The Geology of the Limon Area of Costa Rica.

Gilbert Dunlap Taylor
Louisiana State University and Agricultural & Mechanical College

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The Louisiana State University and Agricultural and Mechanical College, Ph.D., 1975
Geology

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THE GEOLOGY OF THE LIMON AREA OF COSTA RICA

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Geology

by

Gilbert Dunlap Taylor
B.A., Thiel College, 1966
M.S., University of Illinois, 1971
May, 1975
DEDICATION

The author would like to dedicate this dissertation to the memory of Mr. Thomas J. Brazelton, formerly a Professor of Biology and Geology at Thiel College. It was Tom Brazelton who first interested the author in geology and who gave a good basic background in geology to the author.

Although his basic background was in microbiology, Tom Brazelton showed a grasp of geological principles equal to many professional geologists. More important, he had the ability to impart this knowledge to his students. Although he never lived to see his dream materialize, Mr. Brazelton consistently worked toward developing a full-fledged Department of Geology at Thiel. His dedication to geology, his students, and his friends was nearly total and has served well as a standard for the author throughout his academic and professional career.
ACKNOWLEDGEMENTS

The writer wishes to thank his parents for their encouragement and help. There is no doubt that the writer's present educational level could not have been attained without their support.

The help of Dr. W.A. van den Bold of the L.S.U. Department of Geology is gratefully acknowledged. As supervisor of this research, he suggested the problem, assisted during the initial reconnaissance portion of the mapping, field checked the final results, gave invaluable assistance on both regional and local relationships, assisted during the paleontological analysis and critically read the manuscript. Drs. Bob Perkins, Donald Lowe, Harold Anderson, Donald Kupfer and Clyde Moore also criticized the manuscript and gave advice on some of the local relationships encountered.

This research was supported by Grant F70-16 from the Organization for Tropical Studies (OTS). The assistance of that organization is gratefully acknowledged. Logistical problems in Central America were reduced considerably as a result of the assistance of Mr. Jorge Campabadal, the Resident Director in Costa Rica for OTS.

Many other persons aided in the field mapping and interpretation phases of this research. These persons are too numerous to mention individually. All the author can do is thank the residents of Limon, fellow students at L.S.U. and fellow employees at Mobil Oil who helped during the course of this work.

Finally, the author would like to acknowledge the assistance of his wife, Betty. Her moral support, proofreading and typing ability made the final stages of writing this report much easier.
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ABSTRACT

Field mapping of the Limon, Costa Rica area and laboratory analysis of sediment samples taken from the area have revealed a different geologic history from previous interpretations. Earlier workers postulated considerable post-depositional deformation, but field relationships found indicate that relatively little deformation has occurred in the series of interfingering, predominantly shallow marine clastic and carbonate (reef) sediment bodies mapped.

The oldest stratigraphic unit in the area, the Uscari Shale, with a late Miocene to early Pliocene age, was deposited in an outer neritic environment (300-500 m). This deep marine environment shallowed abruptly, but apparently conformably, through the lowermost portions of the Rio Banano Formation (new formation name) to approximately 50 m depth, and the middle section of the formation shows a less abrupt shallowing to 10 m. This shallowing appears to be related to the formation of the Victoria Dome, centered to the southwest of the map area. The middle and upper portions of the Rio Banano Formation contain lithologies which differ from the sandstone that comprises most of the unit. The middle portion of the formation contains a cyclic pebble conglomerate, and the upper part includes numerous coral reefs, which consist principally of *Montastrea* forms with some *Diploria*, *Porites*, and *Acropora* present. The reefs vary in thickness from 2 to over 15 meters with those reefs closer to the modern shoreline being thicker. Both the reef and conglomerate lithologies appear to interfinger with marine sandstones. All three are considered to be in facies with one another and are referred to as the sandstone, conglomerate, and reef facies of the Rio Banano Formation.
Overlying and appearing to smother some of the reefs of the Rio Banano reef facies is a well-sorted, in part brackish, coarse sand, referred to informally as the "Pueblo Nuevo Sands." These sands form low, often badly-leached outcrops in which no paleontologic or stratigraphic trends can be established. The "Pueblo Nuevo Sands" may have been formed by several agencies reworking sediments of the Rio Banano sandstone facies, although tidal currents appear to be the most likely agent.

Unconformably overlying the reefs and sandstones of the upper Rio Banano Formation is a sequence of deep marine (+100 m) siltstones and claystones. Since these resemble the sandstone facies of the Rio Banano Formation closely and appear to have the same source, they are referred to as the Moin Clay Member of the Rio Banano Formation. Planktonic foraminiferal faunas from the Moin Member show it to be of upper Pleistocene age. The deep marine siltstones and claystones of the Moin Clay Member are conformably overlain by shallow marine coral reefs which are, in part, still living. The Moin Clay Member is interpreted as being the result of deposition during an interglacial period when sea levels were at a higher position than normal.

The youngest stratigraphic unit in the area is the Suretka Conglomerate, a series of fluviatile sand, cobble, and boulder bodies. The outcrop band of the Suretka includes sediments presently being deposited by the Rio Chirripo.

Structural deformation in the mapped area is limited, with the major structural feature being the Victoria Dome. Faults radiating from this
dome have determined the position of major streams and evidently affected past sediment distribution in the area. The only fault block containing coral reefs is also structurally the highest block in the area. Adjacent fault-bounded basins appear to have acted as sediment traps, causing the horst block to enter a sediment-starved depositional regime. Some minor folding in the uppermost Rio Banano has also occurred, but field evidence was not sufficient to indicate its origin.
INTRODUCTION

The southern half of Central America, including the countries of Panama, Costa Rica, El Salvador, and Nicaragua is a very young area primarily of volcanic origin. The map of Roberts and Irving (1957) demonstrates the importance of volcanic rocks and the scarcity of sedimentary outcrops in the region. One of the largest areas of sedimentary rocks in southern Central America extends in a band 30 to 60 kilometers wide on the Caribbean coast from 50 km north of Puerto Limon south to Boca del Toro, Panama. This sedimentary area, termed the Limon Basin by Dengo (1962), presents a smooth coast to the sea except for two comparatively large promontories, one at Limon near the northern end of the basin and a second at Puerto Viejo, approximately 90 km south of Limon. The size and economic importance of Limon as Costa Rica's only eastern port has led to the construction of a good road net creating relatively easy access to the adjacent outlying areas. This ease of communication makes the northern promontory a suitable area for a detailed stratigraphic study.

Previous petroleum exploration carried out by the Union Oil Company of California in the Limon area mapped the general geology of a 600 square km area inland from the Limon peninsula. Detailed stratigraphic analyses, however, were impractical in reconnaissance. This study showed the Victoria Dome to be the dominant structural feature in the area. The many lithologic contacts on the Limon promontory were interpreted as structural contacts and a considerable amount of post-depositional deformation was invoked in the
Index Map of Costa Rica

Showing Area of Study
Union Oil geologist's interpretation of the geologic history of the area.

These interpretations were at variance with data from samples collected by W.A. van den Bold. The author has attempted to reconcile these differences by undertaking a detailed stratigraphic study of sedimentation in the northern portion of the Limon Basin. The present project covers an area of about 100 km² including the Limon promontory and the more easily accessible areas to the west and south of Limon.
Climatology and Geography

Limon is situated on the Caribbean coast of Costa Rica within ten degrees of the Equator and experiences a high rainfall of between 2000 and 5000 mm per year. This high rainfall and low mean annual evaporation of 800 to 1000 mm per year creates a large surface runoff as well as a high water table. The average temperature of the region varies little with the season with a summer mean temperature of 75 to 85 degrees F. and a winter mean of 70 to 80 degrees F. Weather patterns of the area are under the year-round influence of the moisture-laden northeast trade winds from the Caribbean. This climate supports a lush tropical rain forest although much of the growth around Limon is secondary. The original tree cover was removed to make room for agriculture, usually banana and cocoa plantations. Following the abandonment of these plantations, natural growth of herbaceous plants turned much of this formerly cultivated area into a tangle of undergrowth. The climate is also responsible for the extensive development of laterite soils. Deep and rapid weathering has destroyed most of the rock outcrops and the only geologically usable outcrops are in the valleys of streams with a velocity sufficient to erode rapidly.

The Limon area is a part of the low Caribbean coastal plain. The inland portions of the map area reach elevations as high as 100 m but most of the area is less than 50 m above sea level.

Communications are well developed by Central American standards with several gravel roads providing all-weather access to outlying areas (See Figure 2). One of these roads connects Limon to La Bomba and has a parallel road from Pueblo Nuevo to near La Bomba.
The other major road goes from Limon to San Jose and provides access to the western portion of the coast of the Limon peninsula as well as inland areas to the west of Limon. The Northern Railroad, which has its main line across the base of the promontory, provides access to the inland areas between Limon and Moin.
Field Mapping Techniques

Most of the field mapping for this project was carried out during June, July and August of 1970. Subsequent laboratory analyses and discussions with various people indicated the presence of certain problem areas. These were re-examined in more detail in February of 1971 and January of 1972. In addition, during this last trip, the type section for the Gatun Formation in the Panama Canal Zone was examined.

The paucity of outcrops and difficulty of communications makes geologic mapping in any tropical country difficult, Costa Rica not excepted. The climate causes very deep and rapid weathering; fresh outcrops can be destroyed in a matter of a few months. Location of outcrops from air photos, although attempted, was thwarted by the dense brush which covers most of the area. Usable outcrops can be found only in the stream beds, where erosion and mass wasting periodically form fresh outcrops, or in man-made exposures in road and railroad cuts.

Although man-made exposures are quite important in some portions of the area mapped, the poor economic condition of this area of Costa Rica has prevented development of an extensive road network. Roads are of very limited extent and only one railroad line penetrates the area. The condition of all roads, except those within one km of Limon, is such that a four-wheel drive is the only reliable means of transportation. For this purpose, a Toyota Land Cruiser was rented in San Jose. Even these roads are often washed out or made impassible by periodic floods. At the time of my first arrival in the area, the Limon-San Jose road had been washed
out in the Rio Reventazon area, forcing me to transport the field vehicle by rail. High water also prevented the author from crossing the Rio Banano except by foot during the entire first mapping period (which was three months long). This severely limited the extent to which the south bank of that river could be mapped.

As a result of the problems in locating and using man-made outcrops, much of the area was mapped from natural exposures found by wading streams. Some areas were still inaccessible even by this method. The area to the east of Nueva Castle and La Bomba, for example, was blocked by quicksand in the river bed. In those areas the geology was inferred from nearby data. A different pattern is used to indicate this on the geologic map.

The base map for this study was the 1:50,000 topographic map of the Limon area published by the Geographical Institute of Costa Rica. Additional detail concerning the stream courses found was obtained through the use of a modified pace-and-compass method. Major changes in direction were measured with a Brunton compass; distances were determined by the use of a 50 m. rope knotted at measured intervals. This method of mapping the streams was made necessary by the heavy brush, which forms a canopy over all but the largest streams, obscuring them from the aerial camera. Sample location, strike and dip information, and outcrop sketches were noted on these maps. Whenever possible, the accuracy of these stream maps was checked by reference to prominent landmarks, aerial photographs, and the topographic base map.

Local variations in outcrop character obviously creates considerable variation in the quality of the data which can be ob-
tained from these outcrops. In many cases, outcrop character was such that only the stratigraphic unit present could be determined with the outcrops being weathered and leached to an extent that precluded taking a meaningful sample or measuring attitude.

In spite of all these problems outlined above, the extensive stream system present permitted sufficient access and data to allow a fairly detailed geologic map of the 100 square kilometer area to be drawn.
Summary of Central American Geology

Most authors divide Central America into two orogens. The northern orogen, comprising Mexico, Guatemala, Honduras, and northern Nicaragua, is considerably older, having a Paleozoic and Precambrian basement. The southern orogen, comprising southern Nicaragua, Costa Rica, and western Panama, is much younger with a Cretaceous and possibly Jurassic basement.

There have been numerous attempts to explain the origin of Central America and the Caribbean region. These range from Lloyd's (1963) suggestion of a series of island archipelagos building up the Central American isthmus to Malfaid and Dinkleman's discussion (1972) of the origin of the Caribbean Plate based on the "New Global Tectonics" of Molnar and Sykes (1966). Although the author is not in complete accord with their sequence of events with time, the model by Dinkleman (1972) seems to agree best with the known geological and geophysical features of the region.

Tertiary volcanism on the Pacific coast and in the Cordillera de Talamanca in the interior, along with interior uplifts, provided source areas for sediments subsequently deposited in the Limon Basin. These sediments have been studied by a number of authors. The basic stratigraphy of the Panama Canal Zone has been described by Woodring (1957). Recent refinement of the stratigraphy in this area by Blacut and Kleinpell (1968) and Bold (1971) has clarified the stratigraphic position of the La Boca Formation. According to these authors, the La Boca was deposited during the middle early Miocene (zones N.6 and N.7 of Blow, 1967) in a relatively deep marine environment. Unconformably overlying the lower Miocene is
the Gatun Formation, deposited in a shallow marine environment during the upper Miocene (Bold, 1971).

The sediments in the southern portion of the Limon Basin in the Rio Sixaola area of southern Costa Rica were described by Redfield (1923). He reported a deep marine unit, the Uscari Shale, which he considered to be of early Miocene age, to be unconformably overlain by a shallow marine sequence which he referred to the Gatun Formation. Samples from the type area of the Uscari Shale collected by W.A. van den Bold show a planktonic foraminiferal assemblage of late early to early middle Miocene age (zones N.8-N.10 of Blow, 1967).

A third area with a similar stratigraphic sequence has been described by Bold (1967) and Rivier (1971) in the Rio Reventazon area of north-central Costa Rica. Both authors show a relatively deep marine, lower to middle Miocene Uscari Shale unconformably overlain by shallow marine Gatun. Rivier's data (1971) show some unusual associations of planktonic foraminifera, and there is some evidence to suggest that some of his specific identifications may be incorrect, especially in the Globorotalia archaeomenardii-G. praemenardii-G. menardii group. Bold (1967) ascribes an early middle Miocene age to the upper Uscari (zones N.9 and N.10 of Blow, 1967).

Different stratigraphic relationships from those described above are shown in the Limon area. There, an upper Miocene (N.18) deep water sequence grades gradually upward into a shallow marine sequence with no evidence of an intervening unconformity. The evidence for this will be discussed below.
Previous Work

Previous geological work in the Limon area has been limited. Gabb (1881) was the first to publish descriptions of fossils, but he also described some stratigraphy, naming the Moin Formation. Olsson (1922), also a mollusk specialist, did a considerable amount of stratigraphic work, introducing the Uscari Shale as a formal name and extending the Gatun Formation into Costa Rica. Woodring (1957) also worked in the Limon area, describing some stratigraphic relationships and refining some of Olsson's (1922) correlations. Mapping by the Union Oil Company of California was carried out from 1953 to 1962, but the results, except for a brief examination of the geologic map, were not available to the author. Union Oil also drilled two test wells around Limon, but the samples were not available for examination.
Stratigraphic nomenclature in Costa Rica is quite confused, as can be learned from a perusal of Hoffstetter (1960). Many of the early workers either described type localities so vaguely that they cannot be found today or the outcrops are now badly weathered. In addition to this problem, some formations were given more than one name. This was often due to lack of knowledge of the early literature by later workers, which in turn was caused by the publishing of early efforts in little-known publications or journals of limited distribution which quickly became unavailable (Gabb, 1881, for example). Another problem in nomenclature crops up with spelling differences from author to author. This has caused apparent stratigraphic differences between areas where no true difference exists. Thus, the Moin Formation of Gabb (1881) has also been termed the Moen (Gabb, 1885), Limon(Moen) (Hill, 1898), Limon (Dall and Hill, 1898), and Port Limon (Rathburn, 1918). See also the uncertainty of the stratigraphic position of the Sheroli (Xirores) Formation of Redfield (1923), referred to in the discussion of the Rio Banano Formation. These problems must be resolved before the actual stratigraphic work can be satisfactorily presented.

