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FORAMINIFERAL BIOFACIES IN SEDIMENTS OF GULF OF BATABANO, CUBA, AND THEIR GEOLOGIC SIGNIFICANCE[1]

ORVILLE L. BANDY[2]
Los Angeles, California

ABSTRACT

The Gulf of Batabano, on the southwest coast of Cuba, is about 180 miles long and 90 miles wide. The floor of the Gulf is a shallow submerged platform area with water depths ranging between 0 and 40 feet. A precipitous declivity, a narrow structural trend, bounds the southern edge of the platform separating shoals of the platform from deep-water facies on the south.

On the platform, foraminiferal abundance and diversity are greatest in the northern and western areas of Batabano Bay. Although ostracodes are common in many of the samples, foraminifera are from 10 to more than 50 times as abundant as ostracodes throughout most of the bay. General biofacies patterns include abundant miliolids in perimeter areas of the bay, an *Elphidium* facies in the central inner area of the bay, and an *Archaias* facies in the southeastern area of the bay. Areas of mud matrix characterize the first two biofacies, whereas non-skeletal grains correlate with the *Archaias* facies.

Detailed and specific dominant foraminiferal faunas include: (1) a brackish *Ammonia beccarii tepida* (Cushman) assemblage in the small embayment in the northeastern part of the bay; (2) a transitional miliolid-*Elphidium* facies in much of the inner bay area; (3) an *Archaias* high-energy biofacies in the southeastern outer part of the bay associated with coarse sediment, relatively stable salinity values, and a rather high oxygen content; (4) a *Discorbis*-miliolid low-energy assemblage in the southwestern outer part of the bay in areas of mud matrix; and (5) a reef tract facies composed of *Amphistegina lessonii* d'Orbigny, *Asterigerina carinata* d'Orbigny, and *Rotorbinella rosea* (d'Orbigny) which are associated with coarse well-sorted sediments, strong currents, and a high oxygen content. Planktonic foraminifera do not occur in the platform biofacies.

Deep-water cores off the Batabano platform show high percentages of displaced platform foraminifera within the benthic faunas, more than 80 per cent planktonic foraminifera in deeper water cores, foraminiferal numbers in the thousands, and rare reworked Miocene foraminifera.

Transgressive and regressive phenomena produce an intercalation of different types of biofacies demonstrating contemporaneity; also, faunal mixing by transportation and displacement provide a degree of correlation between what would otherwise be totally dissimilar biofacies.

Lagoonal areas and the embayment behind the reef-complex have an abundance of miliolids and other smaller foraminifera in fine-grained sediments; in these back-reef areas, an increase in larger foraminifera suggests the probable direction toward the reef-complex and improved reservoir potential in carbonate sediments. Fore-reef deposits exhibit progressively greater abundances of planktonic foraminifera and mixed deep and shallow types of foraminifera with increasing depth of water. Increasing percentages of displaced larger foraminifera in basin deposits may identify basin slopes leading up to fore-reef deposits. Both reef deposits and displaced sands may provides significant reservoir beds for petroleum.

Rapid lateral transitions from shallow-water to deep-water facies suggest the existence of prominent synchronous structural trends.

INTRODUCTION

Carbonate rocks form an important category of many sedimentary deposits of the geologic past; it is important to establish relationships between faunal and environmental patterns of modern carbonate areas to provide precise criteria for defining the significance of facies trends in carbonates of the geologic past. This study is designed to show the patterns of important foraminiferal facies in the carbonate sediments of the Gulf of Batabano, Cuba (Fig. 1), an area with a complex suite of many different facies. It is a companion study to the one by Hoskins (1962) on molluscan faunas and a second one by Daetwyler and Kidwell (1959) on sedimentology of the same area.

Methods of sample collection, laboratory analyses, and sedimentology are described by Daetwyler and Kidwell (1959). Samples for foraminiferal studies were not preserved at the time of collection; although live-dead ratios can not be determined, it is likely that the dominant biofacies patterns reflect the general occurrence of living populations as suggested by studies such as that of live and dead foraminiferal populations

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[2] Department of Geology, University of Southern California.

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of San Pedro Bay, California (Bandy, Ingle, and Resig, 1964). About 173 platform samples and 10 deep-water core samples were available from the Gulf of Batabano. Samples were weighed to the nearest one hundredth of a gram, washed on a 200-mesh screen (0.074 mm openings), and then dried. Foraminiferal counts were made of an aliquot of each of the samples and these counts were converted into percentages.

Previous Work

Vaughan (1918) compared samples from Australia with samples from Florida and the Bahamas, including some from the Florida Keys. *Archaias* (identified as *Orbiculina* by Cushman) was the most abundant form in the Florida Keys, part of the reef-complex, which is similar to the platform edge (reef-complex) facies of Batabano platform. Cushman (1922) studied the ecology of living foraminifera in the Dry Tortugas; however, his study was not quantitative. Norton (1930) studied the foraminifera from Australia and the Florida-Bahama region; he divided the foraminifera into depth-temperature zones.

Thorp (1939) studied the calcareous marine deposits from Florida and the Bahama region, reporting that occasional specimens of planktonic foraminifera were swept into shallow waters. Stubbs (1940) studied Biscayne Bay in southern Florida and reported a dominance of miliolids and the Peneroplidae. His study was followed by that of Bush (1949, 1958) in which a number of porcelaneous species served to identify thirteen biotopes. Bandy (1956) studied the foraminiferal biofacies of the shelf and paralic environments of western Florida, recognizing 5 open shelf depth faunas and a number of paralic faunal groups. Parker (1954) has analyzed the shelf and bathyal foraminiferal distribution of the northeastern Gulf of Mexico.

Illing (1950, 1952) described the mechanical sorting and distribution of foraminifera on the Bahama Banks. Her "exposed margin to ocean" fauna is similar to the reef-complex of Moore (1957) and to that of the Batabano margin; her mixed fauna has many similarities to those on the platform of Batabano.

Moore (1957) reported on the ecology of foraminifera in Florida. Lynts (1962) has studied foraminiferal assemblages of upper Florida Bay and associated sounds and he found them to be predominantly porcelaneous species. Streeter (1963) is currently studying the foraminiferal assemblages of the Great Bahama Bank.

An abstract of the Batabano study was presented at the 48th Annual Meeting of the A.A.P.G. in Houston, Texas, March 25–28, 1963 (Bandy, 1963a).

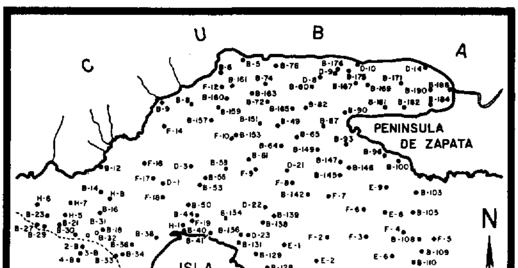


FIG. 1.—Index map of the Gulf of Batabano, Cuba, showing locations of sampling stations.

Description of the Area

General.—The Gulf of Batabano, Cuba, on the southwest coast of Cuba, is about 180 miles long and 90 miles wide. Most of the Gulf is a shallow submerged platform area with a maximum water depth of about 40 feet and an average depth of slightly less than 30 feet. There are many shallow banks covered by only a few feet of water. An important structural trend is represented by the prominent declivity bordering the southern margin of the platform which separates shallow platform carbonates on the north from deep-water carbonates on the south. Within 3 miles south of the platform edge, water depths increase to more than 6,000 feet. Islands, cays, and reefs fringe the seaward margin of the platform.

