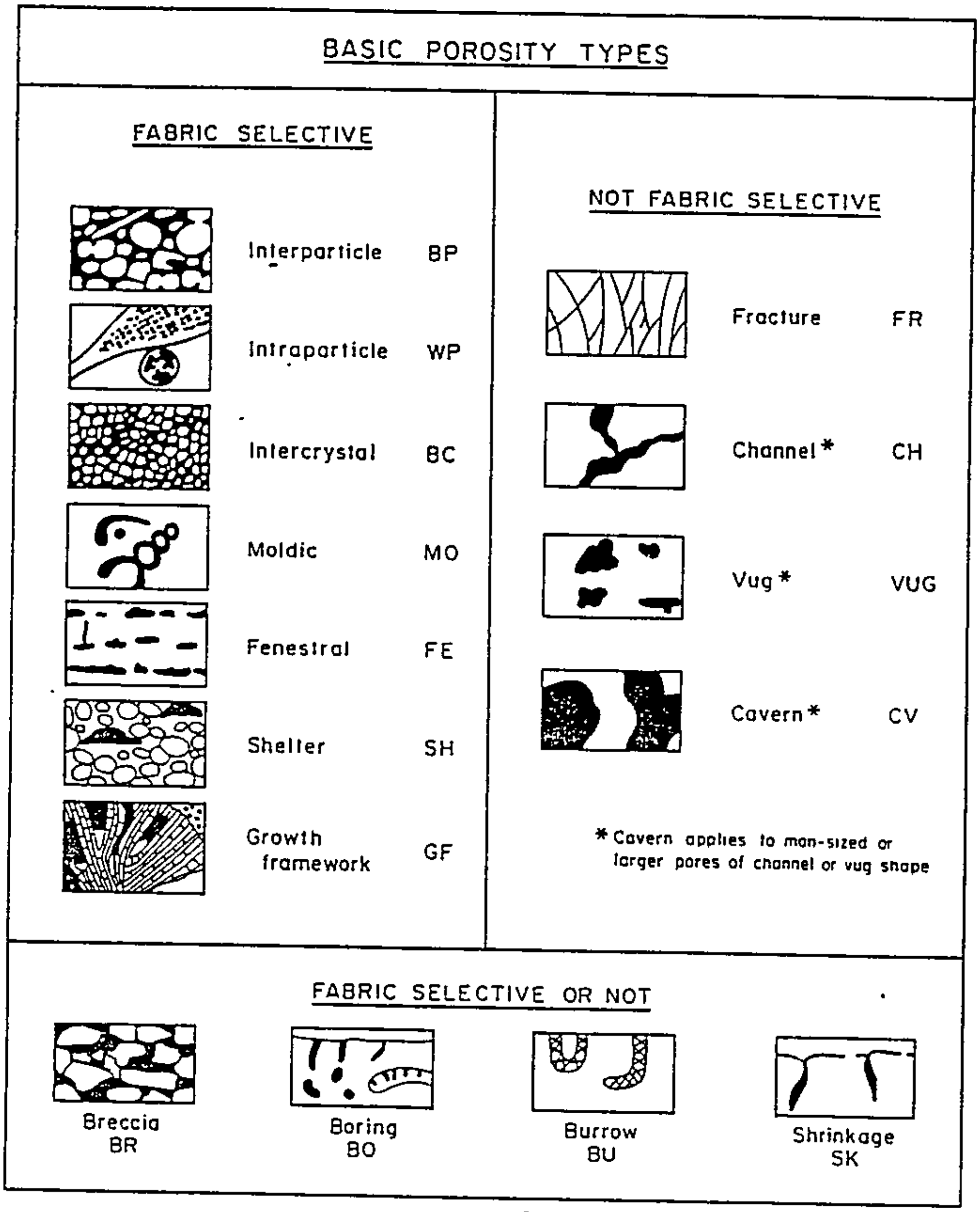
9) No significant amount of matrix porosity was found in the cores analyzed in this study. The average porosity found was 2 percent. The matrix porosity observed is located in intervals of the Apon and Maraca formations. In the Apon Formation porosity is predominantly intercrystalline in the dolomites of cycles A and interparticle in the *Orbitolina* grainstone of the B cycles. In the Maraca Formation moldic porosity was observed in F cycles in mollusk grainstone.