Incorporated in the appendix of this report is a considerable body of sedimentological data. This information has been included with this report so that future workers will have these data should they wish to do a sedimentological analysis. Since a detailed sedimentological analysis was beyond the scope of the original research proposal, these data have not been used extensively in the
preparation of this report.

Rocks in the Limon area have been divided into three main formations: the Uscari Shale of upper Miocene age; the Rio Banano Formation (described and named here) of upper Miocene through Pleistocene age; and the Suretka Conglomerate of probable Pleistocene age. The term "Rio Banano Formation" is used here to replace the name "Gatun Formation" of Olsson (1922).

**Uscari Shale**

The oldest stratigraphic unit in the map area is the Uscari Shale. There is some discussion as to who formally named the unit with many authors citing Vaughan (1924) as the original reference. The Lexique Stratigraphique states, however, that the name "Uscari" was originally an informal name used by field geologists and later formalized by Olsson (1922). Berry (1921) used the term but only in an informal sense.

**Type area**

The name for the Uscari Shale is derived from Quebrada Uscari (Uscari Creek) which provides the exposures for the type locality in the Rio Amoura (Amoura River) area of southeastern Costa Rica. Uscari outcrops in this area were originally described by Olsson (1922) as consisting of "soft, dark-colored shales which, because of their slight resistance to denudation, frequently forms (sic) wide valleys and interior basins."

In contrast to Olsson's description, the Limon Uscari Formation outcrops form some of the most rugged topography in the map area. In view of its soft lithology, this topographic expression probably reflects a relatively recent uplift.
The Limon Uscari Formation would be best described as a silty clay-shale. It is rather poorly indurated in outcrop and is easily broken with the fingers. Its color is a greenish gray (5GY6/1 in the Munsell System of color classification) in fresh outcrop, weathering to a yellowish gray (5Y8/1) with dusky yellow (5Y6/4) spots. Weathered outcrops are quite platy in contrast to the relatively non-fissile exposures of fresh Uscari. The only sedimentary structures visible in outcrop or hand specimens are fine, parallel laminations which thin section analysis shows is due to the parallel alignment of platy clay particles and mica flakes. These laminae are deformed around larger grains in the rock (silt-sized quartz fragments and planktonic foraminifera). Planktonic foraminifera characterize this formation, with the prolific fauna sometimes being visible to the naked eye. Thin section analysis shows this rock to be fine-grained and comprised principally of clay minerals, most notably mixed-layer montmorillonite (determined by X-ray diffraction).

Contacts

The lower contact of the Uscari Formation lies outside the map area and was not observed during the present study. The upper contact, according to Olsson (1922), is formed by an unconformity between the Uscari Formation and the overlying "Gatun" Formation (here renamed the Rio Banano Formation) with a basal conglomerate developed in the "Gatun". No evidence for this unconformity was found in the Limon area.

A detailed study was made of an exposure approximately 240m
long on the northwestern side of the Rio Banano across the area containing the contact between the Uscari and Rio Banano Formations. Shale of Uscari lithology was found at the southwestern end of this area and sandstone similar to that found in the type locality of the Rio Banano sandstone facies at the northeastern end. No structural unconformity was found and the bedding planes observed were essentially parallel throughout the exposure. There was no evidence of a conglomerate layer. Grain size analyses of samples taken every thirty meters across this area show an irregular change in grain size with a net increase upward in the section toward the Rio Banano Formation (to the northeast). The grain size data (estimated from thin section) are summarized in Table 1 below. Also included is grain size analysis of a sample taken well into an area of Rio Banano sandstone facies lithology (sample 1147).

Table 1 - Summary of Grain Size Analyses from the Contact Area between the Uscari and Rio Banano Formations

<table>
<thead>
<tr>
<th>Sample Location from Uscari (Loc. 1150 m)</th>
<th>Average Grain Size (u)</th>
<th>Total Range of Grain Sizes (u)</th>
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<tr>
<td>1150 0</td>
<td>10</td>
<td>clay 200*</td>
</tr>
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<td>1151 60</td>
<td>40</td>
<td>clay 100</td>
</tr>
<tr>
<td>1152 90</td>
<td>60</td>
<td>clay 250</td>
</tr>
<tr>
<td>1153 120</td>
<td>40</td>
<td>clay 150</td>
</tr>
<tr>
<td>1154 150</td>
<td>60</td>
<td>clay 250</td>
</tr>
<tr>
<td>1155 180</td>
<td>30</td>
<td>clay 150</td>
</tr>
<tr>
<td>1148 240</td>
<td>120</td>
<td>clay 400</td>
</tr>
<tr>
<td>1147 1100</td>
<td>250</td>
<td>clay 700</td>
</tr>
</tbody>
</table>

*maximum grain size excludes fossil grains since the other samples involved were non-fossiliferous

This analysis serves to show that, although samples of Uscari and Rio Banano sandstone facies lithology are present at opposite ends
of the sampled section, there is no real trend within samples taken between the end members. This relationship suggests that the Uscari-Rio Banano Formational contact in the Limon area, instead of being an abrupt, unconformable contact, is rather a conformable, generally gradational contact with intertonguing layers of clay, silt and sand. The contact was mapped between samples 1155 and 1148 on the basis of the abrupt increase in grain size noted (See Table 1) at this point (both in the grain size analyses and in the field).

Although most of the samples taken in the contact area were not fossiliferous, faunal comparisons of samples 1148 and 1150 show a definite shallowing of the depositional environment of the younger sample. The evidence for this environmental change will be discussed in the section on Paleontology.

It may be that the conglomerate layer found near Nueva Castle (approximately 4 km northeast of the Uscari-Rio Banano Formation contact as mapped in this study along the Rio Banano) is the "Gatun" basal conglomerate referred to be Olsson (1922). The present author did not consider the base of this conglomerate to mark the upper contact of the Uscari Formation because of a total lack of change in either lithology or environment of deposition from one side of the conglomerate to the other.

Source and Environment of Deposition

The volcanic nature of the most probable source area for the Uscari sediments is emphasized by the montmorillonitic clay which comprises such a large percentage of this sediment. The absence
of all but the most stable minerals suggests either long transport distances, a warm climate or, most probably the case here, both. The fine-grained nature of the sediment is indicative of deposition in a quiet area. Paleontological evidence, to be discussed in detail below, indicates that deposition of the Uscari Shale took place in 400 to 600 m of water in an outer neritic or upper continental slope environment.

Age

Paleontological evidence also shows the Limon Uscari to be of a different age than that determined for the type section of the formation in southeastern Costa Rica by both Olsson (1922) and the present author. The Limon Uscari Formation contains a planktonic foraminiferal assemblage characteristic of late Miocene time (zone N.18 of Blow, 1967) while the type Uscari samples show an early middle Miocene age (zones N.8-N.10).

This might suggest that the Uscari from the type area and the Limon Uscari are not actually related and that the Limon Uscari should be renamed. This has not been done, however, since the sampling program carried out in the Limon Uscari was not sufficient to permit conclusions as to the regional relationships involved. The present study was oriented toward the younger outcrops of the Limon peninsula, so only the Uscari outcrops in the vicinity of the contact with the Rio Banano Formation were sampled. It is entirely possible that the older portions of the Limon Uscari are the same age as the type Uscari and that the upper portions of the Uscari have been removed from the type area. These regional
reconstructions must await a more detailed sampling program in the Limon Uscarì outcrops.
Rio Banano Formation

Introduction

Most of the mapped area shows outcrops of sandstone and coralline limestone described by Olsson (1922) as the Gatun Formation. He states that the Costa Rican Gatun Formation "is equivalent in part to the Gatun Formation of the Canal Zone....In Costa Rica, the Gatun is very much thicker and represented a longer depositional period." He further states that "the Gatun of the Canal Zone seems to represent only the lower part of the formation as developed in Costa Rica." On the basis of the molluscan faunas present, Olsson assigned a middle to late Miocene age to the Canal Zone Gatun Formation and the Costa Rican Gatun. No foraminiferal age or environmental data are available on the Panamanian Gatun since samples taken by the author from the type area for the Canal Zone Gatun were non-fossiliferous.

Terry (1956) shows the Panamanian Gatun to be of middle Miocene age with unconformities forming both contacts. The overlying Chagres Formation, consisting of the Chagres Sandstone and Toro Limestone Members, is shown to be early Pliocene in age.

Planktonic foraminiferal faunas from samples of the "Gatun" of the Limon area taken for this study show that these sediments are of late Miocene (N.18) to Recent age with the bulk of the stratigraphic unit being of Pliocene and Pleistocene age.

Since there is an age disparity between the oldest "Gatun" in the Limon area and the youngest Panamanian Gatun, the term Gatun should not be used in the Limon area since that would imply a lateral
continuity, postulated by Olsson (1922) that apparently does not exist. To avoid the implication that there is stratigraphic continuity between the Limon area and the Panama Canal Zone, the term Rio Banano Formation is proposed for the Limon "Gatun" of Olsson (1922).

Redfield (1923) described a unit he referred to as the Sheroli (also Xiores) Formation which he equated with the littoral facies of the Gatun of Olsson (1922). His description of the Sheroli as a "massive to distinctly-bedded, dark gray to dark-bluish argillite... which are (sic), for the most part, clayey and fine-grained" suggests that this may be part of the Uscari Formation rather than Olsson's Gatun (1922). The clayey lithology of Redfield's Sheroli (1923) is quite different from the sandstone lithology emphasized by Olsson (1922) for the Gatun. The position of the type area for the Sheroli Formation within one minute of latitude and 17 minutes of longitude also partially supports the lithologic indications that the Sheroli may actually be an Uscari equivalent.

General Description and Type Locality

The Rio Banano Formation is a series of intertonguing shallow marine clastic and coral reef facies. The formation can be divided lithologically into four facies: a sandstone facies, a conglomerate facies, a coral reef facies, and a clay facies.

Lithologic (Field) Descriptions

Sandstone Facies

The sandstone facies forms the greatest part of the Rio Banano
Formation and is typical of its lithology. The facies consists of a
greenish, poorly indurated sandstone which is best exposed in bluffs
along the cut bank of the Rio Banano at and above La Bomba. The
exposure on the north bank of the Rio Banano, 700 m east south east
of the railroad bridge at La Bomba is here designated as the type
locality for the Rio Banano Formation. This location has the
advantage of being on the cut bank of the river, which will constantly
provide fresh exposures. This type area is found on the Rio Banano
1:50,000 topographic map, edition 1-IGCR (sheet 3545-I) at 9°55'N,
83°04'W.

The sandstone facies of the Rio Banano Formation would be best
described as a muddy, fine-grained sandstone. Most outcrops are
poorly indurated although there is some local cementation by calcite.
Fresh outcrops of this facies show a medium greenish gray (5G5/1)
color which weathers to a medium grayish orange (10YR6/4). Although
rarely preserved in hand specimens, sedimentary structures are commonly
well-developed, especially in the younger portions of the facies.
None of the outcrops examined showed any fine sedimentary structures,
although larger-scale structures, especially in coarser sediments,
were common. Smaller sedimentary structures, such as laminae, appear
to have been destroyed by bioturbation. This bioturbation is further
evidenced by well-developed lebensspuren, found in some areas, which
closely resemble the "digitating feeding tubes" of Warme (1971, p.38).
The coarser sand layers show moderate-angle (20-30 degrees) cross-
bedding on scales ranging from 3-5 cm. to as much as 20 cm. One
coarse sand layer in the banks of Q. Chocolate shows well-developed
moderate-angle (25°) cross beds interrupted by symmetrical ripple
marks. Other outcrops in the Q. Chocolate area (in the upper part of the Rio Banano Formation) show what could be referred to as festoon cross beds on a scale of about one meter and parallel to the front of a small reef. Features which probably represent primary inclined bedding were observed in a backreef position where sediments of the Rio Banano sandstone facies appeared to have been draped over a carbonate reef rubble sequence.

Conglomerate Facies

The conglomerate facies of the Rio Banano Formation occurs within the sandstone facies of the formation in the Nueva Castle area. This facies is best exposed in outcrops 500 m northwest of Nueva Castle (Rio Banano topographic map) at 9°56'N, 83°04'W where they form a series of resistant, low outcrops in the stream beds.

This facies is poorly indurated, although the coarser portions are more resistant to erosion, forming ridges in the stream beds. Its color is nearly the same as that of the Rio Banano sandstone facies—a medium greenish gray (5G5/1) in fresh outcrop, weathering to a medium grayish orange (10YR6/4). The entire facies shows repetitive graded bedding with a basal pebble conglomerate developed in a medium to coarse sand matrix. This repetition is not apparent in hand specimens since the repetition is on a scale varying from one to as much as twenty meters. The basal conglomerate contains pebbles up to 4 cm in diameter in a matrix with an estimated mean grain size of 0.50 mm (medium sand). This matrix gradually fines upward to a sandstone with an estimated mean grain size of 0.25 mm immediately beneath the base of the next conglomerate layer. Each pebble bed
shows some scour at its base as well as small scale (2-5 cm) cross-bedding in the finer sands above the conglomerates. Overall, sorting is poor with the conglomerates appearing the best sorted.

Reef Facies

The reef facies of the Rio Banano Formation is best developed in the upper part of the formation, although coral occurs sporadically throughout the Rio Banano sequence. The best exposures of the reef facies, as well as the reef facies-sandstone facies contacts, are in a 1500 meter-long series of outcrops in Q. Chocolate 2200 m southeast of the railroad station at Sandoval (see the Rio Banano topographic map referred to above).

The reef facies is best developed in the upper portion of the Rio Banano Formation. Corals in the older portions of the formation are commonly solitary species with the lowest appearance of reef-forming species being in the upper third of the formation. These initial reefs are relatively thin (2-3 m thick) but the thickness of individual reefs progressively increases toward the top of the formation with the youngest exposed reef having a cave system approximately 15 m in height developed in it, indicating a reef thickness of at least that magnitude.

All of these reefs are composed of hermatypic corals identified in the field by the author as belonging to the modern genera Montastrea, Acropora, Porites and Diploria with most of the forms being Montastrea species. In many places, these reefs have been extensively recrystallized by ground water. In most cases, however,
there is still sufficient evidence to demonstrate a coralline origin for these reefs.