Water characteristics.—Data by Ibert and Hood (1959) and Daetwyler and Kidwell (1959) indicate the primary current pattern of Batabano Bay is generally counter-clockwise, with the predominant flow onto the platform from the southeast and the flow off the platform at the southwestern edge. Currents are much stronger (in excess of 1 knot) in the southeastern area of Batabano Bay than elsewhere (less than $\frac{1}{2}$ knot) within the platform area. Caribbean water, with a

salinity of 35–36 parts per thousand, undergoes relatively high evaporation rates as it crosses the edge of the platform, resulting in salinities of about 37 parts per 1,000 in the waters on the open platform. In contrast, rivers dilute the waters along the northern coast of the bay, producing salinity values as low as about 23 parts per 1,000 there. Oxygen values of bottom waters were between 2.5 and 4.7; pH values ranged between 8.1 and 8.7; and water temperatures (August) varied between 32.5°C and 28.5°C. The observed ranges in values for pH and for temperature are probably unimportant in controlling the distribution of foraminiferal assemblages.

Sediments.—Daetwyler and Kidwell (1959) have found the carbonate sediments of Batabano Bay to be very complex (Fig. 2A); however, it should be noted that carbonate mud matrix is a significant common denominator throughout much of the northern, central, and southwestern parts of the platform area. Ovoid grains (probably fecal pellets) and composite grains make up the significant sediment type in the entire southeastern area of the platform. Skeletal sand, sometimes with oölitic grains, is the primary sediment type associated with the reefs and islands along the southern margin of the Batabano platform. Deep-water sediments south of the platform are silts and clays with many foraminifera and pteropods. These would be foraminifera-pteropod limestones or micritic foraminifera-pteropod limestones if lithified, according to Daetwyler and Kidwell.

Foraminiferal Biofacies

General.—Foraminifera on the Batabano platform are exclusively benthic types; foraminifera of the deep-water facies to the south of the platform are principally accumulations of planktonic tests or shells. Values for foraminiferal number,

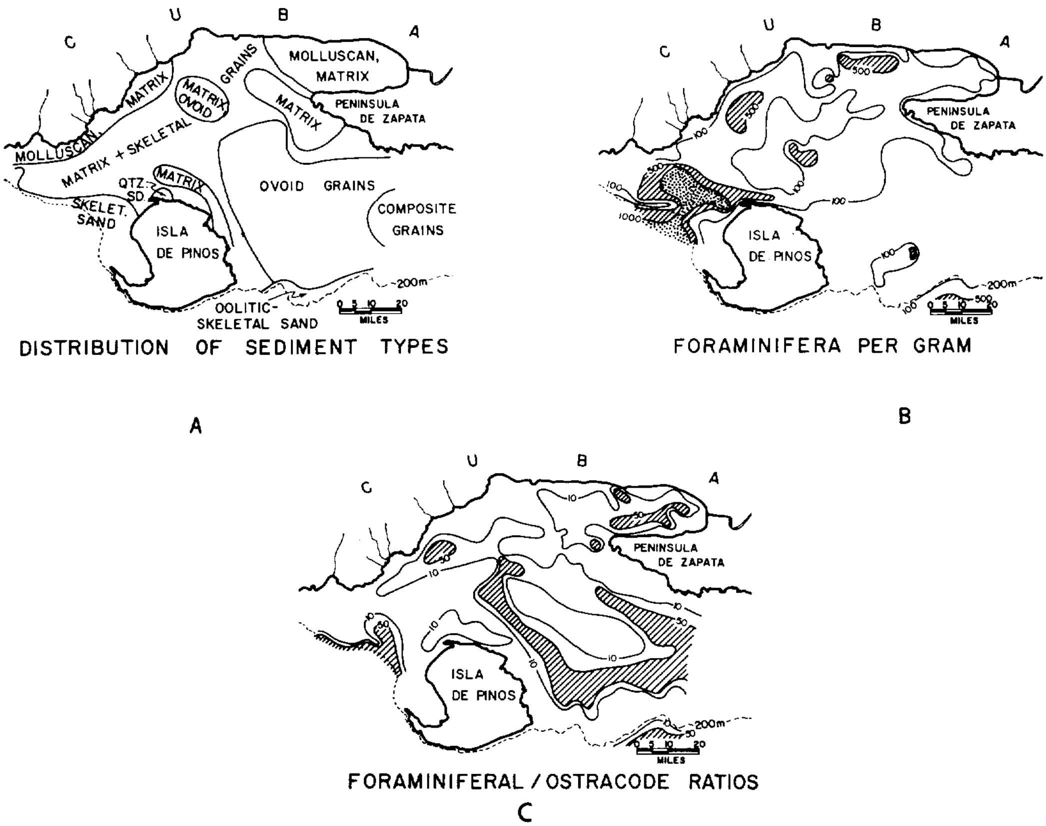


FIG. 2.—A. General sediment types, after Daetwyler and Kidwell (1959). B. Foraminifera per gram of dry sediment. C. Foraminiferal/ostracode ratio map.

numbers of specimens per gram, are convenient for expressing foraminiferal abundance in both modern and fossil assemblages, a method first described by Schott (1935). Generally, foraminiferal numbers (Fig. 2B) are less than 100 in the southeastern area of the platform; they are between 100 and 500 in much of the northern and western part of the platform, and there is a rapid trend from 500 to more than 1,000 in the southwestern area of the platform. High values of several thousand are usual in the sediments of the deeper waters south of the platform. Thus, the platform area of coarsest sediment (ovoid grains) and strongest currents is identified with the smallest foraminiferal numbers; the finest sediment and weaker currents are associated with the higher foraminiferal numbers.

Ostracodes are most abundant in the platform areas of finest sediment. A foraminiferal/ostracode ratio (Fig. 2C) was determined for each of the stations and almost all of the samples have values of more than one. In general, foraminifera are more than 10 times as abundant as ostracodes over a good portion of the platform and more than 50 times as abundant in more restricted areas. Ratio values are generally very high in all deep-water areas off the edge of the platform. Number of species increases with foraminiferal number generally.

Foraminifera of the Batabano platform may be grouped into three categories: miliolids (porcelaneous foraminifera), larger discoidal forms (*Archaias* group), and the smaller miscellaneous foraminifera with calcareous perforate tests (*Ammonia*, *Elphidium*, *Discorbis*). The *Archaias* group includes *Archaias angulatus* (Fichtel and Moll), the dominant member, and the secondary forms *Peneroplis* (*Puteolina*) *proteus* d'Orbigny, *Peneroplis pertusis* (Forskal), and *Sorites marginalis* (Lamarck). It is noteworthy that there are only very minor arenaceous species in the carbonate facies of the Batabano area, in terms of percentage of the foraminiferal populations. Thin sections of many carbonates of the geologic past have abundances of groups comparable with the miliolids and larger discoidal foraminifera of this study; it is important to evaluate gross faunal variations in modern shallow-water areas to understand similar geologic occurrences.