10) The correlation framework established in this study, based on interpretation of depositional styles and environments provides a basic framework into which future studies of the Cretaceous reservoirs in the Maracaibo Basin, including fracture characterization and diagenesis should be projected.

APPENDIX A

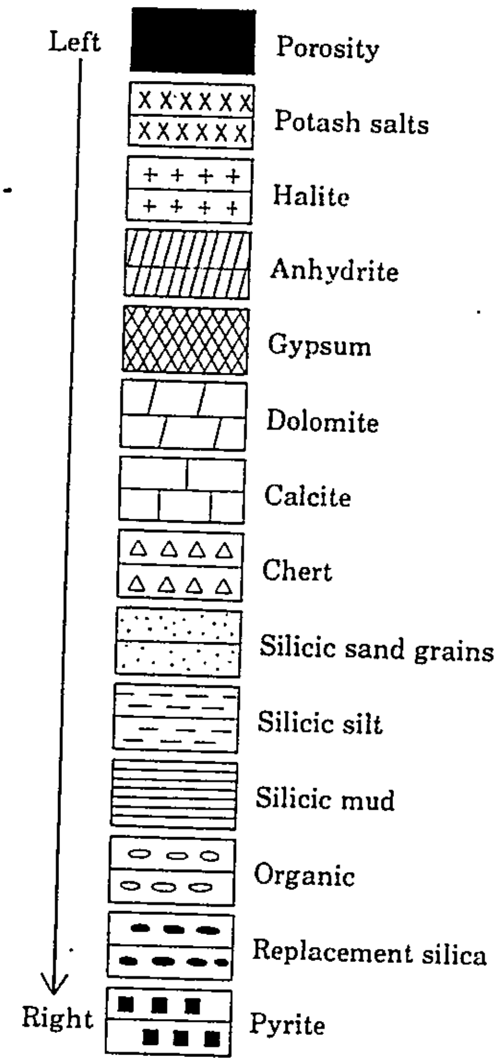
(Core descriptions)

POROSITY



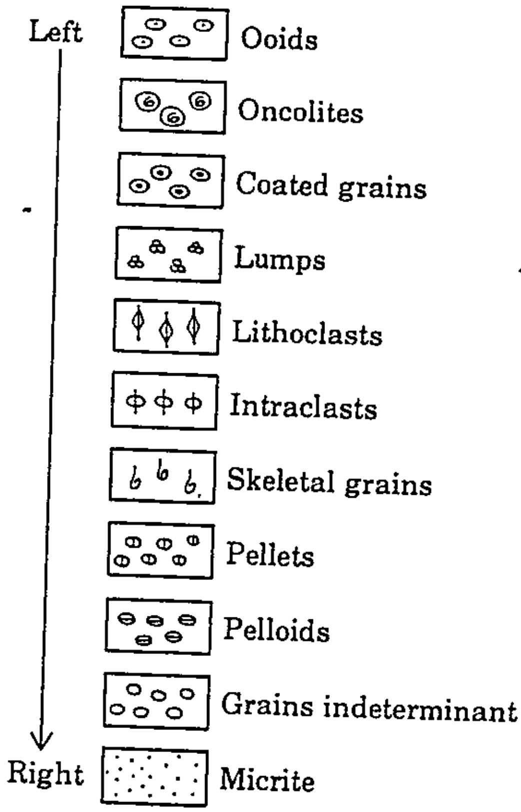
(Choquette and Pray, 1970)

MINERAL COMPOSITION

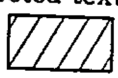


(Bebout and Loucks, 1984)

CARBONATE TEXTURE



Highly altered. Superimpose over interpreted texture.



(Bebout and Loucks, 1984)