Moin Clay Member

The unit referred to above lithologically as the clay facies of the Rio Banano Formation will be referred to formally here as the Moin Clay Member of the Rio Banano Formation. This unit forms a flat plateau immediately to the west of Limon. These sediments outcrop over the entire six kilometer length to the plateau and are exposed in low shoreline outcrops near Portete and Piuta.

Gabb (1881) described rich mollusk faunas from outcrops of clay between Moin and Limon which he called the Moin (also Moen) clay beds. In his manuscript of 1874 (published in 1895), he employed the Moin Formation as a formal name for the first time without, however, precisely indicating a type locality. Hill (1898) refers to what are these same beds as the Pliocene Limon Formation (Limon [Moen] beds).

Woodring (1928, p. 27) calls the mollusk faunas from this sediment body the only large Pliocene fauna described from the Caribbean. This may be taken as an indication of its very young age since Woodring assigns a Miocene age to such strata as the Bowden Beds of Jamaica which, according to all planktonic foraminifera workers, belong in the Pliocene.

The clay and sand unit referred to by Gabb (1881) between Limon and Moin is recognized here as the Moin Clay Member of the Rio Banano Formation. The Moin Formation of Gabb (1881) is reduced to member status within the Rio Banano Formation because of its lithologic and mineralogic similarities to the Rio Banano sandstone facies. X-ray
diffraction analysis shows the clay mineralogy of the two sediment bodies to be nearly identical; both are also nearly the same color in both fresh and weathered outcrops. Grain size analysis of the Moin Clay Member shows a coarsening to the southeast with the coarser samples being very similar to finer-grained samples from the Rio Banano sandstone facies. These two sediment bodies appear to be closely related, suggesting that the Moin Clay Member is a deep water representative of the sandstone facies of the Rio Banano Formation. The Moin Clay Member, however, is a distinct sediment body that is easily recognizable in the field.

As was mentioned above, Gabb (1881) did not specify a type locality for his Moin Formation, specifying only that these sediments were to be found between Limon and Moin. A type locality for the Moin Clay Member of the Rio Banano Formation is here designated as the series of outcrops to be found in the bed of an unnamed stream 800 m east of Portete at 10°01'N, 83°03'30"W. This stream exposes approximately 2.5 km of this member and shows the grain size gradation noted below (see samples 1001-1018).

The Moin Clay Member of the Rio Banano Formation is a more highly variable body of sediment which, in general, shows a finer grain size and different depositional environment than the sandstone facies. Lithologic changes, distributed over at least five meters in the underlying sandstone facies, take place in one or two meters in the Moin Member.

This member is soft and easily eroded. Its color in fresh outcrop is a greenish gray (5GY6/1), showing a chroma and hue
difference of only one division from fresh Rio Banano sandstone facies. Its weathered color, a moderate brown (5YR 4/4) is also quite close to that found in weathered exposures in the older portions of the Rio Banano Formation. No sedimentary structures were observed, possibly having been destroyed by burrowing organisms. The Moin Member contains occasional local horizons with good mollusk faunas and an overall strong microfauna.

Grain size in this facies seems to show an irregular, but consistent increase to the southeast. This relationship was first noted in the field and later confirmed by thin section and sieve analysis of samples taken through the middle of the outcrop area of this member. Those samples farthest to the northwest (nearest to the present shoreline) are nearly pure clay while samples taken further inland toward the southeast are coarser. This grain size trend is probably indicative of a southerly or southeasterly source for this sediment body with the finer-grained portions being the farthest from shore at the time of its deposition.

"Pueblo Nuevo Sands"

A series of well-sorted sandstone bodies was also discovered behind and capping the thicker reefs of the Rio Banano reef facies. This series of sand bodies could possibly be considered to be a member or a facies of the Rio Banano Formation. It is almost certain, however, that the well-sorted sands are derived from older Rio Banano sandstone facies outcrops and should, therefore, be named separately. These sand bodies are of very limited extent and many of the present outcrops are being destroyed for road and building material.
To avoid burdening the stratigraphic literature with yet another name usable at only one locality, it was decided not to give a formal name to these sediments. As these sands are best exposed near Pueblo Nuevo, they will be referred to hereafter as the "Pueblo Nuevo Sands" with the understanding that this is not meant to be a formal stratigraphic name.

In outcrop, these sands are quite friable and easily crumbled. These "Pueblo Nuevo Sands" were not observed in fresh outcrop; weathered outcrops show a moderate yellowish brown color (10YR5/4). The outcrop character of these sands generally prevented the observation of sedimentary structures since these non-resistant sands generally form low, often badly-weathered outcrops. Two exposures, however, did show moderate angle (about 25°) cross-bedding up to five cm in height.

In the field, this sand has the appearance of being quite coarse and porous. Sieve analysis supported this idea, with most of the sediment falling into the sand category (see Appendix). Thin section analysis added the extra information that porosity is quite high. This high porosity evidently leads to high permeability since fossil remains are rapidly leached by ground water. Outcrops of these sands which were fossiliferous in 1968 (van den Bold, personal communication), were totally barren when sampled in 1970 by the author. Fresher outcrops commonly show leaching of the fossil fauna consisting of mollusks, foraminifera and/or ostracods. Extensive ground water circulation is also probably the source of the hematite cement noted in the thin section analysis of the "Pueblo Nuevo Sands." No hematite
cement or fossil leaching were noted in the more poorly sorted and less permeable Rio Banano sandstone facies.

Relationships between Facies in the Rio Banano Formation

The sandstone and conglomerate facies of the Rio Banano Formation seem to be conformable with one another. Although poor outcrop quality prevented a detailed examination of the contact, the Rio Banano sandstone facies appears to grade, albeit rapidly, into the coarser conglomerate facies. In a similar manner, the conglomerate facies appears to grade upward into typical Rio Banano sandstone facies lithology. No other facies of the Rio Banano Formation is in contact with the conglomerate facies.

The sandstone and reef facies of the Rio Banano Formation interfinger laterally and succeed one another vertically. This relationship is best shown in exposures in the Q. Chocolate valley, two of which are shown in Figs. 4 and 5. The reef rubble shown in Fig. 4 can be traced laterally into a thin reef. Fig. 5 is a drawing of an outcrop approximately one kilometer north of the exposure shown in Fig. 4 and shows an interstratified sequence of coral reef, reef rubble, and greenish sand of the Rio Banano sandstone facies. In all cases, the base of the reef material is relatively flat but the upper surface is irregular with reef pinnacles extending into the overlying sand. The lowermost sand layer in this figure contains a thin horizon of coral fragments, most of which are identifiable as _Porites_, with a few pieces possibly referrible to _Acropora cervicornis_.

Figure 4

Figure 5
Several samples taken from the exposure shown in Fig. 5 contained chunks of lignitic wood fragments. Attempts to date these fragments in the LSU Radiocarbon Laboratory were unsuccessful as the samples showed a radioactivity level which did not differ significantly from the background count. All that can be said about the age of these samples and the sediments from which they came is that they are at least $3 \times 10^4$ years old and probably much older.

The relationship between the sandstone and reef facies of the Rio Banano Formation is also well demonstrated in a series of outcrops found immediately behind the Standard Fruit Company box factory between Pueblo Nuevo and Limon, 2.5 km WSW of Limon. Here, bulldozing has uncovered a thick reef underlain by a broad expanse of Rio Banano sandstone with an excellent fauna of marine mollusks. Stream exposures beneath this reef show a number of smaller reefs less than one meter thick scattered throughout the Rio Banano sandstone. These reefs are accompanied by an increase in the numbers of solitary corals in the sandstone. As the main (largest) reef is approached from below, the size and number of these solitary corals increases as does the amount of non-coralline calcareous material, possibly indicating a physical or chemical environment which became increasingly more favorable for the formation of calcareous shells or colonies.

The Moin Clay Member of the Rio Banano Formation lies with an angular relationship on the coral reef trends and sandstone intercalations of the upper Rio Banano Formation. Paleontologic evidence, to be discussed in detail below, indicates that a hiatus,
if present at all, is negligible. The sediments of the Moin Clay Member are thin enough to permit the reef trends of the upper Rio Banano to be visible as ridges on air photographs. Field evidence suggests that the Moin Member was draped over these reefs, with the primary depositional inclination appearing to reflect folds in the Moin Member. This will be discussed in more detail in the Structure section.

The upper contact of the Moin Member is conformable with overlying Recent (in part, living) coral. Although the contact between the two lithologies is abrupt, there is an increase in the number of solitary coral species immediately below the contact, suggesting a gradual change to an environment more favorable to coral growth.

The contacts of the "Pueblo Nuevo Sands" with the underlying Rio Banano Formation facies are somewhat problematical as, in most outcrops, the contact is not visible. In the few outcrops which do show a contact, weathering has often destroyed many details. In some cases, however, reef pinnacles, which do not appear to be the result of leaching (karst topography on the reef) but rather a localized growth increase, can be seen protruding into the overlying "Pueblo Nuevo Sands." Growth lines in those parts of the reef are dome-shaped rather than roughly horizontal, giving the pinnacle the appearance of having been buried. There is no evidence of any transition between the coral reef facies and the "Pueblo Nuevo Sands."

Where no reef is present (for example, to the south of the reef at the box factory outcrop referred to above), "Pueblo Nuevo Sand" lies directly on the (marine) Rio Banano sandstone, again with no
evidence, either paleontologic or sedimentologic, of any transition. The lower contact, where it is visible, is rough and uneven and probable is unconformable. No sediments were observed to overlie the "Pueblo Nuevo Sands."

The relationship between the "Pueblo Nuevo Sands" and the Moin Member of the Rio Banano Formation is unknown in spite of the fact that both appear to unconformably overlie the reefs of the Rio Banano reef facies. Paleontologic evidence shows a wide difference in depositional environment; quite shallow for the "Pueblo Nuevo Sands" and rather deep for the Moin Member (see Paleontology section for more details). The Moin Member is younger than the bulk of the "Pueblo Nuevo Sands" so it is possible that the Moin Member overlies "Pueblo Nuevo" deposits. No evidence was seen for this in the field, however.
Environmental Interpretations

As might be expected from the wide variations in lithology within the Rio Banano Formation, these sediments were deposited under varying conditions. The source of these sediments appears to remain as the volcanic highlands to the west of the map area. Direct evidence for this comes from the volcanic pebbles found in the conglomerate facies as well as the calcic feldspars and pyroxenes found in both the conglomerate and sandstone facies (see data in Appendix). The high montmorillonite percentages found in all three clastic units of the Rio Banano Formation are also indicative of a volcanic source. Folk (1968) states that montmorillonite is typically formed "in a Mg-rich environment, most of it by alteration of volcanic ash...Marine diagenesis has little effect on volcanic montmorillonite, except to change adsorbed cations."

Sedimentary outcrops are also present in the source area as evidenced by the sandstone pebbles found in the conglomerate facies. The illite component of the clay fraction, found in all three clastic units is also somewhat indicative of reworked sedimentary rocks. Folk (1968) states that "much illite is derived from older illitic shales..." Some of the original illite may have been degraded (stripped of its K⁺ ions) during weathering and became montmorillonite when it entered sea water and regained much of its original K⁺ content. The textural inversion noted in the conglomerate facies with quartz grains being better rounded than the less stable feldspar grains suggests sedimentary outcrops in the source area shedding second or third generation quartz grains into the
Limon Basin.

Considerable information is available concerning the depositional environment of these sediments. Paleontological data from the Rio Banano sandstone facies, to be covered in detail below, indicate that that facies was deposited, for the most part, in a shallow marine environment. The wide range in lithology that was noted in the field and borne out by the grain size analysis (see Appendix) indicates that conditions were quite variable over the depositional basin. Locally strong currents created the festoon cross beds and ripple marks noted in this facies. The limited extent of these sedimentary structures indicates that the currents were not persistent for any significant period of time. Further indications of a shallow environment for the sandstone facies comes from the extensive bioturbation noted in the sediment. Although this process is by no means limited to shallow water sediments, it is more common in sediments deposited in that environment (Visher, 1972; Warme, 1971).

The pebbles of the conglomerate facies of the Rio Banano Formation are indicative, most probably, of either hard shoreline outcrops being reworked by cyclic storm action or of normal stream deposition. Other hypotheses are possible, however, such as cyclic tidal channel deposits or a migrating sand-gravel bar. The repetitive nature of this facies with a basal conglomerate and scour followed by upward fining would most favor the stream hypothesis. This would be a normal sedimentary process with the conglomerate layer being the result of flooding. It is also possible that these pebble layers resulted from cyclic storm erosion of lithified
beach deposits. This interpretation would require two different lithologies (basalt and sandstone) outcroppings near one another, an occurrence which is not at all unreasonable. The larger drainage area of a stream would, however, make it easier for these disparate lithologies to be found in the same sediment body. A third possible interpretation for these graded beds is that they are the result of higher stream gradients due to volcanic uplift and/or tectonic uplift in the source areas. Although possible, this latter explanation is tenuous at best due to the short duration of this sedimentary episode as well as its repetitive nature, which would involve repeated volcanic and/or uplift surges over a fairly short period of time.

The reef facies of the Rio Banano Formation is indicative of shallow water since the hermatypic coral species found in these reefs must live within the photic zone. Although this may be over 100 m deep in clear tropical waters, a lower limit is placed on the depositional environment of this facies. Its association in lateral continuity with the shallow water clastic sediments of the Rio Banano sandstone facies further supports a shallow marine environment of deposition for the reef facies of the same formation.

The Moin Clay Member of the Rio Banano Formation was deposited in a middle- to outer neretic environment, according to paleontological evidence. The small grain size (mudstone) found in this facies indicates a quiet environment of deposition. The total lack of any sedimentary structures is most probably the result of intensive
burrowing.

The discontinuous nature of the "Pueblo Nuevo Sands" makes interpretation of their origin difficult since no paleontologic or lithologic trends can be established. Fossil evidence suggests at least some mixing of fresh and salt waters since both normal marine and brackish faunas are found in these sands. The probable unconformable nature of these sediments to normal marine sediments (both carbonate and clastic) could be explained in two ways. The unconformity could be erosional in nature with some hiatus involved. The presence of essentially undisturbed reef pinnacles projecting into the "Pueblo Nuevo Sands", however, suggests a more rapid environmental change. Any erosion would be expected to attack these relatively thin (3-6 cm), high pinnacles first and form a smoother surface than the contorted one noted above.

The preservation of these pinnacles suggests that the reef was buried quickly before erosion could begin to reduce these topographic highs. The high degree of sorting shown by this sand is indicative of currents in the area with some degree of persistence to move the fine fraction of these sediments away. The presence of brackish faunas suggests fresh water influx, possibly due to periodic climatic changes causing heavier than normal rainfall, changing a normal marine environment temporarily into a brackish one.