The trigon plot, a form of multivariate analysis, is valuable in presenting the gross quantitative aspects of biofacies variations on the Batabano

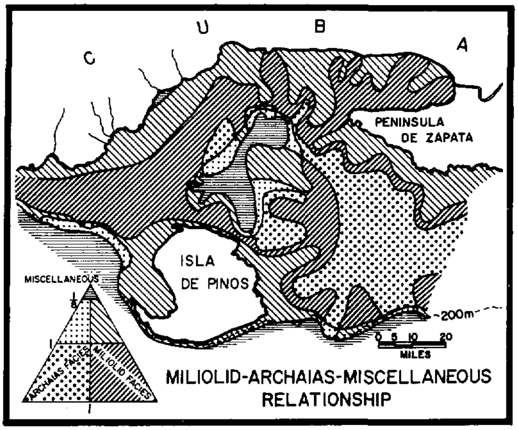


FIG. 3.—Multivariate plot, *Archaias*-Miliolid-Miscellaneous foraminiferal groups, Batabano Bay.

platform (Fig. 3). The northern and central areas of the platform are dominated by miliolids together with miscellaneous smaller foraminifera (mostly *Elphidium* spp.), the back-reef area in the southwestern part of the platform is dominated by miliolids alone, and the southeastern area of the platform has an abundance of *Archaias* populations. The first two groups are associated with lower energy environments (currents of less than ½ knot) and mostly lime mud matrix bottom sediments, the third (*Archaias*) group is identified with a higher energy environment and ovoid grains. Reefs along the southern edge of the platform are characterized by abundant populations of *Archaias* together with skeletal debris, forming an important linear feature parallel with the edge of the platform.

Significant Foraminifera, inner platform area.—One of the most characteristic indices of euryhaline environments is *Ammonia beccarii tepida* (Cushman), a species that comprises more than 10 per cent of the population in much of the small bay in the northeastern area of the platform (Fig. 4A). Better sample control is needed near the mouths of small streams along the northern shore to show the complete distribution pattern of *Ammonia*. A few small isolated occurrences of this species in the central platform area are anomalous and may represent relict or transported specimens. Marsh and estuarine populations were not sampled; they would undoubtedly be characterized by *Miliammina fusca* (H. B. Brady), *Ammotium salsum* (Cushman and Bronniman), and one or two other arenaceous foraminifers.

Two dominant inner and central bay indices are *Elphidium discoidale* (d'Orbigny) and *Elphidium poeyanum poeyanum* (d'Orbigny). *Elphidium discoidale* is a very prominent species in the northeastern area and in the central region of the bay, making up more than 30 per cent of the total population over an area of about 700 square miles (Fig. 4B). *Elphidium poeyanum poeyanum* is also a significant member of the central and inner bay areas, comprising more than 30 per cent of the population over many hundreds of square miles (Fig. 4C).

Miliolids, already discussed in general (Fig. 3), consist of *Quinqueloculina akneriana* d'Orbigny, *Q. bosciana* d'Orbigny, *Q. lamarckiana* d'Orbigny, *Miliolinella subrotunda* (Montagu), *Pyrgo cuspidata* (Terquem (*P. denticulata*) [Brady]), and some other assorted species of minor importance. *P. cuspidata* is somewhat restricted to the northern shore and to islands and shoals in the bay; however, the general distribution accords with areas of carbonate mud matrix. Species of *Elphidium* and the miliolids together show a direct correlation with abundance of carbonate mud matrix (Fig. 4D). Either group alone, *Elphidium* or miliolid, shows very poor correlation with mud matrix. Thus, some areas of lime mud matrix have a dominance of the one group, other areas of mud matrix have a dominance of the other of these two groups, and in still other areas there are intergradations between the two extremes. Depth, temperature and salinity characteristics are essentially the same in these areas of carbonate mud matrix.

Significant Foraminifera, outer platform area.—The outer Batabano platform area is bounded on the south by islands, cays, and prominent linear reef structures. Outstanding differences in the sediment and general foraminiferal biofacies occur between the southeastern high-energy environ-

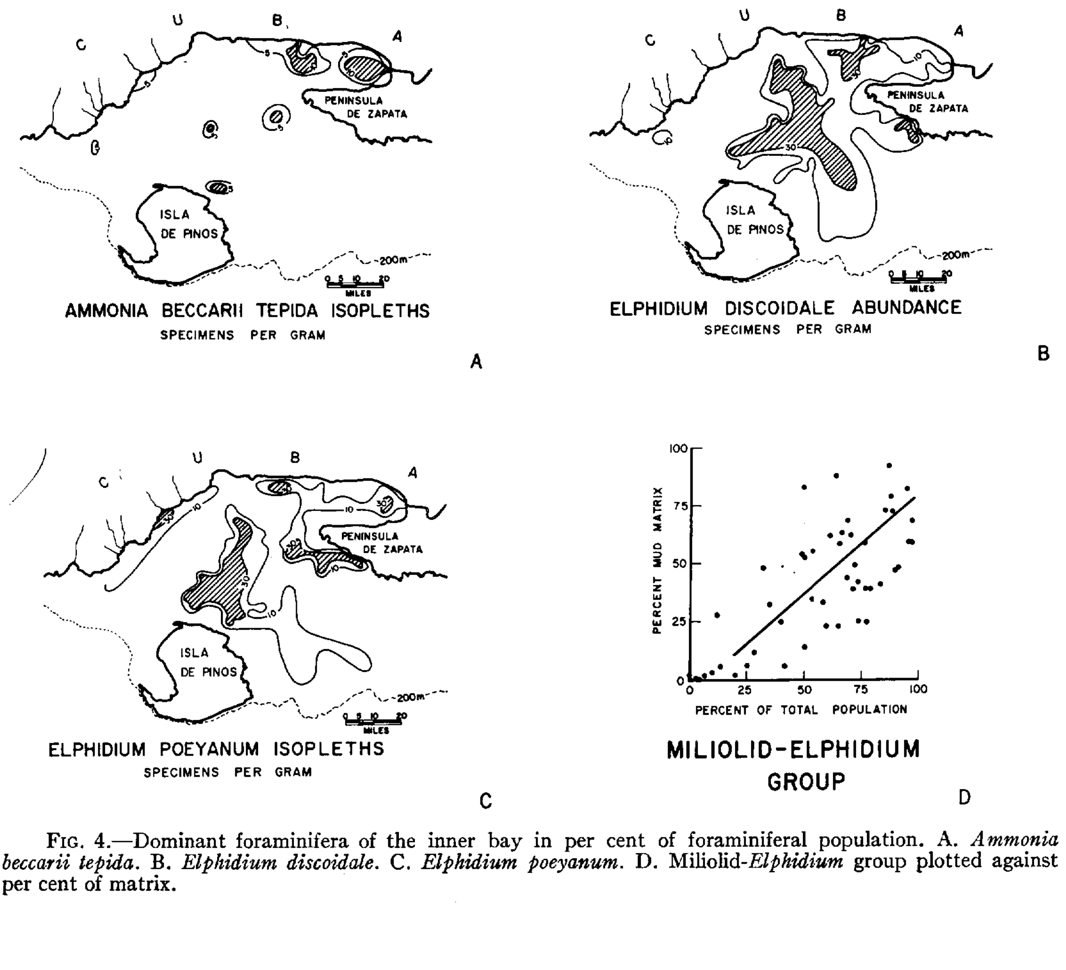


FIG. 4.—Dominant foraminifera of the inner bay in per cent of foraminiferal population. A. *Ammonia beccarii tepida*. B. *Elphidium discoidale*. C. *Elphidium poeyanum*. D. Miliolid-*Elphidium* group plotted against per cent of matrix.

