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RECENT MARINE LIMESTONES FROM THE SHELF OFF TROPICAL BRAZIL

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ABSTRACT

Samples of recent limestones and calcareous sandstones dredged from the continental shelf off northern and northeastern Brazil have been studied.

Three types of rock can be distinguished: (1) calcarenites composed of many organisms and fragments, classified as biomicrites in thin section; (2) algal accretionary limestones, showing almost entirely algal structures, named algal biomicrites; (3) calcareous sandstones, lime-cemented shelf sands of fluvial origin. Besides these, one sample was collected from the continental slope, determined as a foraminiferal intrabiosparite.

Study of fauna and mineralogical composition revealed a recent age for all types, confirmed by the faunal assemblage and the dominance of aragonite and high-Mg calcite.

The lithification of calcarenites and calcareous sandstones occurred by cementation of the loose bottom sediment under favourable conditions, in a marine open shelf environment, up to depths of about 100 m. The algal limestones are growth structures of calcareous algae, chiefly *Lithothamnium.*

RESUMO

Amostras de calcários e arenitos calcários recentes, coletadas na plataforma continental do Norte e Nordeste do Brasil, foram estudadas.

Distinguem-se entre êles, três tipos de rocha: (1) calcarenitos, compostos de muitos organismos e fragmentos, classificados como biomicritos em lâmina petrográfica; (2) aglomerados de algas calcárias, mostrando apenas estruturas de algas, chamadas de alga-biomicritos; (3) arenitos calcários, areias marinhas de origem fluvial, cimentadas por calcita. Além disso, foi coletada uma amostra do talude continental, sendo determinada como um foraminífero-intrabiosparito.

O estudo da fauna e da composição mineralógica provou uma idade recente para todos os tipos, confirmade pela associação faunística e a predominância de aragonita e calcita muito-magnesiana.

A litificação dos calcarenitos e arenitos calcários se realizoupela cimentação do sedimento incoerente do fundo, sob condições favoráveis num ambiente marinho de plataforma aberta, a profundidades de até 100 m. Os calcários de algas são estruturas de crescimento de algas de calcárias, principalmente de *Lithothamnium.*

INTRODUCTION

Recent marine limestone formation has been reported from various places in the world, and studied especially at the Bahamas and the Persian Gulf. Recently lithified sandstones, not from the littoral beach rock zone, have been found in some places; the areas are: Fraser River delta, British Columbia, Canada; Auckland Harbour, New-Zealand; Southeast Louisiana and Chandeleur Islands, USA: Rhone delta, France (G a r r i s o n & others, 1969; v a n S t r a a t e n, 1957). On the shelf of northern and northeastern Brazil recently consolidated calcareous deposits have also been sampled (fig. 1). Some preliminary observations have been published by M a b e s o o n e (1968) and by M a b e s o o n e & C o u t i n h o (1970). In this paper we will provide more information on these limestones and sandstones trying to give an acceptable explanation about their origin.

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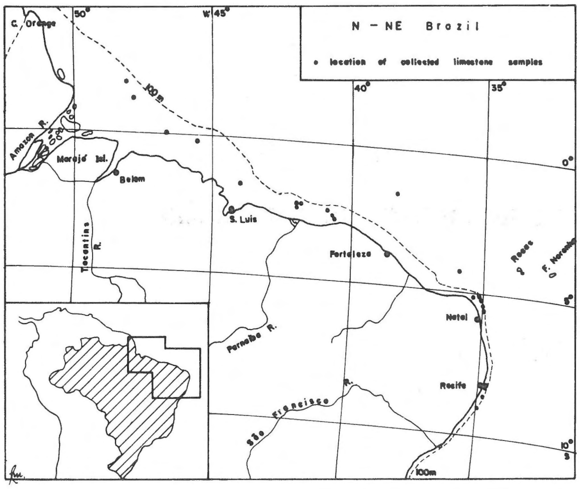

Fig. 1
Occurrence of recent limestones in northern and northeastern Brazil.

The samples have been dredged during the various expeditions made by the Brazilian research vessels in the investigated area, such as "Akaroa" and "Canopus" (SUDENE) and "Almirante Saldanha" (Brazilian Navy), besides some smaller vessels in restricted areas. The generally wide-spread sampling grid did not permit the determination of the extent of such limestone deposits, but is supposed that crust-like phenomena and consolidated rock may occur over many square-kilometres.

The limestones are chiefly found there where the shelf shows a calcareous deposit on its bottom. However, where more mixed sediments occur, limestones have been sampled at a few stations. In front of the Parnaiba river delta and more westward, recent calcareous sandstones are found. Table I gives the location data of all collected samples.