Further indications as to the origin of the "Pueblo Nuevo Sand" comes from their distribution. They are found associated with the thicker, more extensive reef trends. The smaller reefs are
capped by sediments of the Rio Banano sandstone facies while the thicker reefs are most commonly covered with the better-sorted "Pueblo Nuevo Sands." This relationship suggests that the "Pueblo Nuevo Sands" are actually derived secondarily by reworking of sediments of the Rio Banano sandstone facies. This reworking could be done by tidal currents flowing through and around the reefs in a manner similar to that observed by the author in the Florida Keys. These tidal currents would be the strongest around the offshore reefs and weakest further inshore, where the reefs are also smaller. Periodic floods could distribute a blanket of sediment over the entire area which these tidal currents could sort, removing the finer fraction into deeper water outside of the reefs. This hypothesis for the origin of the "Pueblo Nuevo Sands" could theoretically be tested by determining whether there is a gradual gradation from well-sorted "Pueblo Nuevo Sand" to poorly-sorted Rio Banano sandstone facies sediments. The nature of "Pueblo Nuevo Sand" outcrops is such, however, that this cannot be done.
Suretka Conglomerate

The Suretka Conglomerate was first described by Berry (1921) from outcrops near the village of Suretka (now abandoned) in the Rio Sixaola area of southeastern Costa Rica. In the Limon area, the conglomerate is exposed over a broad area west of Limon in roadcuts and stream exposures. Although no direct relationship exists between the type locality and the Limon outcrops, no age or lithologic difference can be shown between the two occurrences. Neither can any age equivalence be demonstrated. Since no significant differences can be shown between the type occurrences and the Limon Conglomerates, the term Suretka Conglomerate has been retained in the Limon area to avoid burdening the stratigraphic literature with yet another local formation, even though the Limon occurrences may not be related in any way to the Rio Sixaola sediments. Since no upper contact was observed, no estimate can be made for the thickness of this formation in the Limon area. A minimum thickness of ten meters is indicated by outcrops of that height, however.

This conglomerate contains a wide variety of grain sizes ranging from clay particles to boulders up to a meter in diameter. These widely-separated grain sizes do not occur together, however, as the formation is internally divided into many distinct sediment bodies (not mappable at the scale of this report), each of which is well-sorted.

The Suretka is characterized by an abundance of moderate-angle (25°) cross-bedding and trough cross-stratification. Small cross beds are best developed in an isolated outcrop of sand and
gravel near Sandoval where cross beds up to five cm high are found. Cross-bedding is also developed in the more extensive exposures along the Limon-San Jose road but on a much larger scale (on the order of meters rather than centimeters). The most common sedimentary structure in Suretka outcrops is trough cross-stratification. This is especially well-developed in the Rio Toro area where symmetrical and asymmetrical bodies of cobble-sized particles cut across sand bodies, and boulder beds interrupt cobble and sand layers.

Contacts

The Suretka-Rio Banano contact was mapped on the basis of the upstream limit of Suretka-lithology cobbles and boulders in the stream gravels. This contact is often also marked by the reappearance of Rio Banano sandstone facies outcrops. The presence of a boulder or cobble conglomerate on top of the Rio Banano makes it difficult to determine if any angular relationship exists between the two since dips were patently impossible to determine in the Suretka due to the nature of the formation. The relationship between the Rio Banano and Suretka Formations seems to be an angular unconformity with some scour indicated at the base of the Suretka. No overlying sediments were observed.

Source

The high percentage of basaltic rock fragments found in the Suretka as well as its clay mineralogy (chlorite and montmorillonite) demonstrates a basic igneous source for this sediment, obviously the volcanic belt a few tens of kilometers to the west. No sedimentary rock fragments were noted in the Suretka.
Depositional Environment

The sedimentary structures found in the Suretka Conglomerate are indicative of deposition in a fluviatile environment when compared with data in Visher (1972). The width of the outcrop band (some 15 km of nearly continuous exposure) suggests that a major stream was responsible for Suretka deposition. The more southeastern exposures (in the Rio Toro area) are much more significantly weathered than outcrops further west. This shows evidence for a net northwestern migration of the stream in addition to its considerable short-term lateral migrations, evidenced by the rapid lateral changes in sediment characteristics.

A part of the Suretka outcrop area includes the flood plain of the Rio Chirripo, a river approximately 40 km north-north-west of Limon. Although it is presently depositing cobble and pebble-sized particles, the presence of large boulders on its banks shows that its flow regime has been considerably different in the not too distant past. Air photos show that this stream meanders greatly and is commonly braided. This stream is most probably similar to the type of stream responsible for the deposition of the entire Suretka Conglomerate, even to its highly variable flow regime.

Because no fossils were found in the Suretka and attempts to obtain radiocarbon dates on wood fragments taken from these sediments showed only negative results, the age of this formation cannot be positively determined. Because it is the youngest stratigraphic unit in an area of known Pleistocene deposits and includes recent deposits, it most probably is of late Pleistocene to Recent
age.
PALEONTOLOGICAL DATA

Field Collecting of Samples

During the course of the field work for this project, an extensive sediment sampling program was undertaken. The location of each sample was determined by the author on the basis of outcrop freshness (leached or weathered outcrops were avoided whenever possible), proximity to other sample locations, and lithologic uniqueness (monotonous lithologies were sampled less frequently than areas with rapidly changing lithology). In the case of long, more or less continuous outcrops, samples were taken at measured intervals, at lithologic changes, or both. A completely statistical sampling program with sample locations determined by random selection on a grid or at specific measured intervals was deemed logistically impractical due to the irregular distribution of small outcrops throughout the area. A purely statistical sampling program, if carried out in an area with this kind of outcrop pattern, would result in many samples not showing bedrock but rather soil or Recent stream deposits. Shipping costs prohibited any but outcrop samples. Logistics problems also led to the non-random sampling program with the most accessible areas being along roads and streams, where most of the outcrops are also located.

Processing

The samples taken were processed for micropaleontological examination by Varsol preparation and standard washing techniques,
using a Curtain power washer with a 200-mesh sieve. To prevent contamination from sample to sample, this sieve was immersed in green dye after each sample and green-stained fossils were discarded.

Isolation of Specimens

Collections of macrofossils were made in the field in horizons containing good faunas. These specimens were removed individually from the outcrop and high graded in the field to select the best representative sample possible while maintaining a reasonable collection size. These specimens were wrapped individually in soft paper for shipment.

Microfossil collections were made utilizing standard micropaleontological picking techniques. The greater majority of the samples were examined until 300 individual ostracods and/or foraminifers were found, or until the sample was determined to be barren or nearly so. According to Dennison and Hays (1967), the examination of 300 individuals permits the detection of any species which comprises at least 2% of the population. Samples with high percentages of planktonic foraminifera, which have a greater potential of being biostratigraphically significant, were examined until 1000 individuals had been counted. According to Dennison and Hay (1967), this permits the detection of forms which comprise as little as 0.5% of the population. These percentages are given for a significance level (α) of 0.01 (1% probability of missing a species present in
greater than 0.5% or 2% of the population. Since no statistical analysis of these faunas has been attempted, the application of the more detailed technique to a few samples will introduce no bias. The increased probability of detecting species present in low frequencies greatly increases the reliability and precision of biostratigraphic determinations.

Specimens were selected for the faunal plates (see Appendix) on the basis of the best specimen of that species observed. Foraminifera were photographed on a Joelco JSM-2 Scanning Electron Microscope following the evaporation of a gold thin film coating over the specimens. Macrofossils were whitened with magnesium oxide and photographed with a 35 mm camera. These plates are not all-inclusive of the Limon faunas since many of the species (both macro- and microfossils) did not have specimens which were well enough preserved for inclusion. The plates are, however, representative of the faunas since no common or significant form was excluded.

**Faunas Found**

**Uscari Shale**

The Uscari Shale samples contained some of the most prolific faunas encountered. Following is a list of the more common species found in the Uscari Shale.
Rio Banano Formation

Faunas recovered from the Rio Banano Formation are quite varied, as might be expected from its variable lithology. The basal portion of the sandstone facies contains a fauna with some elements of the Usctari list above. This basal Rio Banano sandstone facies fauna includes:

- Quinqueloculina sp.
- Globigerinoides trilobus
- Lenticulina calcar
- Pyrgo sp.
- "Cibicides" floridanus
- Hanzawaia strattoni
- Frondicularia sp.
- Globorotalia cultrata cultrata
- Globorotalia cultrata menardii

The stratigraphically younger portions of the Rio Banano sandstone facies contain different faunial elements. Samples from the upper portion of the Rio Banano sandstone facies commonly include the following foraminiferal species:

- Cribroelphidium poeyanum
- Amphistegina lessoni
- Cribroelphidium gunteri
- Reussella atlantica
- Floralis atlantica
- Ammonia beccarii

- Bolivina striatula
- Archaias compressus
- Globigerinoides trilobus
- Globigerinoides ruber
- Hanzawaia strattoni
- Orbulina universa
Faunal List - Upper Rio Banano sandstone facies (continued)

Siphonina pulchra  
Poroeponides repandus  
Planulina foveolata

Samples taken from the conglomerate facies of the Rio Banano Formation were, for the most part, barren. One sample which did have a fauna present contained the following species:

Neoeponides regularia  
Globorotalia cultrata menardii  
Textularia conica  
Assorted miliolids  
Pyrgo sp.  
Textularia panamanensis

Cribroelphidium gunteri  
Nodobaculariella sp.  
Rosalina floridana  
Globigerinoides trilobus  
Poroeponides repandus

No attempt was made to separate foraminiferal faunas from the reef facies of the Rio Banano Formation. Faunas were derived, rather, from the closely-associated sandstone facies samples.

The Moin Member of the Rio Banano Formation also contained a prolific and varied foraminiferal fauna. This fauna commonly included the following species:

Globorotalia truncatulinoides  
Globorotalia cultrata menardii  
Marginulinopsis marginulinoides  
Orbulina universa  
Bolivina subaeneriensis  
Assorted miliolids  
Planulina foveolata  
Tritaxia mexicana  
Nodosaria sp.

Sphaeroidinella dehiscens  
Sigmoilopsis schlumbergeri  
Uvigerina perigrina  
Globigerinoides trilobus  
Globigerinoides ruber  
Pulleniatina obliquiloculata ss.  
Globoquadrina dutertrei  
Siphonina pulchra  
Siphonina bradyana

Samples from the "Pueblo Nuevo Sands" generally show a rather depauperate and limited fauna with the following forms comprising most of the population:

Cribroelphidium poeyanum  
Assorted Miiliolids  
Ammonia beccarii

Amphistegina lessoni  
Hanzawaia strattoni  
Cribroelphidium gunteri
Suretka Conglomerate

None of the samples taken from Suretka Conglomerate outcrops showed any fossil material at all.

Biostratigraphy

Age determinations for this study were done exclusively with planktonic foraminifera to avoid the correlation of facies rather than time intervals, a problem which commonly crops up when attempts are made to use benthonic organisms for establishment of ages.

Specific determinations for this study were made from Blow (1969), Postuma (1966) and Berggren (1973). Stratigraphic ranges for these species follow Blow (1969). Data from Lamb and Beard (1972) were not used in the biostratigraphic analysis because the author feels that significant discrepancies exist between their work and what has been published on the Calabrian faunal succession in the Italian type section, which is the basis for determining the basal Pleistocene. These discrepancies result in significantly younger age determinations when compared to data from other workers. Distribution charts for all samples are included in the appendix as an aid to future evaluation of the Limon data.

Good planktonic foraminiferal assemblages were recovered only from the Uscari Shale, the lower Rio Banano sandstone facies and from the Moin Clay Member of the Rio Banano Formation.

Uscari Shale

The Uscari Shale samples, while having a more abundant
planktonic fauna, did not contain the indicator species necessary for detailed zonation, permitting refinement only to an N.14 to N.18 determination (middle Miocene to lower Pliocene). This age is based on the concurrent ranges of *Globorotalia cultrata menardii* and *Sphaeroidinellopsis subdehiscens s.s.*

**Rio Banano Formation**

**Basal sandstone facies**

The most accurate biostratigraphic determinations (based on the presence of more short-ranging species) were made from the basal Rio Banano sandstone facies. Sample 1146, for example, shows a good N.18 fauna (upper Miocene to lower Pliocene age). This age determination was made on the basis of the concurrent ranges of *Sphaeroidinellopsis subdehiscens s.s.* and *Globigerinoides conglobatus s.s.* This age determination is supported by data from sample 1148, taken approximately 75 m stratigraphically above sample 1146. Sample 1148 shows a mid N.17 to upper N.18 age (lower upper Miocene to lowermost Pliocene). This age determination is based on the concurrent ranges of *Pulleniatina obliquiloculata* and *Sphaeroidinellopsis subdehiscens s.s.*

**Upper sandstone facies**

Although most of the samples from the upper portion of the Rio Banano sandstone facies contained a biostratigraphically non-diagnostic fauna, samples 1070 and 1233 from the Empalme Moin area are datable. The presence of *Pulleniatina obliquiloculata primalis*
in sample 1233 would place its age between mid N.17 and lower N.20 (late Miocene to upper middle Pliocene). Sample 1070 contains *P. obliquiloculata praecursor*, whose stratigraphic range is N.19 to middle N.21 (upper lower Pliocene to uppermost Pliocene). The apparent position of these two samples nearly on strike with one another suggests that the sediments in the Empalme Moin area may be middle Pliocene (N.19 to middle N.20) in age. It cannot, however, be absolutely demonstrated that these two samples came from the same stratigraphic unit, so this age refinement is speculative. These two samples do, however, demonstrate at least a Pliocene age for sediments in the Empalme Moin area.

**Moin Clay Member**

Samples from the Moin Clay Member of the Rio Banano Formation from the plateau west of Limon show an excellent planktonic foraminiferal fauna. These samples all contain *Globorotalia truncatulinoides*, a form which is restricted to the Pleistocene (Bolli, 1966; Blow, 1969; Berggren, 1973). The presence of *Sphaeroidinella dehiscens excavata* permits further refinement since Blow (1969) restricts that subspecies to his N.23 zone (*Globigerina calida/Sphaeroidinella dehiscens excavata* assemblage zone) which is late Pleistocene to recent in age. Other planktonic forms present which are not, however, of biostratigraphic importance are: *Globigerinoides trilobus, G. elongatus, G. sacculifer, G. ruber, Globorotalia dutertrei, Globorotalia cultrata s.s., G. cultrata*
menardii, Orbulina universa, Spaaeroidinella dehiscens and miscellaneous Globigerina sp. This Pleistocene determination from the Limon area is supported by data from Akers (1973) on planktonic foraminifera from the Limon area.

Strong differences of opinion exist between mollusk specialists and planktonic foraminiferal workers on the age of these sediments. Olsson (1922) reports an early Miocene age for the Type Uscari although this author has determined a younger late early to early middle Miocene age (zones N.8-N.10) on samples from the type area of that formation. Nothing as young as Pleistocene has been reported by mollusk workers, yet the author has found a rather large area of Pleistocene outcrop (determined as Pliocene by Gabb (1881), a determination with which Woodring (1928) concurs). These differences may be due to the nature of the organism used for dating. Planktonic foraminifera, while showing a certain amount of provincialism in that they are not found in abundance in shallow water and are temperature controlled, nevertheless show variations only over several tens of degrees of latitude. Mollusks, on the other hand, are strongly facies controlled, and a good possibility exists that facies, rather than time intervals, are being correlated. The most commonly-used method of dating by mollusk workers, that of determining the percentage of extant species in a fossil fauna, compounds the correlation problem. Although it is the author's firm belief that the planktonic foraminifera are a more biostratigraphically reliable group of organisms, this discrepancy between mollusk and
planktonic foraminiferal dates will have to be resolved in the future.