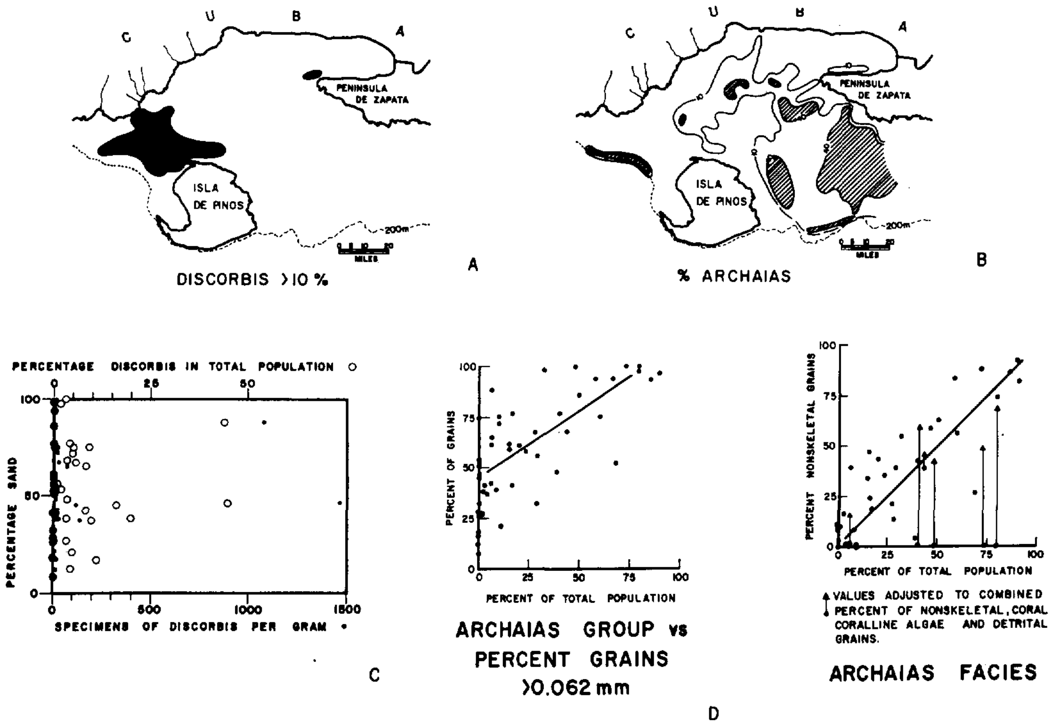


FIG. 5.—Dominant foraminiferal indices of outer bay. A. *Discorbis mirus* in per cent of foraminiferal population. B. *Discorbis mirus*, in per cent of population and specimens per gram, plotted against per cent of grains larger than 0.062 mm. C. *Archaias* in per cent of foraminiferal population. D. *Archaias* group plotted against grains larger than 0.062 mm. E. *Archaias* group plotted against non-skeletal grains.

ment and the southwestern low-energy environment, as already discussed. *Discorbis mirus* Cushman is a good index species to the low-energy environment in the southwestern area (Fig. 5A); however, plots of *Discorbis* (in percentage and specimens per gram) against sand-size particles show no significant trend (Fig. 5B).

Archaias angulatus (Fichtel and Moll) is the dominant foraminifer in the southeastern area of the Batabano platform and also in a linear belt associated with the reef-complex along the southern edge of the platform (Fig. 5C). It, together with the secondary forms of this group, comprises more than 40 per cent of the foraminifera in more than 1,000 square miles of the platform area. The *Archaias* facies is identified with ovoid and composite grains in the southeastern area of the platform and with skeletal debris and coarse sediments of the reef areas. This species is significant in the offshore area of western Florida (Bandy, 1956) between depths of 0 and 100 feet; the prominent declivity off the southern edge of the Batabano platform effectively restricts the reef-front populations of this shallow-water species to a very narrow band along the edge of the platform. Small areas of occurrence in the central area of the bay may represent relict assemblages. It is noteworthy that all samples composed of more than 50 per cent *Archaias* group occur in sediments which contain more than 50 per cent sand-size particles (Fig. 5D). A direct correlation also occurs between this group and the percentage of non-skeletal grains (Fig. 5E); an especially good correlation occurs between *Archaias* facies and non-skeletal grains combined with coral, coralline algae, and detrital grains. *Archaias* populations appear to correlate with bottom waters which have oxygen values of more than 4.0 ml./l.

Vertebralina and *Nodobaculariella* occur in the western, northern, and in parts of the eastern area of Batabano Bay; however, their occurrences are of minor importance based upon samples now available. *Valvulina oviedoiana* d'Orbigny is a unique arenaceous species exhibiting a very patchy distribution pattern within the bay upon diverse sediment types, in different depths of

water, and in waters of different salinities; however, it is also of secondary importance in defining the principal biofacies of Batabano Bay.

Diagnostic reef-complex species.—The combination of *Amphistegina lessonii* d'Orbigny, *Asterigerina carinata* d'Orbigny, and *Rotorbinella rosea* (d'Orbigny) is characteristic of the reef areas forming a linear belt of abundance along the southern margin of the Batabano platform (Fig. 6A). These, together with *Archaias*, form 80–100 per cent of the populations associated with the reef-complex samples of this investigation. *Amphistegina lessonii* may be represented in this fauna for a different reason than that for the other components; it appears to live on sea grass in water depths in excess of 80 feet so that some of its tests will accumulate on the sea floor in the region of its normal environment and others will be rafted into shoal waters of the reef facies. Sediments of the reef areas are well sorted, relatively coarse, and accumulate in a zone of turbulence. The *Amphistegina* group occurs in samples with a predominance of grains or sand-size particles (Fig. 6B) and, based on inadequate data, it may be identified with oxygen values of more than 4.5 ml./l. (station G-2).

Diagnostic bathyal facies.—Of the deep-water cores, 9 provided limited faunal data between depths of 1,260 and 11,000 feet off the southern edge of the Batabano platform. Tests of planktonic species comprise more than 80 per cent of the foraminiferal assemblages and radiolarians were noted in samples 6B (11,000 feet) and 11B (6,600 feet). Displaced platform species form one third to two thirds of the benthic populations in the sample sequence, giving a measure of the sediment transport down the declivity bordering the Batabano platform. Indigenous deeper-water species include *Cibicides robertsonianus* (Brady), *Cibicides wuellerstorfi* (Schwager), *Pseudoeponides tener stellatus* (Silvestri), *Nonion pompilioides* (Fichtel and Moll), and others. Although the samples from deeper water are few in number, there is a striking similarity between these and other deep-water samples of the Gulf of Mexico (Parker, 1954), and a major contrast between the deep-water biofacies and the foraminiferal groups on the platform.

Daetwyler and Kidwell (data to be published later) suggest that the Batabano platform margin consists of abrupt and steep subsea cliffs which are fault-controlled, and they report abundant displaced shallow-water skeletal debris on the abyssal plain some 40 miles south of the Batabano platform. The presence of significant numbers of displaced foraminifera in the core samples is accordant with the conditions of sediment transport down the declivity.