CARBONATE STRUCTURES

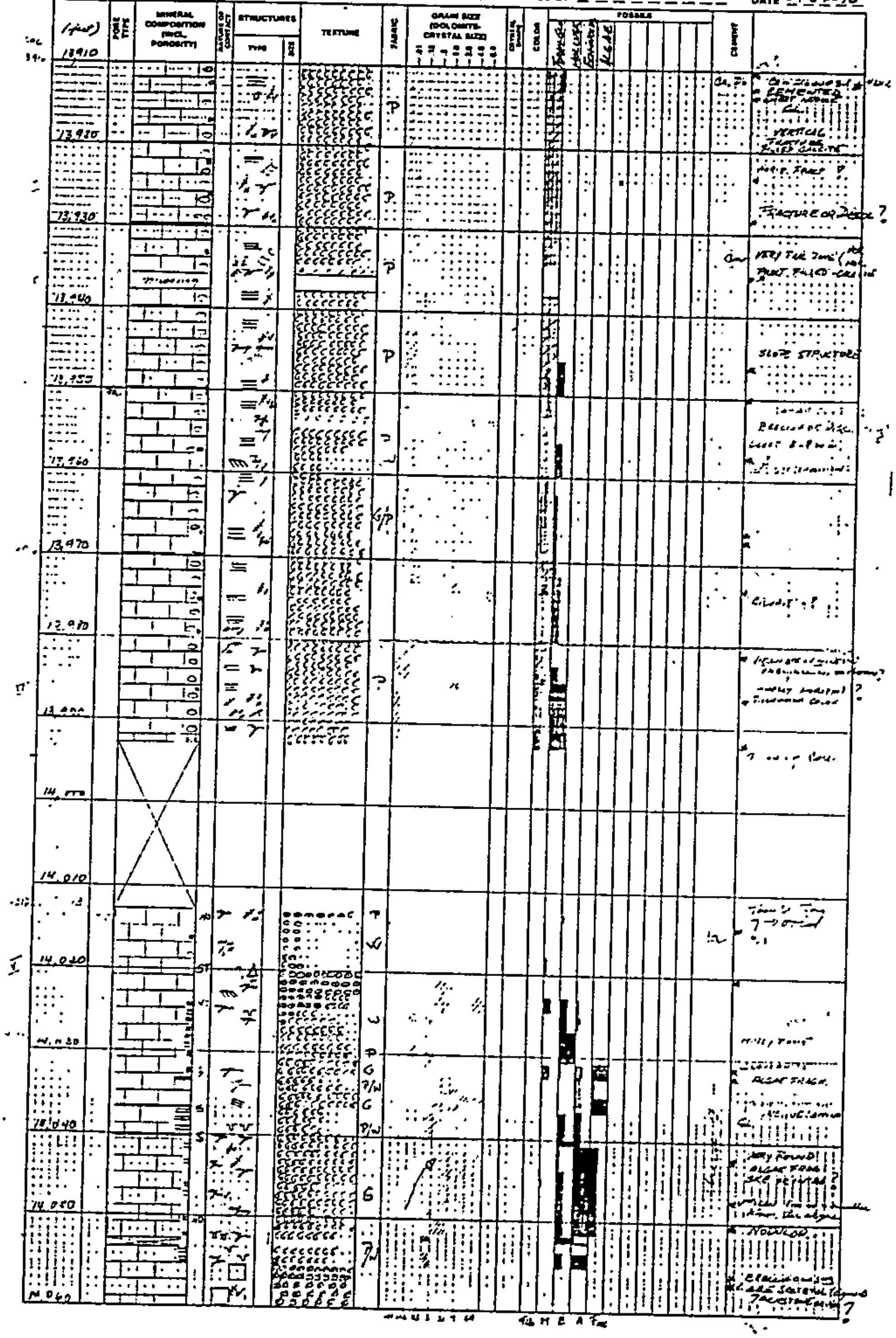
- Streaky
- Streaky laminated
- Microstreaky
- Stylolites
- Fractures
- Cloudy
- Shale and bituminous partings
- Interbedded
- Truncated surface
- VS Scoured surface
- Convolute
- Graded beds
  - Fining up
  - Coarsening up
- Lamina types - sketch diagrammatically example - irregular laminations
- Ripple marks
- Cross bedding
- Brecciation types
  - Fracture
  - Mosaic
  - Chaotic
- Solution cavity with breccia
- Highly disturbed
- Hardground
- Boudinage
- Burrows
  - Vertical
  - Horizontal
  - Suggested
- Clasts
- Borings
- Keystone structures
- Mudcracks
- Birdseye
- Fenestral
- Organic framework
- Geopetal
- Roots
- Sheet cracks

(Bebout and Loucks, 1984)