**Depositional Environments**

**Previous Work**

Paleoecologic analyses and paleontologic determinations were done principally by comparison with data presented by Phleger and Parker (1951), Albens (1966), Cebuski (1967), Bandy (1954, 1956) and Smith (1964). Most of these references cover faunas slightly deeper than the majority of the faunas found in this study, making Bandy (1954) the most useful reference, both for specific determinations and paleoecologic analyses, due to its considerable information on very shallow water faunas.

Bandy (1954) divided the inner and middle neritic environments into four zones. Not all of the species that he utilized were present in the Limon shallow water samples, possibly due to the warmer Caribbean waters in contrast to Bandy's sampling area in the Gulf of Mexico, 20-30 degrees further north.

Very shallow water (1-11 m) is characterized, in the Limon area, by a fauna comprised of *Archaiastr compressus*, *Florilis atlanticus*, *Cribroelphidium gunteri*, *Ammonia beccarii* and sometimes *Cribroelphidium poeyanum* with low planktonic percentages (0-20 percent).

Deeper water (11-25 m) is characterized by *Rosalina floridana*, *Hanzawaia strattoni*, *Planulina foveolata*, *Asterigerina carinata*, and rarely, *Quinqueloculina horrida*. This fauna is accompanied by more planktonic foraminifera, commonly comprising 15 to 35 percent of the
foraminiferal fauna.

The zone between 25 and 60 meters is characterized by *Planulina foveolata* and *Bigenerina irregularis* with the disappearance of *Rosalina floridana* from the fauna. *Uvigerina perigrina* also makes its first appearance here. Planktonic percentages climb higher to 30-50 percent of the foraminiferal fauna.

Bandy's fauna 4 (Bandy, 1954), representing water depths from 60 to 90 meters is represented in the Limon area by *Planulina foveolata*, *Uvigerina perigrina*, *Eggerella bradyi* and *Hanzawaia concentrata*. Planktonic percentages are even higher here, averaging between 50 and 70 percent of the foraminiferal fauna.

The shallow (littoral) habitat is strongly dominated by *Ammonia beccarii* and *Cribroelphidium poeyanum*. This environment is also often marked by the presence of a rich ostracod fauna, especially the genus *Perissocytheridea* and possibly *Reussicythere* (van den Bold, personal communication). A relationship shown in Bandy (1954) between salinity and generic distribution can probably be extended into the Caribbean. This shows a salinity range of 5-36°/oo for *Ammonia*, 10-36°/oo for *Cribroelphidium*, 20-36°/oo for Miliolids and 27-36°/oo for other species.

In many cases, the overlap of the indicator species listed above were used to informally subdivide these depth zones. For example, the occurrence of *Rosalina floridana* and *Bigenerina irregularis* together would suggest a depth toward the bottom of the *Rosalina-Planulina* and the top of the *Planulina-Bigenerina* depth zones or about 30-40 meters.
The sample by sample results of the paleontological analysis are incorporated in distribution charts in the back pocket of this report.

In general, the paleoecologic analyses made were internally consistent with no sample or group of samples contradicting the overall pattern to be presented below.

**Environmental Determinations**

The samples analyzed show four main faunas indicative of the following environments: outer neritic (300-600 m), middle neritic (+100 m), inner neritic (1-70 m), and a shallow brackish environment (1-10 m). These depth suggestions result from a comparison of the faunas from Limon and the depth-salinity information from the literature cited above. Although some paleontologists might draw somewhat different conclusions as to absolute water depth, the relative depth determinations would generally be the same regardless of the analyst.

**Uscari Shale**

The deepest environment was found in samples from the Uscari Shale on the north bank of the Rio Banano, especially sample 1150. This outer neritic environment is characterized by a high percentage (60-80%) of planktonic foraminifera with the benthonic fauna strongly dominated by *Uvigerina perigrina* and *U. hispido-costata*. Also present in the fauna were *Pullenia bulloides*, *Nodosaria pyrula*, *N. lamnulifera* and "*Cibicides* floridanus*. This fauna suggests deposition in 200 to 400 meters of water with sample 1150 possibly
being as deep as 500 meters.

**Rio Banano sandstone facies**

Immediately across the Uscari-Rio Banano contact in the Rio Banano sandstone facies, sample 1148 shows an abrupt shallowing to an outer to middle neritic environment (100-150 m). The horizontal distance between this sample and those taken in the Uscari is 180 m with the Uscari-Rio Banano contact between the two groups of samples. This horizontal distance translates to approximately 90 m of stratigraphic separation. Unfortunately, the close-spaced samples taken across the contact area were barren, precluding a more precise location for this environmental change.

Samples 1146 and 1147, taken in the lower portion of the Rio Banano sandstone facies approximately 300 m stratigraphically above the near-basal sample 1148, show deposition in even shallower water with a 20-50 m depth range. This overall shallowing trend continues to sample locations 1145 and 1144a, another 250 m stratigraphically above sample 1147, which show deposition in only 10-20 m of water. This last shallow water fauna is found through the remainder of the samples taken to the east toward La Bomba with an occasional sample showing an even shallower 1-10 m depth (see samples 1132 and 1163, for example).

The south side of the Rio Banano shows a similar relationship between faunas with the exception that the deepest marine environment was not found. It is believed that this lack of the deeper environment is due to sampling problems rather than an actual
environmental difference from one bank of the river to the other. The Uscari-Rio Banano contact on the south side of the river has been shifted south and west by faulting into a remote area with few outcrops in the Uscari Shale. Sample 1183, taken in the immediate vicinity of the contact in the Rio Banano sandstone facies, shows a fauna characteristic of deposition in approximately 100 m of water. A shallowing sequence found in samples taken stratigraphically above this sample is almost identical to that found on the northern bank of the river. This parallelism suggests to the author that both sides of the fault (which trends up the modern river channel) had the same tectonic and sedimentologic history and that the deeper marine facies are actually present on the southern side of the fault but were not sampled due to the remoteness and paucity of the outcrops.

Samples taken from the upper portions of the Rio Banano sandstone facies in the Q. Chocolate-Q. Bartolo area vary in depth from very shallow (less than five meters) to around 20 m. (samples [1019-1063]), at the deepest. Although there is no strong evidence from the foraminifer and ostracod populations, there may be some brackish influxes in the Q. Chocolate area (two samples, 1060 and 1063 do contain a brackish fauna). These possible brackish layers are marked by a restricted macrofauna with Crassostrea, a form which has been restricted to a brackish environment in recent sediments by the oyster drill. Several instances of Crassostrea shells filled with
sediment containing a marine foraminiferal fauna indicate the possibility of considerable reworking and distribution of sediment and fossils. This implies periodic strong currents crossing a brackish environment, moving some of the macrofauna offshore and leaving it as a lag deposit in a normal marine environment.

Rio Banano conglomerate facies

The samples taken from the Rio Banano conglomerate facies in the Nuevo Castle area show a fauna characteristic of deposition in shallow marine conditions (1-10 m).

Moin Clay Member of the Rio Banano Formation

A fauna indicative of middle to outer neritic environments was found in the samples from the Moin Clay Member outcrops found west of Limon. This fauna is characterized by a high percentage of planktonic foraminifera (60-80 percent) and a benthonic fauna with Planulina foveolata, Uvigerina perigrina, Bolivina subaeneriensis and Siphonina pulchra. Also present, although in lower frequency, is Tritaxia mexicana and miscellaneous Nodosaria species. This fauna is characteristic of deposition in a middle to outer neritic environment (60-100 m). The samples furtherest north (see sample 1004) have a fauna which, according to data in Phleger and Parker (1957), most likely lived in 90 to 100 meters of water. Sample 1018, taken near the middle of the plateau, does not contain as high a percentage of the deeper forms such as Uvigerina perigrina and shows the appearance of shallower forms such as Siphonina pulchra and Virgulina sp. The suggested depth of deposition for this sample
is 60-90 meters.

"Pueblo Nuevo Sands"

Samples from the "Pueblo Nuevo Sands" show a mixture of environments. Some samples show a normal shallow marine fauna consisting of *Cribroelphidium poeyanum*, *Amphistegina lessoni*, assorted Miliolids, *Textularia conica* and *Globigerinoides trilobus* with around 5% planktonic foraminifera. The ostracods from these samples also show a very shallow environment under normal or near-normal salinities (van den Bold, personal communication). Other samples show a distinctly brackish fauna of *Ammonia beccarii*, *Cribroelphidium poeyanum* and *C. gunteri* along with brackish ostracods (*Perissocytheridea* sp. and possibly *Reussicythere* sp. -van den Bold, personal communication). Since these beds are defined on the basis of a particular lithology (a well-sorted sand), it is evident from the paleontological data that these sediments were deposited in different or possibly periodically changing shallow water environments.

**Mollusk Faunas**

Numerous horizons in the Rio Banano sandstone facies, Moin Clay Member, and "Pueblo Nuevo Sands" yielded mollusk faunas. These collections were turned over to Dr. E.H. Vokes of the Tulane University Department of Geology who kindly identified the specimens. Representative species from this study and previous collections by Dr. Vokes are figured in Plate 12.

On the basis of fairly restricted, possibly non-representative sampling, there appears to be some form of faunal restriction shown by
the mollusk faunas: the Moin Clay Member of the Rio Banano Formation contains a deeper water fauna including *Sconsia striata*, *Drillia macilenta* and *Conus mayei*. According to Dr. Vokes (personal communication), this latter species has been reported only from deep water sediments between 92 and 240 fathoms (184 to 480 m). *Sconsia striata* is also a deep water form. This deep water mollusk fauna gives independent support to the foraminiferal paleoecologic determinations.

The remaining mollusk faunas do not show the restrictions found in the Moin Clay Member. Outcrops of "Pueblo Nuevo Sand" often show *Murex olssonii*, *Fusinus miocosmus* and *Dermomurex aspella*. Rio Banano sandstone facies collections commonly include *Voluta virescens*, *Chicoreus* sp. (commonly *C. moinensis*) and *Conus recognitus*.

Plate 12 does not contain all of the mollusk species in the Limon area but is representative of the faunas found. Many of the specimens were not preserved well enough for inclusion in the plates. Others were well-preserved in the outcrop but had been leached to the point where they could not be removed from the matrix without breaking the specimen.
Radiocarbon Dating

The presence of wood fragments in several samples from the Rio Banano sandstone facies and the Suretka Conglomerate led the author to attempt to date these samples by radiocarbon methods. Nine samples of both wood and shell were processed by the author in the LSU Radiocarbon Laboratory in the Nuclear Science Department, but the material was radiometrically dead.

This laboratory utilizes the benzine process for radiocarbon dating. In this process, the carbon is liberated from the sample as carbon dioxide by acidification, in the case of carbonate material, or by burning in pure oxygen, in the case of wood fragments. This carbon dioxide is then run onto pure lithium metal heated to 700°C to produce lithium carbide. The addition of water to the lithium carbide produces acetelyne gas which then passes onto a vanadium catalyst, converting the acetelyne to benzine. To this known volume of benzine is added a measured amount of a liquid which fluoresces upon alpha particle bombardment. This mixture is then placed in a Beckman Liquid Scintillation Counter for at least ten 100 minute counting periods in alternation with National Bureau of Standards oxalic acid and petroleum coke standards. Age calculations are made on the basis of a ratio of the net counts per minute per gram for the sample to that of the oxalic acid contemporary standard.

Nine samples were processed in the laboratory: samples 1052, 1053, 1056, 1060, 1093, 1010, 1025, 1047, and 1239. None of the samples gave a usable date with none having a mean disintegration count that
was significantly above that of the background standard (petroleum coke NBS standard). Although the lack of success with this method prevents any positive conclusions, the negative evidence that even the stratigraphically youngest sample processed (sample 1010) was at least 30,000 years old is useful data.
STRUCTURE

Folds

The major structural feature in the Limon region is the Victoria Dome, which was defined by mapping by Union Oil. This dome is centered at Petroleo, to the southeast of the study area. The northeast-dipping strata of the Limon area are on the northeast flank of this doubly-plunging anticline. In the map area, the dome can be demonstrated by the change in strike from east along the Rio Blanco, to WNW along the Rio Banano, to north in Q. Maria Luisa and then back to NW further to the southeast of Q. Maria Luisa. The dips also generally flatten to the northeast, away from the dome center.

The northeast flank of the dome is also roughly outlined by a persistent topographic ridge which occurs in the Rio Banano Formation, hereafter referred to as the Rio Banano ridge, between the Rio Banano and the Rio Blanco. It changes in strike from east-west along the Rio Blanco to NNW-SSE along the Rio Banano. This ridge, which was observed only on topographic maps, is believed to be the result of a resistant layer or layers similar to those described above as the conglomerate facies of the Rio Banano Formation near Nueva Castle. This Rio Banano ridge is indicated on the geologic map (see pocket in back) by oversized attitude symbols with no order of magnitude indicated for the dip. As can be seen from the map, this ridge appears to be offset across the Rio Banano.

The strata generally dip away from the center of the dome,
although some exceptions are found. The Q. Chocolate exposures show two broad, gentle folds which cause the reef section to repeat in outcrop. Total dip changes across these folds are in the order of magnitude of 20-25 degrees.

Another set of broad folds is found in the Empalme Moin area. These are shown by dip information obtained primarily from the Moin Clay member. Total dip changes across these features are also in the 20 to 25 degree range.

**Faults**

Three faults were recognized on the basis of stratigraphic offsets and field relations. None of the faults mapped showed any evidence of an escarpment or of fault gouge.

All of the faults (or fault zones) mapped are on the site of streams. The largest of these is a combination flexure and fault zone which is presently the site of the Rio Banano. It shows a horizontal offset of the Uscari-Rio Banano contact of approximately one kilometer with the northern block being upthrown relative to the southern. Using an average dip of 30° over the area, this would imply a vertical displacement of 200 to 250 m. The offset of the Rio Banano ridge mentioned above is in the same direction and of the same magnitude as the offset of the Uscari-Rio Banano contact. Further evidence for this fault zone was found on the river bank in the Uscari Shale 100 m south of the Rio Banano contact where a small fault has downfaulted a wedge of Rio Banano sandstone facies into the Uscari.
Two other faults were mapped, one trending down the Rio Blanco and the other down the Rio Madre. Both were mapped on the basis of stratigraphic offsets of the Uscari-Rio Banano contact.

There is a suggestion on the topographic maps that the Rio Banano ridge may be offset along a line which skirts the southern flank of the Limon promontory. This may indicate the presence of a northeast-southwest trending, down-to-the-southeast fault which is buried in the alluvium closer to Limon. Due to the remoteness of the area of this possible fault, it was not possible to examine the area of the Rio Banano ridge for further evidence of this fault. This apparent topographic offset is the only evidence for this fault and there is no apparent offset of the topographic expression of the Uscari-Rio Banano contact.

All of these faults are regarded as hinge faults with displacements decreasing to zero at the center of the dome.