Miocene fossil foraminifera occur in cores 3B, 5B, 6B, 11B, and 12B. These include: *Cassidulina moluccensis* Germeraad, *Cassidulina subglobosa horizontalis* Cushman and Renz, *Globoquadrina altispira globosa* Bolli, and *Sphaeroidinella seminulina seminulina* (Schwager). Core 11B (28–46

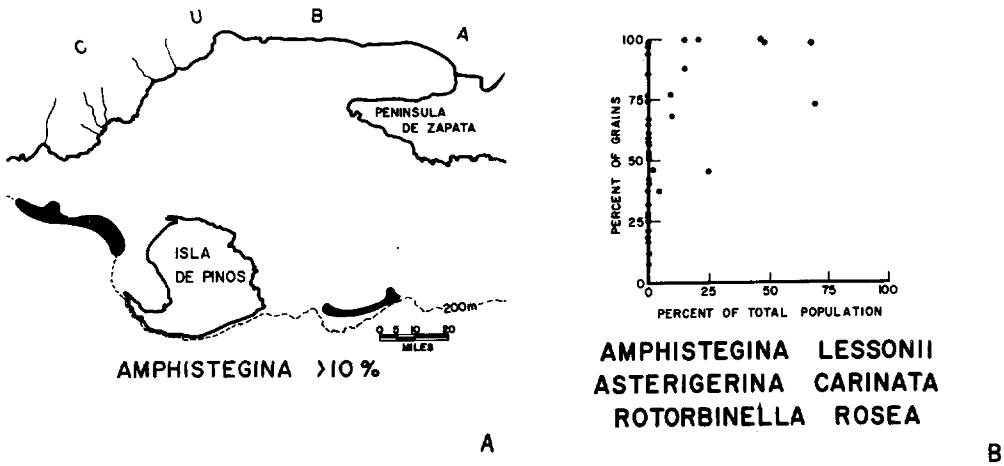


FIG. 6.—A. *Amphistegina* group (*Amphistegina lessonii*, *Asterigerina carinata*, and *Rotorbinella rosea*) in per cent of foraminiferal population. B. *Amphistegina* group plotted against grains larger than 0.062 mm.

inches) and 12B (0–14½ inches) contained *Globorotalia menardii flexuosa* (Koch), a subspecies no younger than Late Pleistocene according to Ericson, Ewing, Wollin, and Heezen (1961).

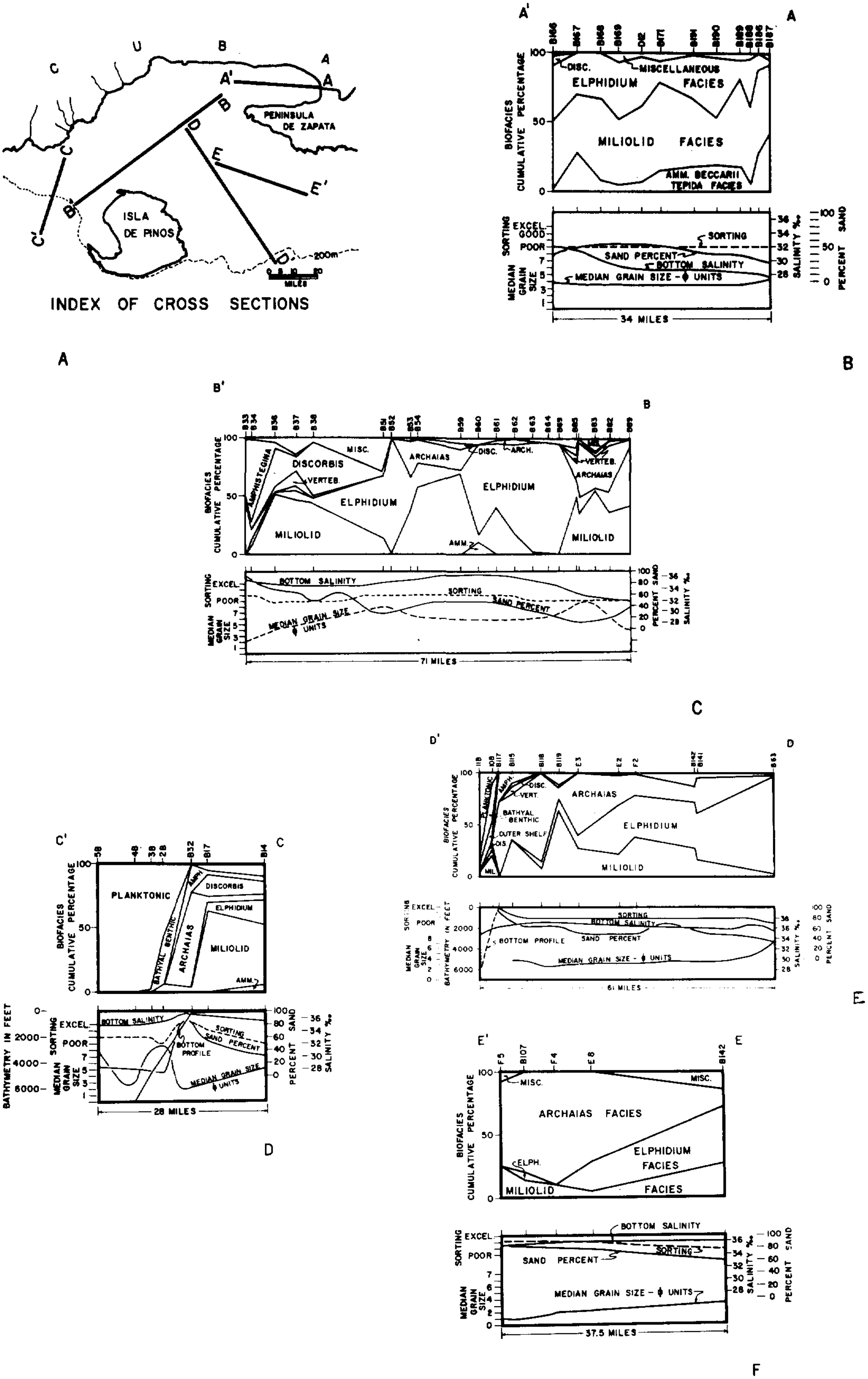
Prominent faunal displacement, the occurrence of Miocene fossils in some of the cores, the few cores available, and the lack of preserved samples from the sediment-water interface make it undesirable to attempt to establish concise foraminiferal zonation within the deeper water facies of this study. Extensive depth control data are already available in the work of Parker (1954) for the northeastern Gulf of Mexico and the deep water zonation given in that work is likely applicable to the deep-water facies off Cuba.

Frequency distribution of species groups along selected profiles.—Profiles are selected to illustrate the frequency distribution of the total foraminiferal population across the major environmental divisions represented in the Gulf of Batabano (Fig. 7A). Profile A–A′ extends from the mouth of a stream to the western end of the small northeastern bay; profile B–B′ extends from the western end of the small bay to the southwestern area to the west of the Isla de Pinos; profile C–C′ crosses the reef area to the deep-water area west of Isla de Pinos; profile D–D′ crosses from the north-central part of the bay to the reef area at the southern edge of the platform, and it ends in deeper water at coring station 11B; and profile E–E′ extends southeastward from the central area of the bay to station F-5. Environmental factors of median grain size, sorting, salinity, and per cent sand are given for the same stations used for the foraminiferal values in each profile for comparison of values. Depth of water is not given for the shoal-water stations of the platform area; bottom profiles are indicated for the deeper-water sections.

Profile A–A′ embraces 12 stations spanning a distance of 34 miles from the mouth of a stream, the Rio Hatiguanico, to the western part of a small northeastern bay (Fig. 7B). It is significant to note that only three faunal groups comprise more than 90 per cent of the fauna at any station within the Ensenada: *Ammonia beccarii tepida* fauna, miliolid fauna, and the *Elphidium* fauna. The *Elphidium* fauna is of much reduced importance near the mouth of the Rio Hatiguanico. The sediments are poorly sorted, sand varies from about 30 to slightly more than 50 per cent along the profile, the median grain size is between 3.5 and 4 (phi units), and the salinity is about 28 parts per 1,000 in the eastern portion of the small bay and it increases to about 32 in the western area of this profile.