It was not possible to apply all investigation methods in this study. The following analyses have been made: description of hand specimens and thin sections, determination of macro and microfauna, and mineralogical analysis.

All limestones and calcareous sandstones collected in the beach environment have been excluded here and are subject of a forthcoming paper.

MACROSCOPICAL ASPECT

The hand specimens can be divided into three types of rock which are different in composition and texture. The first type consists of yellowish to grey calcarenites with clearly distinguishable elements. The second type shows algal accretions or crust-like algal limestones. The third type has the aspect of very friable sandstones in which the quartz sand grains are of medium size. A characteristic sample of each type is described below:

16: An arenitic rock composed almost entirely of medium-fine sand-size fragments of calcareous organisms of which algae and foraminifera are the chief constituents. The sample has a whitish-grey colour, is very porous and friable, and shows a great number of borings besides a thin crust of algae. There is no visible dominant element so that the rock may be called a *calcarenite*.

15: A nodule-shaped, almost white-coloured concretion of algal growth. It is composed of *Lithothamnium* and *Lithophyllum.* The surface of the limestone is somewhat irregular and in the borings one may find an accumulation of foraminifera and other sand-size organisms or fragments. In cross-section one can easily distinguish the algal structure and its way of growth. The sample may be called an *algal (accretionary) limestone*.

18: Fragments of a medium sandstone, in its centre composed of quartz grains and at the surface of a mixture of quartz and sand-size fragments of calcareous organisms. Locally a thin algal crust occurs. In cross-section, the centre of the sample has a grey colour and the periphery a more yellowish one. This colour difference is due to the lime component of the sample surface, which makes the rock more friable there. The name may be *calcareous sandstone.*

The following sample, a rather coarse-grained coquina, comes from the continental slope; its type is somewhat different from the other samples.

1: A yellowish-brown rock, of medium to coarse-sand size, composed entirely of calcareous organisms. No dominant species can be distinguished. The sample is very friable. Only a few borings can be seen. Name: *calcarenite.*

TABLE I
Analysis data of collected samples.

Sample	Location		Depth	Bottom facies	Macroscopic aspect	Thin section	Foraminifera		Other components				
							dom.	others	1	2	3	4	5
1	9°01,0′S	34°51,2′W	370-560 m	continental slope	friable calcarenite	foram. intrabiosparite	V		R	C	A	R	
2	10°28,9′S	36°15,5′W	25	algal facies	compact limestone	algal biomicrite			A			R	
3	8°01,1′S	34°48,3′W	10	algal facies	algal limestone crust				A				
4	8°48,0′S	34°47,2′W	22	mixed littoral/ biodetritic fac.	friable calcarenite	algal biomicrite	IV	I, II, III	F′	C	A		
5	4°40,0′S	36°34,0′W	63	algal facies	algal limestone				A				
6	4°48,0′S	35°06,0′W	69	algal facies	algal limestone				A				
7	4°55,0′S	34°58,0′W	90	algal facies	algal limestone				A				
8	5°05,0′S	34°57,0′W	69	algal facies	algal limestone	algal biomicrite			A				
9	5°25,0′S	34°56,5′W	69	algal facies	algal limestone	algal biomicrite			A				
10	8°42,0′S	34°47,0′W	58	algal facies	algal limestone	algal biomicrite			A				
11	2°03,0′S	40°29,0′W	65	near slope	coarse calcarenite	biomicrite with intracl.	II	III, IV		R	A		
12	3°51,8′S	33°46,4′W	60	platform Rocas	algal limestone				F′	A			
13	4°46,0′S	35°24,0′W	39	algal facies	algal limestone	algal biomicrite	IV	all	A′				
14	3°59,5′S	35°53,7′W	140	bank of shelf	calcarenite	biomicrite	IV	II, V	A	F			
15	1°47,0′S	37°57,0′W	57	bank of shelf	algal limestone	algal biomicrite			A	P	R	R	
16	2°21,5′S	40°24,5′W	37	biodetrital facies	calcarenite	biomicrite	IV	all		F	A		
17	2°31,0′S	40°22,0′W	23	quartz sand facies	calcarenite with quartz	calcareous sandstone	IV	I, III		C	F		A
18	2°22,0′S	41°51,5′W	37	delta Parnaiba riv.	sandstone w. algal crust	slightly calc. sandstone	IV	I, III		C	A		F
19	2°15,0′S	41°51,0′W	52	delta Parnaiba riv.	calvareous sandstone		IV	I, III			R		A
20	1°36,0′S	44°01,0′W	31	quartz sand facies	calcareous sandstone						R		A
21	0°06,0′S	45°50,0′W	51	mixed littoral/ biodetritic fac.	sandstone w. algal crust	algal biomicrite w. quartz			A		C		F
22	0°13,0′N	46°55,0′W	36	quartz sand facies	slightly calc. sandstone		II	I, III					A
23	2°28,0′N	48°13,5′W	85	Amazon river area	calcareous sandstone	calcareous sandstone	II	all		F	C		A
24	3°00,0′N	48°54,0′W	76	Amazon river area	calcarenite with quartz	calcarenite with quartz	II	I, V		C	F		A
25	2°07,8′S	42°26,2′W	73	near delta Parnaiba river	calcarenite	micritic limestone w. quartz	IV	II, III, V		F	A		R