Relative motion analysis of these faults shows all of them to be down-to-the-southeast faults, except for the one which trends down the valley of the Rio Madre, which is a down-to-the-west fault.

A more complex structural interpretation of this area, invoking a considerable amount of post-depositional deformation is also possible. The reef trends could be interpreted as being repeated by eastward-plunging folds. This interpretation would necessitate a major compressional period, which is not reflected in the regional geology of southern Central America (Dengo, 1962). The more complex interpretation would also need a reef approximately five kilometers square, a rather unlikely occurrence.
GEOLOGIC HISTORY

According to Hoffstetter (1962), sedimentation in eastern Costa Rica during the Paleogene and early Neogene was primarily deep marine, reflecting a relatively stable, slowly subsiding basin. During the early Pliocene, this tectonic stability was ended by a period of regional uplift and volcanism.

The uppermost Miocene-lower Pliocene in the Limon area reflects this regional tectonic change. Paleoecologic information shows a rapid shallowing from the deep marine Uscari Shale (300-500 m) to the quite shallow (+20 m) Rio Banano sandstone facies. Sediments also became noticeably coarser as is evidenced in the grain size difference between the Uscari Shale and Rio Banano sandstone facies.

Much of this shallowing in the Limon area is probably due to the formation of the Victoria Dome. The cause of its formation is not known but is undoubtedly related to the regional tectonic change. During this period of time, the entire southern Central American orogen was affected by uplift and volcanism, some intrusions and uplift. The Limon area, being more remote from the center of tectonic activity, was not lifted above sea level as were the Talamanca land masses to the west as all samples taken for this study indicate that marine or near-marine conditions existed during most of the geologic history of the area. Although considerable shallowing is noted in the Limon area, there is no evidence to demonstrate any unconformity within the Miocene-Pliocene succession. The uplift of the Talamanca source area would be expected to change the sedimentary regime of the Limon area from slow (shale) to rapid
(sandstone). This change in regime has been noted above as the change from the Uscari Shale to the basal Rio Banano sandstone facies.

During the deposition of the greater part of the Rio Banano sandstone facies, tectonic conditions evidently stabilized as indicated by the nearly constant depositional environment. Normal marine sedimentary processes gradually deposited the mass of sandstone and siltstone referred to here as the Rio Banano sandstone facies.

Although no direct evidence can be shown to indicate the origin of the rapid vertical and horizontal changes in lithology noted in both the field descriptions and laboratory analyses of the sandstone facies, combined with the tectonic stability noted above, several hypotheses will be put forward. It should be noted that these suggestions are speculative and not supported by any specific evidence. They are being presented to indicate what the author's thoughts are concerning the problem.

Source area changes could conceivably explain these rapid lithologic changes to some extent although uplift or increased volcanism would be more likely to produce greater, more consistent lithologic changes rather than the minor, rapid changes noted in the sandstone facies. Changes in stream regime could cause these rapid, local changes, however. Episodes of strong stream flow would naturally bring coarser material into the area while slower flow would deposit finer silt and clay. This hypothesis is strengthened by the presence in several outcrops of coarse sand layers with ripple marks on top overlain by a silty clay (see p. 23). The ripple marks give evidence of a current much stronger than could have been
present during the deposition of the silty clay.

These continuous and rapid changes in stream regime are a common occurrence in the area with nearly daily changes being observed in present streams.

This regime change hypothesis also can explain the Rio Banano conglomerate facies by exceptionally large floods bringing unusually large particles into the map area. This type of flood is by no means unusual since one of the extant rivers, the Rio Blanco, is able to transport boulders up to five meters in diameter at peak flow. It would also be possible to regard the Rio Banano conglomerate facies as a cyclic storm deposit except that there are no known coarse-grained sediment bodies in the area to be reworked. It is possible that storm action was responsible for distributing this conglomerate along the shore after deposition near a stream mouth. In general, the simplest explanation for both the conglomerate facies and the variable lithology in the sandstone facies is periodic changes in the flow regime of the streams supplying sediment to the area.

It is difficult to determine what tectonic style affected the area following the cessation of uplift. As was noted above, the paleoenvironmental analyses show the environment to be relatively stable after the initial uplift surge. Whether this represents deposition in a slowly subsiding basin with sedimentation equaling subsidence or a gradual accretion to the northeast, with the deeper facies not being exposed, is not known. The regional picture of uplift and volcanism would, however, suggest that a sudden change to a negative tectonic style would be rather unlikely. Assuming
tectonic stability (rather than slow subsidence), normal sedimentation would move the shoreline to the northeast, forming a relatively thin, but laterally extensive, body of shallow marine sediments. If a slowly subsiding basin existed, a thick sedimentary package would be formed.

A United Nations exploratory water well drilled near La Bomba was reported (personal communication from the driller) to have encountered 200-300 feet of sand underlain by "mud." This could indicate a relatively thin Rio Banano section immediately underlain by older, finer (Uscari?) sediment. The author did not see any cuttings and was not able to obtain samples from any of the U.N. wells in the area or the Union of California well drilled near Limon to test this hypothesis. Although by no means, conclusive, the information volunteered by the U.N. driller suggests a relatively thin, but widespread package of Rio Banano sediments. No firm conclusions can be drawn from this type of hearsay evidence, however.

At some time during the shallow water depositional phase of the geologic history of the Limon area, local tectonics became important as differential uplift across the fault zones became significant. This differential uplift cannot be demonstrated from paleontologic evidence since no outcrops are found in the younger portions of the section to the north and south of the fault block containing Limon, but are buried under recent alluvium. The Limon block is unique in that it remained high while the surrounding blocks dropped down relative to the Limon block. This relative motion has been demonstrated previously in the Structure section
across the Rio Banano and Rio Madere fault zones. Stratigraphic offsets show these to be down-to-the-southeast and down-to-the-west faults respectively.

The formation of local fault basins on either side of the Limon block would effectively trap any clastic sediment (except for suspension and chemical load) moving toward the map area, changing the sediment budget of the Limon area to a sediment-starved situation. This sediment budget change is evidenced by the start of coral growth. Since coral cannot tolerate rapid sedimentation or turbid conditions, the initiation of coral growth on the Limon block reflects this change in sediment budget or at least a drastic reduction in sedimentation.

Coral growth on the Limon block appears to follow a pattern. Those reefs encountered the farthest from the modern shoreline are quite thin, do not have a great lateral extent, and are interbedded with the Rio Banano sandstone facies. As the modern shoreline is approached, these reefs become thicker and of greater lateral extent. This is obviously due to more favorable conditions for coral growth, with conditions becoming increasingly more favorable with time or with environment.

In the former explanation, coral growth would begin at the environmental limits for corals. Growth would be slow and the reefs easily destroyed by sediment influx or salinity changes. As conditions became more favorable for these shelf-edge reefs, they would become more lush, thicker, extend further laterally, and become more difficult to destroy. This change in conditions would be the result of lower
sedimentation with time.

This explanation is summarized graphically in Figure 6. This figure is not meant to accurately reflect the geology of the Limon area, but is strictly diagrammatic. It shows the "thick pile" hypothesis advanced above with a thick sequence of sediments comprising the upper Tertiary section in Limon. As conditions became more sediment-starved toward the upper portions of the column, the reefs became thicker and more luxuriant.

An alternative hypothesis is summarized in Figure 7. Again, this figure is strictly diagrammatic and is not meant to reflect accurately exact geologic conditions in the Limon area. This second hypothesis assumes that all or most of the reefs are contemporaneous. This hypothesis further would favor the "thin pile" hypothesis with a thin shallow marine section overlying older deep marine sequences. According to this hypothesis, reefs formed closer to shore would tend to be less luxuriant and more vulnerable to fresh water and sediment influxes. As the position of the reef moved further into an open marine environment, many conditions (sedimentation, salinity, and food supply, to name a few) would improve, allowing the reef to expand in all directions. Thus, the outer reef would be the largest, both in thickness and lateral extent.

Although both alternatives can account for the coral distribution that has been noted in the Limon area, the first explanation (see Figure 6) requires a more complex set of conditions. The change in sediment budget must continue to become increasingly
sediment-starved since the "younger" reefs are thicker. At the same time, sediment influxes (of decreasing importance with time) must enter the area periodically since clastic sediments are associated with all of the reefs. This association is closer with the "older" reefs situated further inland (toward the bottom of the section).

This explanation, although plausible, is more complex than assuming all the reefs to be more or less contemporaneous. In the second case, the reefs nearest the shore would be periodically smothered by rapid sedimentation brought about by flooding of the local streams. Following the re-establishment of a sediment-starved budget, these reefs would start over, creating an inter-stratified reef-sediment sequence such as that noted in the Q. Chocolate area sketched in Figure 5. At the same time, reefs growing further offshore would be less affected by these sediment and fresh water influxes and in a more stable environment as to salinity and food supply. Those reefs would be able to grow to a greater thickness in this more favorable environment.

This sort of reef distribution on a shallow shelf with an outer (fringing) reef and a series of patch reefs behind it is by no means unique. It has been observed by the author in the Florida Keys and has been reported by Newell (1964) from the Bahamas.

Since no well data were available to test these hypotheses, no choice can be made between these two interpretations. The simplicity of the contemporaneous theory makes it more attractive, but both are possible.

Either hypothesis for the origin of the reefs can account for the well-sorted, reef-capping sands referred to above as the "Pueblo
Figure 6. - Diagrammatic representation of the "thick pile" hypothesis for the origin of the stratigraphic sequences found near Limon. Top of diagram is northeast (near Limon), bottom is southwest.
Figure 7 - Diagrammatic representation of the "thin pile" hypothesis for the origin of the stratigraphic sequence found near Limon. Top of diagram is northeast (near Limon), bottom is southwest.
Nuevo Sands." These sands are associated only with the reef deposits, usually lying behind or capping the reefs. The thicker, more extensive exposures of the "Pueblo Nuevo Sands" are associated with the larger reefs. As was noted in the Stratigraphy section, this unit is characterized by its well-sorted nature and sand-sized particles. Any hypothesis as to its origin must account for both its sorted character and its apparent close relation with the reef deposits.

The local nature of this unit makes interpretation difficult since no petrographic or paleontologic trends can be demonstrated. The fauna present in these sands is mixed, with some of the faunas being brackish and others open marine. The situation suggests that periodic influxes of fresh water could be reducing local salinities to brackish levels. The local floods or periodic climate changes suggested by the burying of the thinner reefs could also provide sediment for the "Pueblo Nuevo Sands." Reworking of these sediments, which would most probably have an initial grain size distribution similar to that found in the Rio Banano sandstone facies (although sometimes containing a brackish fauna), could result in a well-sorted sediment. This reworking could be the result of tidal or wave-generated currents stirring these sediments and sorting out the fine fraction. A certain amount of sorting would probably occur during the initial deposition, but the degree of sorting shown by the "Pueblo Nuevo" would require some sort of secondary reworking. This reworking would not significantly affect the fauna because it is of a grain size similar to or larger than the sands.
A mechanism observed by the author in the Florida Keys could easily account for this reworking. Tidal surge channels are to be found in and around these Florida reefs with tidal currents being sufficient to sort the debris coming off the reefs. Since the south Florida area is in a sediment-starved condition with no nearby source of clastic sediments, this material is all reef rubble. With periodic clastic influxes such as have been shown to occur in the Limon area, there is no reason why this surge channel material could not be primarily clastic in nature.

The series of shallow-water events which has been outlined above was abruptly terminated by a wedge of upper Pleistocene middle to outer neritic sediment. This is deposited unconformably on the shallow marine sediments of the Rio Banano reef and sandstone facies and is immediately overlain by Recent (living in part) coral reef. This rather abrupt change in environment could be due to two main possibilities, eustatic sea level change or tectonics. The rapid return to an environment similar to that which existed before the initial change argues strongly against a tectonic cause for this change. Eustatic sea level changes in the 50 to 100 m range have been suggested from Pleistocene sediments (Erickson and Wollin, 1968; Erickson, et.al., 1963) in other areas. An abrupt rise in sea level would kill the reefs and limit the effectiveness of the sediment traps of the adjacent fault basins, causing a fine-grained, deep-water clastic sediment body to be deposited over the entire area. As has been documented in the Stratigraphy section, this is a good
brief description of the Moin Clay Member of the Rio Banano Formation.

Following the close of the interglacial period which caused the sea level rise responsible for these changed conditions, sea level would drop to normal levels, returning the Limon area to conditions similar to those that existed before the sea level rise. Reef limestone which immediately overlies these deeper-water sediments gives evidence for this return to a shallow marine, sediment-starved condition. A portion of this capping reef is still living although some of it has been killed by exposure above sea level.

The exposure of this reef gives evidence for an uplift, possibly epeiric, in the uppermost Pleistocene or Recent. The magnitude of this uplift cannot be quantified but is undoubtedly small (no more than 15 m) since the reef could not have been formed at a great depth and is now exposed only a few meters above sea level at its highest point.

The planktonic foraminiferal dating of the Moin Clay Member of the Rio Banano Formation cannot be refined any further than upper Pleistocene. It is tempting to try to correlate this sediment package with the Sangamon interglacial period, which was the warmest of the interglacial periods (Erickson and Wollin, 1968; Erickson, et al., 1964) although the longer Yarmouth interglacial could have allowed more complete melting of the glaciers and thus a higher sea level. Since both of these interglacial periods are beyond the capabilities of radiocarbon dating, neither of these suggestions can be proven. Future research may provide the biostratigraphic detail needed for
more refined upper Neogene zonation, but that detail does not yet exist.

The presence of down-thrown fault blocks on either side of the Limon peninsula following the uplift mentioned above has allowed the basins formed to continue as sediment traps, maintaining the high Limon block in a sediment-starved condition, except where local streams are eroding older clastic sediments.

The epeiric uplift deduced above from the exposure of the coral overlying the Moin Clay Member was also probably the cause of the extension into the area of the fluviatile sediments of the Suretka Conglomerate. Previously, paleoecologic evidence had indicated that deposition in the map area was almost entirely marine with the paleoshoreline being further west. The epeiric uplift moved the shoreline to its present position, forcing the streams in the area to lengthen and form fluviatile deposits in the Rio Madre area, as well, possibly, as other areas along the coast. The large size of the particles present and the sedimentary structures outlined above in the Stratigraphy section suggest that the depositing agent for the Suretka Conglomerate was a braided stream. The lateral continuity between weathered Suretka and the modern flood plain of the Rio Chirripo, which air photos show to be braided, indicates that both may have been formed by the same stream which gradually migrated to the northwest.

This epeiric uplift may also account for the series of folds occurring in the Empalme Moin-Moin area in the Rio Banano Moin Clay Member. Slight differences in the local magnitude of this uplift
could have formed these broad folds. They could also have been formed through gravity sliding of the still-soft sediments following this uplift. A third explanation can be found in field indications which suggest that these folds may be due to differential compaction between the competent Rio Banano reef facies and the incompetent Moin Clay Member of the Rio Banano Formation which overlies these reefs. The greater majority of the dip measurements taken in this part of the map area were taken in the Moin Clay Member sediments, giving some credence to the differential compaction explanation. The closely-detailed structural field mapping needed to resolve this question was not done at the time that the initial mapping was done since this problem was not recognized at that time. Since the data needed to resolve the problem are not available, all that can be said concerning the origin of these folds is that any or all of the three processes outlined could be responsible for these features.