Profile B–B′ is made up of 20 stations extending 71 miles from the western area of the small northeastern bay to the reef area at the southwestern edge of Batabano platform (Fig. 7C). The dominant miliolid-*Elphidium* faunas are reduced in two areas along the profile in the central and inner part of the bay, where the profile crosses localized abundances of the *Archaias* populations. In the outer platform area of the southwestern area, *Discorbis mirus* becomes significant and the *Elphidium* populations are much reduced. The reef area, at the southwestern end of this profile, exhibits a dramatic change to more than 90 per cent *Amphistegina-Archaias* faunal groups. *Vertebralina-Nodobaculariella* faunas occur as very minor elements in two positions along the profile. *Elphidium*-miliolid faunas occur throughout the range of salinities and sorting categories, but appear to be reduced in areas with high sand percentages and with large median diameters (low phi units). *Archaias* faunas appear to cross nearly all of the values recorded; however, much better correlation with sand was demonstrated in the plots of this group on coordinates (Fig. 5D). *Discorbis mirus* is dominant in the southwestern platform area; however, similar environmental conditions exist elsewhere in the bay without the development of this group. Their dominance must be ascribed to parameters other than those measured. *Amphistegina* faunas are restricted to areas of fair to good sorting, median grain sizes within the sand category, and with more than 90 per cent grains larger than 0.062 mm. Reef-front areas are also characterized by great turbulence and high oxygen content.

Profile C–C′ is 28 miles long, it embraces 7 stations, it parallels the previous profile in part, and then continues into the deeper water area off the platform. Faunas dominating this trend in sequence are the *Discorbis mirus-Elphidium*-miliolid association in the back-reef area, the *Amphistegina-Archaias* complex in the reef and forereef area, and a planktonic-bathyal benthic faunal assemblage in the bathyal zone. The first association is in the area with a range of poor to good sorting, 30–60 per cent sand, a median grain size in the range between silt and sand, and salinity values between 35.5 and 36 parts per 1,000 in the


INDEX OF CROSS SECTIONS
ISLA DE PINOS
PENINSULA DE ZAPATA
200m
MILES
A
ELPHIDIUM FACIES
MILIOLID FACIES
AMM. BECCARII TEPIDA FACIES
MISCELLANEOUS
DISC.
BIOFACIES CUMULATIVE PERCENTAGE
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bottom waters. *Amphistegina-Archaias* faunas of the reef-complex are associated with salinity values of more than 36 parts per 1,000, excellent sorting, more than 90 per cent grains larger than 0.062 mm., and by a coarse median grain size. Planktonic-bathyal benthic faunas of the deep-water cores are associated with median grain sizes of considerable range, salinity values of about 35 parts per 1,000, fair sorting, and less than 20 per cent grains over 0.062 mm. These values represent a combination of indigenous or planktonic foraminifera and displaced sediment with shallow-water foraminifera from the platform. As shown in plots by Lowman (1949), Bandy (1956), and others, planktonic specimens are more abundant than benthic specimens in the bathyal facies of the Gulf of Mexico; the Caribbean is similar in this respect.

Profile D–D′ is 61 miles long, crossing from the inner part of the bay, across the high-energy area of the platform toward the southeast, and into the bathyal zone off the edge of the platform (Fig. 7E). The inner area has almost 100 per cent of the *Elphidium* group at the northern end of this profile. Toward the southeast there is a gradual change to increasing percentages of miliolids and the *Archaias* group, next a complete dominance of the *Archaias* group in the high-energy back-reef area, a change to a combined *Amphistegina-Archaias* association in the reef and reef-front positions, and finally a rapid change to the dominant planktonic and bathyal benthic foraminifers in the bathyal zone to the south. Sediments show poor to fair sorting excepting in the reef areas where the sorting is excellent. Fifty to seventy per cent of the sediment is sand along this profile on the platform, with a marked increase to more than 85 per cent sand in the reef areas. Values for median grain size increase from silt-size in the *Elphidium* facies at the north end of the profile to sand-size particles southward across the remainder of the platform biofacies. Salinity values range from slightly less than 36 to more than 37 parts per 1,000 and are considered to be unimportant in explaining the biofacies variations along this profile.

Profile E–E′ is about 37 miles long and it extends southeastward from the central area of the bay into the high-energy outer platform facies (Fig. 7F). The miliolid-*Elphidium* groups are dominant in the central area (at E) with a small representation of the *Archaias* group. A progressive increase in domination by the *Archaias* facies is well illustrated in this profile toward the southeastern part of the platform. Paralleling this transition is a gradual increase in the percentage of sand-size grains from about 60 to more than 80, an increase in median grain size, and a change from fair to good sorting. The bottom salinity changes slightly; however, it is so minor that it is not considered to be a significant controlling factor here. Sediment and salinity values for the southern area of this profile are similar to the conditions in the fore-reef areas in profiles C–C′ and D–D′ and yet the *Amphistegina* complex, so abundant in those cases, is absent in this profile. Thus, it is unlikely that the *Archaias* group is reworked or transported into the bay from the reef areas where it is also a dominant group. If this were the case, the *Amphistegina* complex would also be transported into the interior platform area.

Geologic Significance of Foraminiferal Biofacies in Carbonates of Gulf of Batabano, Cuba

General.—The geologic significance of foraminiferal trends in carbonates of the Gulf of Batabano may be subdivided into three main categories: (1) implications as to correlation, (2) relationship of biofacies to lithofacies, and (3) relationships of biofacies to structure and topography.

Implications as to correlation.—It is demonstrable that there are almost no species in com-

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Fig. 7—A. Index of cross sections of Gulf of Batabano, Cuba. B. Profile A–A′ showing dominant foraminiferal facies and environmental parameters in innermost area of bay. C. Profile B–B′ showing foramininiferal and environmental trends from inner area across bay to southwestern edge of platform. D. Profile C–C′ showing facies trends from quiet back-reef area across southwestern edge of platform into bathyal depths on south. E. Profile D–D′ showing facies trends from central inner area of bay across southern high-energy back-reef areas of platform into bathyal depths on south. F. Profile E–E′ showing facies trends in southeastern part of bay.

mon between some paralic environments (Bandy, 1963b); foraminifera of the Gulf of Batabano provide outstanding examples of major facies changes both on the platform and in the deeper waters of the bathyal zone on the south. On the platform, there are dramatic changes from 100 per cent *Archaias* populations in parts of the southeastern area to almost entirely *Elphidium* populations at station B63 (Fig. 7E), to populations of miliolids-*Elphidium-Ammonia* in the Ensenada. Further, foraminiferal samples of the reef-complex may consist of *Archaias* and *Amphistegina* groups alone, providing no correlation with the miliolid-*Elphidium* complex in many northern areas of the bay. Still further, the deep-water planktonic and deep-water benthic suites are in distinct contrast to those facies on the platform. Quantitatively and qualitatively, biofacies changes are dramatic.