Core description well VLA-711

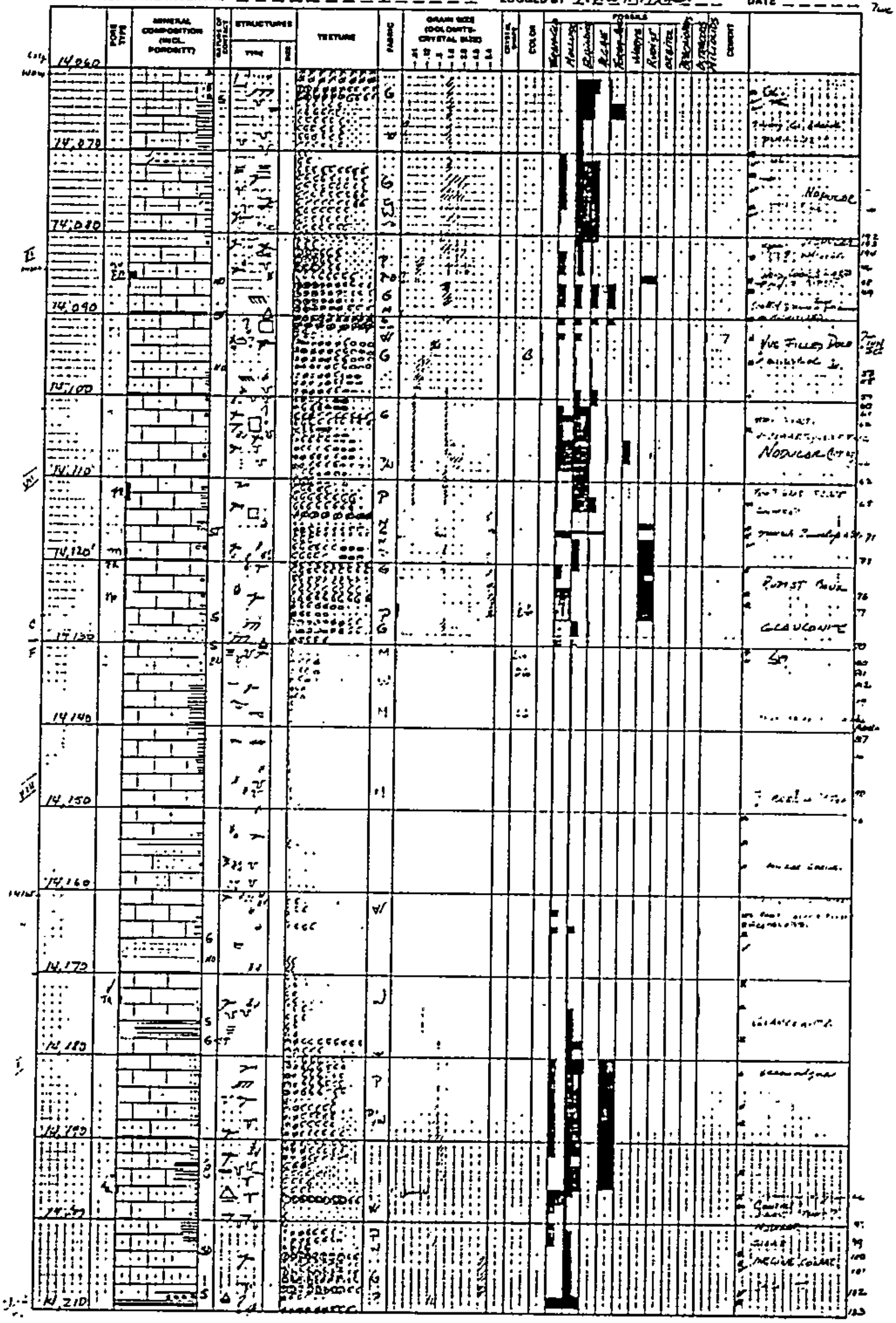
WELL VLA-71L COUNTY MARACAIBO - BLOCK I STATE VENEZUELA.

STRATIGRAPHIC INTERVAL 13910' - 14828' LOGGED BY I. Azpiritxaga DATE 04-04-90



WELL VLA-711 COUNTY Maracaibo - Block I STATE Venezuela

STRATIGRAPHIC INTERVAL 13910'-14128' LOGGED BY I. Azpiritxaga DATE



WELL YLA-71 COUNTY ______ STATE ______

STRATIGRAPHIC INTERVAL 13910' - 14828' LOGGED BY J. AZPIRITXAGA DATE 04-26-90