The series of stratigraphic sequences outlined above in the summary of Central American Geology between Panama, southern Costa Rica, northern Costa Rica, and the Limon area may be more closely related than is immediately apparent. Examination of the distance to the nearest uplift area shows that the Limon area would be situated the farthest from its uplift axis, the Cordillera de Talamanca (100 km). The others are closer (50-60 km) to inland uplift areas. Comparison of the length of the hiatus represented by the unconformity in that area with the distance to the uplift axis suggests that an offlap relationship may exist between these four areas.
This offlap relationship could be generated by an uplift causing regional shallowing, deforming the areas closer to the axis of uplift to a greater extent than more remote areas. Those areas closest to the axis of uplift would be exposed to erosion, producing an angular unconformity between pre-uplift rocks and later-deposited shallow marine sediments. This unconformity would gradually be reduced in importance away from the axis of uplift, finally becoming an inconspicuous bedding plane disconformity farther offshore. The age of the sediments immediately beneath this unconformity would become younger as the distance from the uplift axis increased since the amount of section removed through erosion would be less.

The apparent transgressive nature of the Uscari-Gatun unconformity would fit closely with this model. The greatest time gap (the middle Miocene) occurs in Panama, where the outcrop area is also the closest to the area of uplift. The gap across the unconformity becomes of lesser importance in the Rio Sixaola and Rio Reventazon areas where the Talamancan source areas are further away. The Limon area, comprised of outcrops located in an even more remote position from any uplift axis, has no apparent unconformity between the deep and shallow marine deposits of the Uscari and Rio Banano Formations.

These broad regional relationships may be complicated in detail by slightly different times of uplift in the widespread areas under consideration, but the model does explain many of the stratigraphic differences observed.
BIBLIOGRAPHY

Akers, W.H., 1972; Planktonic Foraminifera and Biostratigraphy of some Neogene Formations, Northern Florida and Atlantic Coastal Plain; Tulane Studies in Geology and Paleontology, v. 9, no. 1-4, 140 p.

Albers, C.C., 1966; Foraminiferal Ecological Zones of the Gulf Coast; Proceedings, GCAGS, pp. 345-348.

Bandy, O.L., 1954; Distribution of some Shallow-water Foraminifera in the Gulf of Mexico; USGS Prof. Paper 254-f, pp. 125-142.

Bandy, O.L., 1956; Ecology of Foraminifera in Northeastern Gulf of Mexico; USGS Prof. Paper 274-g, pp. 179-199.

Bandy, O.L. and R.E. Arnal, 1957; Distribution of Recent Foraminifera off the West Coast of Central America; Bull. AAPG, v. 41, pp. 2037-2053.

Barker, R.W., 1960; Taxonomic Notes on the Species Figured by H.B. Bradley in his Report on the Foraminifera Dredged by the H.M.S. Challenger During the Years 1873-1876; SEPM Special Publication 9, 238 p.

Beard, J.H., 1969; Pleistocene Paleotemperature Record Based on Planktonic Foraminifers, Gulf of Mexico; Trans. GCAGS, pp. 535-553.

Berggren, W.A., 1973; Recent Advances in Cenozoic Planktonic Foraminiferal Biostratigraphy, Biochronology, and Biogeography; Atlantic Ocean; Woods Hole Ocean. Inst. Contribution 3464, 125 p.


Blow, W.H., 1967 (1969); Late Middle Eocene to Recent Planktonic Foraminiferal Biostratigraphy; Proc. First Int. Conf. on Planktonic Microfissils, v. 1, pp. 199-421.

Bolli, H.M., 1959; Zonation of Cretaceous to Pliocene Marine Sediments Based on Planktonic Foraminifera; Bol. Informativo de Venezuela, pp. 17-33.

Bold, W.A., 1967; Miocene Ostracods from Costa Rica; Micropaleontology, v. 13, no. 1, pp. 75-86.
Bold, W.A., 1971; La Posicion Estratigrafica de la Formacion La Boca, Panama; III Reunion de Geologos de America Central, Actividades Generales y Resumenes, p. 31.

Bold, W.A., 1973a; Ostracoda of the La Boca Formation, Panama Canal Zone; Micropaleontology, v. 18, no. 4, pp. 410-442.


Cebuski, C.E., 1967; Foraminiferal Populations and Faunas in Barrier Reef and Lagoon, British Honduras; In AAPG Memoir 11, pp. 311-327.


Folk, R.M., 1968; Petrology of Sedimentary Rocks; Austin, 170 p.


Hoffstetter, R. (ed.), 1962; Lexique Stratigraphique International Amerique Latine, Fash. II - America Centrale; Centre Nacional de la Recherche Scientifique, 384 p.

Lamb, J. and J.H. Beard, 1972; Late Neogene Planktonic Foraminifera in the Caribbean, Gulf of Mexico and Italian Stratotypes; Univ. Kansas Paleont. Inst., Article 57 (Protozoa 8), 67p.
Lehmann, E.P., 1957; Statistical Studies of Texas Gulf Coast Recent Foraminiferal Facies; Micropaleontology, v. 3, no. 4, pp. 325-356.

Lloyd, J.J., 1963; Tectonic History of South-Central American Orogen; In Backbone of the Americas, AAPG Memoir 2, pp. 88-100.


Malfait, B.T. and M.G. Dinkleman, 1972; Circum-Caribbean Tectonic and Igneous Activity and the Evolution of the Caribbean Plate; Bull. GSA, v. 83, pp. 251-272.

Molnar, J. and L.R. Sykes, 1967; Seismology and the New Global Tectonics; JGR, v. 73, no. 18, pp. 5855-5899.

Moore, W.E., 1957; Ecology of Recent Foraminifera in the Northern Florida Keys; Bull. AAPG, v. 41, no. 4, pp. 727-741.


Parker, F.P., et. al., 1951; Ecology of Foraminifera from San Antonio Bay and Environs, Southwest Texas; Cushman Fdn. Foram. Research Special Publication 2, 74p.


Phleger, F.B. and F.L. Parker, 1951; Ecology of Foraminifera, Northwest Gulf of Mexico; GSA Memoir 46, 154 p.

Rathburn, M.J., 1918; Decapods, Crustaceans from the Panama Region; U.S. Nat. Museum Bull. 103, pp. 123-184.

Redfield, A.H., 1923; Petroleum Possibilities in Costa Rica; Econ. Geology, v. 18, no. 3, pp. 354-381.


Rivier, F. 1973; Contribucion Estratigrafica sobre la Geologia de la Cuenca de Limon, Zona de Turrialba, Costa Rica; Publ. Geol. ICAITI, No. IV, pp. 149-159.


Selli, R. 1967; The Pliocene-Pleistocene Boundary in Italian Marine Sections and its Relationship to Continental Stratigraphies; Progress in Oceanography, v. 4, pp. 67-86.

Smith, P.B., 1964; Ecology of Benthonic Species; USGS Prof. Paper 429-b, 63 p.


Vaughan, T.W., 1924; West Indian, Central American and European Miocene and Pliocene Molluscs; Bull. GSA, v. 35, pp. 867-886.

Viner, G.S., 1972; Physical Characteristics of Fluvial Deposits; In Recognition of Ancient Sedimentary Environments, SEPM Special Pub. 16, pp. 49-97.

Woodring, W.P., 1957; Geology and Paleontology of the Canal Zone and Adjoining Parts of Panama; USGS Prof. Paper 306-a, pp. 1-145.
Table 2 - Petrographic Summary, Uscair Shale

A) Texture

1) End Member Percentages
   Terrigenous materials - 88%
   Allochemical materials - 12%
   Orthochemical materials - 0%

Main rock group - impure allochemical rock (after Folk, 1968)

2) Grain Size (estimated from thin section)
   Mean - 10μ
   Extreme range - clay size to 200μ
   (Note: This excludes fossils, which may reach 1000μ)
   16-84% - clay size to 90μ

3) Cementing
   No cementing materials were observed. The rock is held together by mutual attraction of parallel grains of clays and mica.

B) Mineral Composition

1) Terrigenous component
   Quartz - very fine sand and silt-sized particles (0.125-0.0078 mm) with irregular distribution; grains angular to subangular and roughly equant; extinction straight to slightly undulose (unstrained); comprises an estimated 5% of the rock

   Feldspar - only orthoclase observed as very fine sand to silt-sized particles (0.125-0.0078 mm) with irregular distribution; comprises an estimated 1% of the rock

   Clay minerals - comprises most of the rock (approx. 80%) with individual grains not identifiable in thin section. X-ray diffraction shows the presence of chlorite and mixed-layer montmorillonite (65% montmorillonite)

2) Allochemical component
   Glauconite - identified in some grains (less than 2%) in thin section by its green color in both plane polarized light and under crossed nicols as well as its granular appearance; grains in the silt range and ovoid in shape

   Calcite - present as foraminiferal tests comprising up to 10% of the rock (by volume estimation in thin section), distribution random, mean size around 750μ (range 500-1000μ)

3) Orthochemical component - none
Table 3 - Petrographic Summary, Rio Banano Formation, sandstone facies

A) Texture

1) End Member Percentages (formation range)
   Terrigenous materials - 60-90%
   Allochemical materials - 5-35%
   Orthochemical materials - 0-5%
   Main rock group - fine sandy clay to muddy sand

2) Grain size (ranges)
   Mean
   Formation - 0.30-0.90 mm
   Type section - 0.125-0.09 mm
   Extreme range - clay size to 1 mm
   16-84% Range
   Formation - 0.05 mm - clay
   Type section - 0.15 mm - clay
   Sorting (based on Inclusive Graphic Standard Deviation)
   Formation - very well sorted (IGSD=0.2990) to moderately well sorted (IGSD=0.9050)
   Type section - well sorted to very well sorted

Gravel fraction - no gravel sized particles were found

Sand fraction (formation range)
   Percent - 98.6-62.9
   Mean - 0.9 mm
   Range - 0.5-0.625 mm

Mud fraction
   Percent - 1.4-37.1
   Silt vs. clay - 2-30% clay
   Silt median not determined

3) Textural maturity
   Immature (clay percentage greater than 5%)

4) Cementing
   Some samples show poor cementing by secondary calcite.
   Most, however, have no cement with the rock being held together by a clay matrix. Those samples with secondary calcite also commonly have a low clay percentage.

B. Mineral Composition

1) Terrigenous component
   Quartz - grains range in size throughout the silt and sand size range with irregular distribution; grains usually subangular and roughly equant; extinction straight to slightly undulose (unstrained); comprises up to 95% of the rock.
   Feldspar - both orthoclase and plagioclase observed (ratio - about 1:4 with more plagioclase) as sand-sized particles; distribution irregular; plagioclase commonly kaolinized; comprises up to 10% of the rock.
Table 3 (Continued)

Micas - very minor accessory mineral, comprises less than 1% of the rock; the few grains observed were probably biotite (high birefringence)

- Clay minerals - comprises up to 30% of the rock with individual grains unidentifiable in thin section. X-ray diffraction shows these clays to be comprised of mixed-layer montmorillonite (58-59% montmorillonite), illite and either kaolinite or chlorite or possibly both of these last two clay minerals.

2) Allochemical component

Glaucnite - identified in thin section and x-ray diffractograms from some samples. Present in low percentages (less than 5%).

Calcite - present as foraminiferal tests, ostracod valves, mollusc shells and mollusc shell fragments; distribution generally random; comprises up to 25% of the rock

3) Orthochemical components

Calcite - present as rare cement in some samples. Most samples show no cement although it is locally important, forming hard nodules. It is most probably derived from ground water solution of calcareous fossils.

Pyrite - present in a very few thin sections in very low percentages (much less than 1%). It is probably an alteration product of glauconite since it is found only in samples which do contain glauconite.
Table 4 - Petrographic Summary, Rio Banano Formation, conglomerate facies

A) Texture
1) End member percentages
   Terrigenous materials - 99%
   Allochemical materials - 1%
   Orthochemical materials - none observed
   Main rock group - gravelly sand
2. Grain sizes
   Mean - 0.6mm
   Extreme range - 40mm to clay size
   16-84% range - 1-0.25mm
   Sorting - poor (IGSD=1.063)
   Gravel fraction
      Percent - 0-5%
      Mean - approximately 5mm
      Range - 2-40mm
   Sand fraction
      Percent - 90-94%
      Mean - 0.5-0.25mm
      Range - 0.625-2mm
   Mud fraction
      Percent - less than 2%
      Mean - not measured directly but probably in the silt category (0.0625-0.0039mm)
      Range - 0.625mm - clay
3) Textural maturity
   Submature - clays less than 5% but grain size (16-84% statistic) is greater than one phi unit.
4) Cementing - nearly nonexistent with the clay fraction providing the only bonding noted

B) Mineral composition
1) Terrigenous component
   Quartz - grains range in size from a medium pebble (up to 16mm in diameter) to fine silt; distribution irregular; grains compact and angular to subangular; extinction straight to slightly undulose; comprises up to 97% of the rock
   Feldspar - grains range in size from 0.5mm to fine silt; distribution shows a concentration of feldspars in the coarser layers; both plagioclase and orthoclase present (x-ray diffraction shows the former to be calcic) in approximately a 1:3 ratio; grains equant and regular; comprises from 0 to 8% of the rock
   Micas - very rare flakes of biotite (?) present
Table 4 (Continued)

Clay minerals - comprised of mixed-layer montmorillonite (60% montmorillonite), chlorite, kaolinite and itilite; comprises no more than 2% of the rock; concentrated in the finer portions of the facies

Rock fragments - comprises a large part of the coarse portion of the facies (up to 50%); consists of basaltic pebbles with some sandstone pebbles (similar in lithology to the Rio Banano sandstone facies) present

2) Allochemical component

Calcite - present as rare foraminiferal tests; concentrated in the finer portions of the facies; comprises considerably less than 1% of the rock.