Although it is true that there are many instances of little or no correlation between biofacies of the modern Gulf of Batabano, it is important to note modifying factors and conditions in this connection. Two mechanisms serve to provide for a degree of correlation: (1) specimens or assemblages from one biofacies become transported by currents to sites of deposition in other biofacies regimes on the platform and, in turn, some of the platform facies are also displaced into deeper waters by submarine slumps, turbidity current transport, and other processes; and (2) transgressive and regressive phenomena produce an intercalation of the different kinds of biofacies showing that they are contemporaneous when viewed in proper geologic perspective.

Relationship between biofacies and lithofacies.—Positive correlation exists between miliolid-*Elphidium* populations and carbonate mud matrix, it exists between the larger discoidal forms (*Archaias* group, *Amphistegina* group) and sand grains, and it is also usual to find clays and silts associated with abundant planktonic foraminiferal tests in deep-water facies of the Gulf of Batabano. There is little correlation, apparently, between sediment type and species such as *Discorbis mirus*.

Larger specimens of foraminifera, the discoidal shapes of this study, do occur in areas of carbonate mud matrix only as minor assemblages. Thus, as in profile D–D′ (Fig. 7E), an increase in percentages of larger foraminifera signifies a probable increase in grain size. This provides a definite clue as to the probable direction of reservoir potential in carbonate sediments. Henson, in his report on reef formations in the Middle East (1950), pointed out that back-reef limestones of miliolids and peneroplids are typically dense and nonporous; however, the fore-reef detrital limestones are porous and remain so after deposition if laid down below the zone of rapid lime-crystallization. Miliolids and peneroplids (*Archaias* group) of the Batabano study are identified with the general southeastern area of the platform well behind the back-reef area in the usual sense, a condition not unlike that of Florida Bay and the boundary reef-complex of southern Florida (Ginsburg, 1956; Moore, 1957). Henson highlighted the association of basinal source beds interfingering with fore-reef carrier beds, the latter serving as conduits for oil to migrate upward to the reef-reservoirs.

Fore-reef deposits of the Batabano area are disseminated down the declivity leading into deep-water toward the south. One core (1B), at a water depth of 1,180 feet off the southwest edge of the platform, contains mostly displaced debris from the platform and the reef-complex; other cores contain varying amounts of displaced assemblages and platform debris, including *Halimeda*. Thus, the intercalation of fore-reef debris and deep-water biofacies occurs on a pronounced slope in the Gulf of Batabano, spanning a breadth of 2–3 miles off the southern edge of the Batabano platform. As shown originally by Lowman (1949), Grimsdale and Van Morkhoven (1955), Bandy (1956), and Bandy and Arnal (1960), planktonic foraminifera are more abundant than benthic foraminifera in sediments of the bathyal zone in the Gulf of Mexico. Eighty to ninety-nine per cent of the foraminiferal tests are planktonic types in the deep-water cores of the Gulf of Batabano. Probably the correct value is more nearly 99 per cent planktonic tests in the globigerinid sediments of the bathyal zone, if only indigenous benthic specimens and planktonic tests are considered. Thus, as in the case of the Middle East reef study of Henson, globigerinid carbonate sediments are indicative of the deeper-water basin deposits and it is important to determine the trend and breadth of the zone of interfingering of these deposits with the fore-reef debris.

The significance of fore-reef deposits in oil exploration is well recognized and complex. The value of basin deposits as good source beds is discussed by Emery (1960) for modern and Pliocene

basin deposits of southern California. If deeper silled, poorly ventilated basins bounded the southern edge of the Batabano platform in a manner like that of southern California or as in the Permian reef-basin example of West Texas, conditions would be much more ideal for the development of proper source beds. Under these conditions, both reef-complex (as in the Middle East examples of Henson, 1950) and prominent basinal turbidites (as in the Los Angeles Basin turbidites described by Sullwold, 1961) are favored as sites of accumulation of petroleum.

Relationships of biofacies to structure and submarine topography.—Dramatic variations in biofacies on Batabano platform are not associated with structural and topographic changes; however, the rapid transition from entirely benthic foraminifera to mostly planktonic forms is an offshore trend which is associated with the structural trends bounding platform areas such as Batabano, the broad shelf off western Florida (Bandy, 1956), and in other parts of the Gulf of Mexico (Lowman, 1949). This rapid change from benthic to planktonic sepcimens is accompanied by the influx of deep-water species groups, buliminids, uvigerinids, and by the appearance of radiolarians in the deeper-water samples of the Gulf of Batabano. It is important to recognize the kinds of facies changes associated with sediment-energy regimes and those associated with changes in depth of water. Analysis of bathyal foraminifera reveals no temperature control of a number of isobathyal species and species groups (Bandy and Echols, 1964); the same morphotypes occur with similar upper depth limits in highly dissimilar oceanic areas such as the Antarctic and the Gulf of Mexico. Rapid biofacies changes involving these bathymetric indices suggest prominent structural trends and provide means of analyzing topographic features of basins (Bandy and Arnal, 1960).

Examples of biofacies trends unrelated to structural trends and of those identified with structural trends or abrupt changes in bottom topography are seen in many geologic examples. Comparable carbonate facies are well illustrated in the Cretaceous carbonates of the Aquitaine (Cuvillier, 1951) and Italy (AGIP Mineraria, 1959). Tabulated here are some general comparisons between the modern facies of the Gulf of Batabano and the Aptian-Albian (Lower Cretaceous) facies of Italy.

Gulf of Batabano, Modern Facies	*Italy, Aptian-Albian Facies*
1. Low-Energy Environment, Fine-Grained Substrate, Euryhaline (?) Assemblage	
Miliolid facies with ostracodes	Miliolid-ostracode facies, Valle de Cornappo, NE. Italy
2. Transitional	
Miliolid-*Archaias* facies	Miliolid-*Coskinolina* facies, Valle del Torre, NE. Italy
3. High-Energy Environment, Coarse-Grained Substrate, Stenohaline Assemblage	
Archaias-ovoid grain facies	Oölitic-orbitoidal facies, Settefrati, Lazio, Central Italy
4. Deep-Water or Basinal Biofacies	
Planktonic facies with foraminifera and radiolaria	Planktonic facies with foraminifera and radiolaria, Gubbio, Umbria, Central Italy

Carbonate facies of the Lower Cretaceous Aptian-Albian of Italy (also the Upper Cretaceous) are uniquely comparable with the modern carbonate biofacies of the Gulf of Batabano. The first three biofacies combinations are platform or shelf-type associations which are identified with specific areas of sediment type, environmental energy or strength of currents and wave action, and oxygen content. There is no implication in these three cases of profound topographic or structural change. In contrast, the abrupt change to an almost total planktonic facies, with planktonic foraminifera and radiolarians, implies a dramatic change to markedly deeper-water conditions. If this change occurs within a restricted band, it implies that there was a structural trend separating the two kinds of facies at the time of deposition unless subsequent thrusting has brought the two regimes into juxtaposition.

Summary and Conclusions

1. Batabano platform is a back-reef area of shoals, 90 by 180 miles in extent. Foraminifera

on the platform are exclusively benthic and almost entirely calcareous; those from the deep-water facies off the platform are more than 80 per cent planktonic.

2. On the platform, ostracodes and foraminifera are more abundant in areas of mud matrix than on a coarse-grained substrate. Foraminifera are 10–50 times as abundant as ostracodes on the platform; they are more than 100 times as abundant as ostracodes in deeper-water facies.

3. Foraminiferal numbers are less than 100 in platform areas with ovoid grains; values of between 100 and 500 are common in platform areas of carbonate-mud matrix; values of several thousand occur in deeper-water facies.

4. Prominent miliolid-*Elphidium* faunas occupy the northern part of the platform, miliolid-*Elphidium-Discorbis* faunas occupy the low-energy back-reef area in the southwestern part of the platform, and an *Archaias* assemblage is predominant in the southeastern high-energy back-reef area.

5. On Batabano platform, *Ammonia beccarii tepida* is a euryhaline index; and miliolid-*Elphidium* assemblage is identified with a substrate of carbonate mud matrix; an *Archaias* population of larger discoidal foraminifera is abundant in areas of ovoid grains, composite grains, and in skeletal sands along the edge of Batabano platform in the reef-complex.

6. The primary reef-complex has an abundance of *Archaias*, together with *Amphistegina lessonii*, *Asterigerina carinata*, and *Rotorbinella rosea*. This complex defines a linear trend parallel with the southern margin of the Batabano platform. Reef populations are associated with sand-size particles and with oxygen values of more than 4.5 milliliters/liter.

7. Platform facies are displaced into deeper bathyal and abyssal depths as much as 40 miles south of the platform. There is no evidence of deep-water facies being introduced onto the platform. Some Miocene foraminifera are reworked into the sediments of the deeper samples.

8. Abrupt transitions from shallow platform types of biofacies to deep-water facies delineate structural trends in modern marine environments; similar criteria are useful in defining structural trends of the geologic past. Deep-water facies are recognized by the abundance of planktonic foraminifera, radiolaria, and deep-water types of benthic foraminifera.

References

AGIP Mineraria, 1959, Microfacies Italiane (dal carbonifero al Miocene medio), Milano, Italy.

Bandy, O. L., 1956, Ecology of foraminifera in northeastern Gulf of Mexico: U. S. Geol. Survey Prof. Paper 274-G, p. 179-204.

——— 1963a, Foraminiferal biofacies in sediments of the Gulf of Batabano, Cuba (abs.): Am. Assoc. Petroleum Geologists Bull., v. 47, no. 2, p. 349–350.

——— 1963b, Dominant paralic foraminifera of southern California and the Gulf of California: Contr. Cushman Found. Foraminiferal Research, v. 14, pt. 4, p. 127–134.

——— and Arnal, R. E., 1960, Concepts of foraminiferal paleoecology: Am. Assoc. Petroleum Geologists Bull., v. 44, no. 12, p. 1921–1932.

Bandy, O. L., and Echols, R. J., 1964, Antarctic foraminiferal zonation: Antarctic Research Ser., Am. Geophys. Union, v. 1, p. 73–91.

Bandy, O. L., Ingle, J. C., Jr., and Resig, J. M., 1964, Facies trends, San Pedro Bay, California: Geol. Soc. America Bull., v. 75, p. 403–424.

Bush, J., 1949, A preliminary report of the foraminifera of Biscayne Bay, Florida, and their ecological relations: Unpub. master's thesis, Indiana Univ.

——— 1958, The foraminifera and sediments of Biscayne Bay, Florida and their ecology: Unpub. Ph.D. thesis, Univ. Washington.

Cushman, J. A., 1922, Shallow-water foraminifera of the Tortugas region: Cqrnegie Inst. Washington, Pub. 311, Pap. Tortugas Lab., v. 17, p. 1–88.

Cuvillier, J., 1951, Correlations stratigraphiques par microfacies en Aquitaine Occidentale: E. J. Brill and Company, Leiden.

Daetwyler, C. C., and Kidwell, A. L., 1959, The Gulf of Batabano, a modern carbonate basin: 1959 Fifth World Petroleum Cong., Sec. I, Paper 1, p. 1–19.

Emery, K. O., 1960, The sea off southern California: John Wiley and Sons, Inc., 366 p.

Ericson, D. B., Ewing, M., Wollin, G., and Heezen, B. C., 1961, Atlantic deep-sea sediment cores: Geol. Soc. America Bull., v. 72, p. 193–285.

Ginsburg, R. N., 1956, Environmental relationships of grain size and constituent particles in some south Florida carbonate sediments: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 10, p. 2384–2427.

Grimsdale, T. F., and Van Morkhoven, F. P. C. M., 1955, The ratio between pelagic and benthonic foraminifera as a means of estimating depth of deposition of sedimentary rocks: Fourth World Petroleum Cong., Proc., Sec. I/D, p. 473–490.

Henson, F. R. S., 1950, Cretaceous and Tertiary reef formations and associated sediments in Middle East: Am. Assoc. Petroleum Geologists Bull., v. 34, p. 215–238.

Hoskins, C. W., 1962, Molluscan biofacies in calcareous sediments of Gulf of Batabano, Cuba: Am. Assoc. Petroleum Geologists Bull., v. 46, p. 269, Abstract.

——— 1964, Molluscan biofacies in calcareous sediments, Gulf of Batabano, Cuba: Am. Assoc. Petroleum Geologists Bull., v. 48, no. 10, p. 1680–1704.

Ibert, E. R., and Hood, D. W., 1959, Hydrographic survey of the Gulf of Batabano, Cuba: Texas A. and M. Research Found. Proj. 183, Ref. 59-4F, p. 1–8.

Illing, M. A., 1950, The mechanical distribution of Recent foraminifera in Bahama Banks sediments: Ann. and Mag. Nat. History, ser. 12, v. 3, no. 33, p. 757–761.

——— 1952, Distribution of certain foraminifera with-

in the littoral zone on the Bahama banks: Ann. and Mag. Nat. History, ser. 12, v. 5, no. 51, p. 275–285.
Lowman, S. W., 1949, Sedimentary facies in Gulf Coast: Am. Assoc. Petroleum Geologists Bull, v. 33, p. 1939–1997.
Lynts, G. W., 1962, Distribution of Recent foraminifera in upper Florida Bay and associated sounds: Contr. Cushman Found. Foraminiferal Res., v. 13, pt. 4, p. 127–144.
Moore, W. E., 1957, Ecology of Recent foraminifera in northern Florida Keys: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 4, p. 727–741.
Norton, R. D., 1930, Ecologic relation of some foraminifera: Scripps Inst. Oceanography Bull., tech. ser., v. 2, p. 331–338.
Parker, F. L., 1954, Distribution of the foraminifera in the northeastern Gulf of Mexico: Mus. Comp. Zoology Bull., Harvard Coll., v. 111, no. 10, p. 453–588.
Schott, W., 1935, Die Foraminiferen in den aquatorealen Teil des Atlantischen Oceans: Deutsche Sudpolar Exped., v. 11, pt. 6, p. 411–616.
Streeter, S., 1963, Foraminifera in the sediments of the northwestern Great Bahama Bank (abs.): Geol. Soc. America, v. 74, no. 12, p. 165.
Stubbs, S., 1940, Studies of foraminifera from seven stations in the vicinity of Biscayne Bay: Florida Acad. Sci. Proc., v. 4, p. 225–230.
Sullwold, H. H., 1961, Turbidites in oil exploration, *in* Geometry of sandstone bodies: Am. Assoc. Petroleum Geologists, p. 63–81.
Thorp, E. M., 1939, Florida and Bahama calcareous deposits, *in* Recent marine sediments—a symposium: Am. Assoc. Petroleum Geologists, p. 283–297.
Vaughan, T. W., 1918, Some shoal-water bottom samples from Murray Island, Australia, and comparison of them with samples from Florida and the Bahamas: Carnegie Inst. Washington Pub. 213, Pap. Tortugas Lab., v. 9, p. 285–288.