3) Orthochemical component - none noted
Table 5 - Petrographic Summary, Rio Banano Formation, Moin Clay Member

A) Texture

1) End member percentages (unit range)
   Terrigenous materials - 80-90%
   Allochemical materials - 1-20%
   Orthochemical materials - none noted
   Main rock group - claystone or mudstone

2) Grain size (sample 1017 only)
   Mean - 0.3mm
   Extreme range - clay size to 0.7mm
   16-84% range - 0.4-0.12mm
   Sorting - moderately sorted (IGSD=-.662)

Grain Size estimated for the unit in thin section
   Mean - 0.0078mm (70)
   Extreme range - clay size to 0.12mm
   16-84% range - clay size to 0.312mm (50)
   Sorting - poor

   Sand fraction
   Percent - 1-20%
   Mean - not determined
   Range - 1-010625mm

   Mud fraction
   Percent - 80-90%
   Silt vs. clay - 30-90% clay
   Silt median not determined

3) Textural maturity - immature (clay percentage greater than 5%)

4) Cementing - no secondary cement was observed; the clay matrix provides the only bonding

B) Mineral composition

Quartz - grains range in size throughout the sand and silt range with irregular distribution, grains subangular and equant, extinction straight to slightly undulose, comprises up to 5% of the rock

Feldspar - very rare grains of anorthite (composition from x-ray diffraction) showing severe kaolinization

Clay minerals - dominated by mixed-layer montmorillonite (58% montmorillonite) and kaolinite with some chlorite and illite present; comprises an estimated 30-90% of the rock

Calcite - present as foraminiferal tests, ostracod valves molluscan shells and molluscan fragments; distribution shows local layering; comprises from 1-20% of the rock; fossils show little or no dissolution by ground water

No orthochemical minerals were noted
Table 6 - Petrographic Summary, "Pueblo Nuevo Sands"

A) Texture

1) End member percentages
   Terrigenous materials - 90-99%
   Allochemical materials - 0.9%
   Orthochemical materials - 1% and less

   Main rock group - sandstone

2) Grain sizes
   Mean - 0.18mm
   Extreme range - clay size to 0.5mm
   16-84% range - 0.25 - 0.125mm

   Sorting - very well sorted (IGSD = 0.463)
   Gravel fraction - none
   Sand fraction
      Percent - 94-99%
      Mean 0.18mm (estimated)
      Range - 0.5 - 0.125mm

   Mud fraction
      Percent - 3-6%
      Silt vs. clay - 25% clay
      Silt median not determined

3) Textural maturity - Mature
   Clay percentage low, 16-84% range small (less than 1); grains subrounded to rounded

4) Cementing - secondary hematite only bonding agent, present in all samples in small quantities (up to 1% of the rock)

B) Mineral composition

1) Terrigenous component
   Quartz - ranges in size throughout the sand and silt range, comprises the bulk of the sand fraction; distribution random, grains rounded subrounded, roughly equant; extinction straight to slightly undulose, comprises 90-95% of the rock

   Feldspar - only orthoclase observed as fine and very fine sand grains; distribution random; grains subangular; most show strong kaolinization; comprises less than 1% of the rock

   Clay minerals - comprise no more than 2-3% of the rock; X-ray diffraction shows the presence of mixed layer montmorillonite (53% montmorillonite), Chlorite, kaolinite and possibly illite

2) Allochemical component
   Calcite - present as foraminiferal tests and ostracod valves with some molluscan shells and shell fragments; comprises up to 9% of the rock but is absent in many samples
Table 6 (Continued)

3) Orthochemical component

Hematite - present as a coating on sand grains; only cement present; comprises up to 1% of the rock

Kaolinite - results from the kaolinization of orthoclase and is impossible to separate from primary kaolinite (if present), comprises less than 1% of the rock
Table 7 - Petrographic Summary, Suretka Conglomerate

A) Texture
1) End member percentages
   Terrigenous materials - 99-100%
   Allochemical materials - none
   Orthochemical materials - 0% to less than 1%
2) Grain size - meaningless due to the wide ranges in grain sizes along with very rapid vertical and horizontal changes
3) Textural maturity - Submature
   Clay percentage less than 5% but the 16-84% range is probably greater than one phi
4) Cementing - some samples show hematite coatings which may act as cement. Thin sections of some finer-grained samples show no secondary overgrowths or diagenetic interpenetrations.

B) Mineral composition
1) Terrigenous component
   Quartz - present in low percentages as angular grains showing straight of slightly undulose extinction; distribution confined to finer-grained (sand-sized) sediment bodies.
   Feldspar - orthoclase present in fine-grained (sand-sized) bodies as rare, angular grains. Plagioclase (determined by x-ray diffraction to be anorthite) common (in finer-grained bodies) as angular grains.
   Rock fragments - comprises the bulk of this formation, especially the coarser-grained bodies. Most of these fragments are basaltic in nature (with plagioclase, pyroxene, amphibole and olivine grains identified in thin section) with two general types being noted; one is aphanitic and the other contains plagioclase phenocrysts up to 300μ long.
   Pyroxene - Comprises up to 15% of the finer, sand-sized sediment bodies as angular, elongate grains. These grains have a tendency to be concentrated in layers with individual grains showing somewhat of a parallel orientation.
   Olivine - present as rare, angular but equant grains, usually associated with concentrations of pyroxene grains in the finer portions of the formation.
   Clay minerals - x-ray diffraction shows the presence of mixed-layer montmorillonite (62% montmorillonite) illite, kaolinite and chlorite from a 62μ filtrate sample from a fine-grained bed.
Table 7 (Continued)

2) Allochemical component - none noted
3) Orthochemical component - very minor amounts of hematite present as grain coatings in a few samples. Its distribution seems to be limited to the sand-sized sediment bodies in the formation.
Plate 1 - Planktonic Foraminifera from the Limon Area

1,2,6 - *Hastigerina aequilateralis* 100X (sample 1211)
3,7,30 - *Sphaeroidinella dehiscens* 100X (sample 1018)
4,5,9 - *Globorotalia acostaensis pseudopima* 200X (sample 1211)
8,14,15 - *Pulleniatina obliqueloculata* 100X (sample 1018)
10,11,12 - *Globigerina bulloides* 200X (sample 1018)
13 - *Orbulina bilobata* 100X (sample 1211)
16,22,27 - *Globigerinoides trilobus* 100X (sample 1004)
17,18 - *Globigerina dutertrei* 100X (sample 1004)
19,20,21 - *Globigerinoides sacculifer* 100X (sample 1102)
25,29 - *Globigerinoides conglobatus* 100X (sample 1018)
26 - *Sphaeroidinella dehiscens excavata* 100X (sample 1018)
Plate 2 - Planktonic Foraminifera from the Limon Area

1 - *Orbulina universa* 200X (sample 1004)

2,3,7 - *Globorotalia truncatulinooides* (sinistral) 200X (sample 1018)

4,8,10 - *Globorotalia acostaensis humerosa* 200X (sample 1211)

5,6 - *Globigerinoides ruber* 200X (sample 1004)

9,12,13,16 - *Sphaeroidinelopsis subdehiscens* 200X (samples 1147,1148)

11,14,15 - *Globoguadrina altispire* 200X (sample 1189)
Plate 3 - Benthonic Foraminifera from the Limon Area

1, 2, 3 - "Cibicides" floridanus 100X (sample 1147)

4, 9 - Triloculina linneana 100X (sample 1156)

5, 10 - Nonion affine 200X (sample 1004)

6, 7 - Uvigerina cf. hispida 200X (sample 1211)

8 - Plectofrondicularia floridana 100X (sample 1004)

11, 15 - Ammonia beccarii 200X (sample 1060)

12, 16 - Lenticulina americanus 100X (sample 1190)

13, 14, 17 - Discorbis floridanus 200X (sample 1082)

18, 19, 20 - Siphonina pulchra 200X (sample 1004)
Plate 4 - Benthonic Foraminifera from the Limon Area

1 - *Lagenia spirata* 100X (sample 1211)

2,8 - *Spiroloculina soldanii* 100X (sample 1144)

3,4 - *Tritaxia mexicana* 50X (sample 1004)

5 - *Reussella atlantica* 100X (sample 1019)

6,7 - *Amphistegina lessonii* 100X (sample 1066)

9 - *Bolivina subaenariensis* var. *mexicana* 100X (sample 1075)

10 - *Nodosaria albatrossi* 50X (sample 1147)

11,12 - *Floralis atlanticus* 200X (sample 1019)

13,14,15 - *Bigenerina irregularia* 100X (sample 1158)

16,17 - *Cribroelphidium gunteri* 100X (sample 1029)

18,19 - *Kanzawaia concentrica* 100X (sample 1164)

21 - *Virgulina pontoni* 100X (sample 1177)

22,25 - *Marginulinopsis margulinoides* 50X (sample 1004)

23,24,28 - *Poroeponides repandus* 100X (sample 1066)

26,27 - *Planulina foveolata* 100X (sample 1004)

29,34 - *Uvigerina perigrina* 100X (sample 1147)

30 - *Archais compressus* 100X (sample 1178)

31 - *Peneroplis proteus* 100X (sample 1161)

32 - *Textularia panamanensis*? 200X (sample 1156)

33 - *Textularia conica* 200X (sample 1066)

35,36,37 - *Nonionella basiloba* 200X (sample 1211)
Plate 5 - Benthonic Foraminifera from the Limon Area

1 - *Lagena tenuis* 200X (sample 1039)
2,3,4 - *Gyrodina multilocula* 200X (sample 1211)
5 - *Uvigerina flinti* 200X (sample 1004)
6,9,13 - "*Cibicides* florianus" 100X (sample 1147)
7,8,12 - *Quinqueloculina* sp. 200X (sample 1004)
10,14 - *Textularia mayor* 100X (sample 1069)
11 - *Bifarina decorata* 200X (sample 1019)
15,16 - *Nodobaculariella atlantica* 100X (sample 1082)
17,21 - *Cribroelphidium poeyanum* 200X (sample 1056)
18,19,20 - *Pyrgo* sp. 200X (sample 1004)
Plate 6 - Mollusca and Benthonic Foraminifera from the Limon Area

Mollusca

1,16 - Chicoereus consuela 2X (sample 1075)
2,15 - Demomurex aspella 2X (Glades Unit, Belle Glade, Florida)
3,4 - Voluta virescens 2X (sample 1066)
5,11 - Voluta virescens 2X (sample 1086)
6,8 - Chicoereus moinensis (holotype) 2X (sample 1086)
7,13 - Conus mayei 2X (sample 1075)
9,14 - Demomurex aspella 2X (Empalme Moin Area)
10,17 - Conus recognitus 2X (sample 1086)
12 - Mitra swainsone var. limonensis 2X (sample 1010)
18 - Murex olssonii (holotype) 2X (sample 1010)
19,21 - Sconsia striata 2X (sample 1010)
21,22 - Voluta alfaroi 2X (sample 1030)
23,25 - Drillia macilenta 2X (sample 1010)
24,26 - Fusinus miocosmus 2X (Empalme Moin Area)
27 - Voluta virescens 2X (sample 1086) (photographed in ultraviolet light to show color banding)

Foraminifera

28,29 - Spirillinia decorata 90X (sample 1177)
30 - Textularia conica 90X (sample 1066)
31 - Nodosaria subsoluta 45X (sample 1148)
32 - Textularia conica 90X (sample 1066)
Plate 7 - Photographs of Limon Area Outcrops: Suretka Conglomerate and Uscari Shale

Top - Typical outcrop of the Suretka Conglomerate showing the rapid vertical changes in lithology found in that formation. Photograph taken of an outcrop near Sandoval.

Bottom - Weathered outcrop of Uscari Shale demonstrating the fissility which develops upon weathering. This outcrop is located on the north bank of the Rio Banano at sample location 1150.
Plate 8 - Photographs of Limon Area Outcrops: Rio Banano Formation, sandstone and reef facies

Top - Coral pinnacle of the Rio Banano reef facies penetrating overlying clastic rocks. These overlying sediments are too badly weathered to determine their lithology but they are closely related laterally with sediments of the Rio Banano sandstone facies. Photograph taken in the Q. Chocolate valley.

Bottom - Fresh exposure of Rio Banano sandstone facies showing reef detritus intermixed with the sandstone. This reef detritus evidently came from a large reef approximately 40 m from this outcrop. This roadcut occurs at the top of the hill north and east from the Q. Chocolate valley.
Plate 9 - Photographs of Limon Area Outcrops: Rio Banano sandstone facies and "Pueblo Nuevo Sands"

Top - This view shows the contact between the Rio Banano sandstone facies (highly fossiliferous [mollusk fragments] at this location) and the "Pueblo Nuevo Sands" with the "Pueblo Nuevo Sands" being on top. This outcrop is formed by a railroad cut between Limon and Empalme Moin.

Bottom - Photograph from the Q. Chocolate area showing coarse, ripple-marked sandstone overlain by a fine silty clay. Outcrop occurs in the Rio Banano sandstone facies.
Gilbert Dunlap Taylor was born on September 21, 1944 in Sharon, Pa., the son of Mr. and Mrs. Gilbert Taylor, Sr. He received his secondary education in the Sharon Public School System, graduating from Sharon High School in 1962. He then went to Thiel College and received a Bachelor of Arts degree in zoology in 1966. He went to the University of Illinois for graduate study in geology and as a teaching assistant in introductory geology courses. After two years there, he left Illinois to attend Louisiana State University for further graduate training in geology. He completed his Master of Science degree at the University of Illinois in 1971 with a thesis entitled The Conodonts of the Mansfield and Brazil Formations (Morrowan) of the Illinois Basin. While a student at L.S.U., he served as a teaching assistant in both introductory and advanced geology and paleontology courses.

In 1972, he left L.S.U. to accept a position as a Research Geologist at the Mobil Field Research Laboratory in Dallas, Texas. After 9 months, he was transferred to the Mobil Exploration Services Center as a Senior Paleontologist, a position which he still holds.

In February of 1975, he married the former Mary Elizabeth Anglim of Dallas, Texas.
Candidate: Gilbert Dunlap Taylor, Jr.

Major Field: Geology


Approved:

[Signatures]

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

[Signatures]

Date of Examination:

March 6, 1975
## Faunal Distribution Chart

**Main Member - Rio Banano Formation**

<p>| TAXON | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 4. Orbolina Universa | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 13. Uvigerina Perigrina | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 15. Globigerinoides Trilobus | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 17. Cythereella Sp. | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 20. Krithia Molitchoidea | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 25. Cytheropteron Renzi | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 10. Sphaerodinella Dehiscens | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 1. Globorotalia Truncatulinaeides | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 7. Planulina Poveolata | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 21. Parakrithe Sp. | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 9. Nodosaria Sp. | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 8. Tritaxia Mexicana | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 3. Marginulopsis Marginulinaeides | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 55. Paraclinidae Sp. | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 19. Krithia Sp. | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 5. Bolivina Subaenariensis Var. Mexicana | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 6. Miliolids | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 14. Melonis Affinis | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 11. Sphaerodinella Dehiscens Excavata | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 12. Sigmoilina Schlumbergeri | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 23. Bosquetina? Sp. | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 24. Costa Aff. Robinsoni | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 18. Argilloecia Sp. | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 16. Pulleniatina Obliqueculata | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 2. Globorotalia Morardii | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 26. Loxoconcha Dorsotuberculata | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 30. Lankestrina Sp. | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 31. Siphonina Pulchra | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 27. Globoradiina Outertrei | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 28. Pulleniatina Finalis | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 29. Siphonina Bradyana | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 34. Floralis Atlanticus | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 36. Reussella Atlantica | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 38. Poroponides Repandus | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 41. Bairdia Sp. | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 42. Radinella Ex Gr. Confragosa | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 52. Paracytheridea Sp. | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 81. Amphistegina Lessoni | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 97. Globigerina Sp. | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 110. Pyrgo Sp. | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 146. Elphidium Advenum | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 147. Anchistrochiles Sp. | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 148. Cativella Sp. | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |
| 217. Cytheropteron Renzi | **| * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * |</p>
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Legend

- Reed
- Railroad
- Stream
- Coral Reef
- Sinkhole
- Bridge

SCALE

0 cm  1  2