Legend: 1 – algal fragments, 2 – foraminifera, 3 – diverse fragments, 4 – micro-mollusks, 5 – quartz, generally rounded and glossy grains;
A – abundant, F – frequent, C – common, R – rare; A′, F′ – abundant or frequent *Halimeda.*

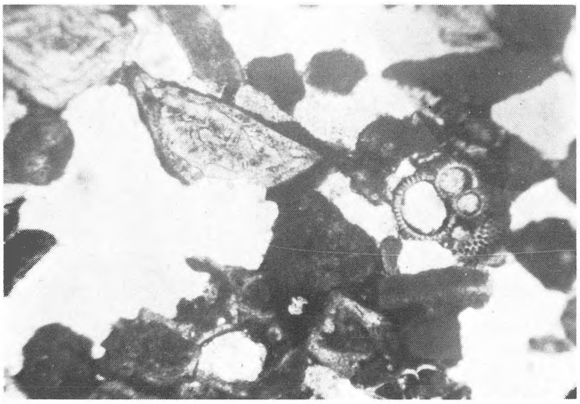

Fig. 2A
Sample 16: biomicrite. Scale 10/0.25-8x.

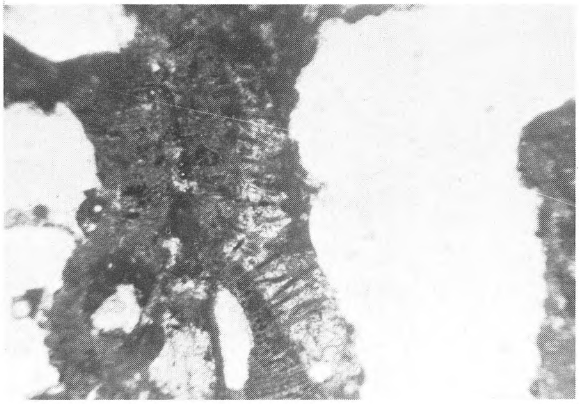

Fig. 2B
Sample 15: algal biomicrite. Scale 10/0.25-8x.

PETROGRAPHIC CHARACTER

Most of the thin sections have been studied by Mr. J.I. Xavier (fellowship of C.N.Pq.; internal report, 1969). The conclusion was that in the classification of Folk (1959) all but one sample are micrites, whereas the only different one (sample 1 from the continental slope), appears to be sparitic. Again the same three types already mentioned can be distinguished, besides the talus sample:

16 – calcarenite: The sample is composed dominantly of micro-organisms and their fragments: foraminifera, gastropods, bryozoans, echinoderms and calcareous algae, making up ± 80% of the total. A few corroded quartz grains occur. About 10% of the remainder is filled up with a microcrystalline calcitic cement, whereas the rest consists of pores and open spaces in which at the borders a growth of fibrous aragonite is visible. The fossils are well preserved and do not show any sign of recrystallization. In Folk's classification the sample is a *biomicrite* (fig. 2A).

15 – algal limestone: A typical algal structure of *Lithothamnium* with many open spaces in which no aragonite is determined. Within the algal framework some micro-organisms, chiefly foraminifera, appear to be included. The algal structures tend to disappear as a micritic mass with a more or less homogeneous aspect. The sample may be called: *algal biomicrite* (fig. 2B).

18 – calcareous sandstone: Chiefly subrounded to rounded medium-size quartz grains constitute the bulk of the sediment. The pores are only partly filled by a microcrystalline calcitic cement so that an attack of the quartz does still not occur at all places. Rarely a fragment of a micro-organism can be distinguished. There occur also a few oxidized glauconite grains. The aspect of the sand is that of a well-worn deposit from an agitated environment (beach or very shallow sea). The rock can be termed as a *calcareous quartz sandstone* (fig. 2C).

1 – calcarenite (from continental slope): The composition of the allochemic material shows a great number of rather small foraminifera, a certain quantity of intraclasts and a small number of other organisms and fragments such as ostracods, molluscs and algae. The cement is very scarce but where it

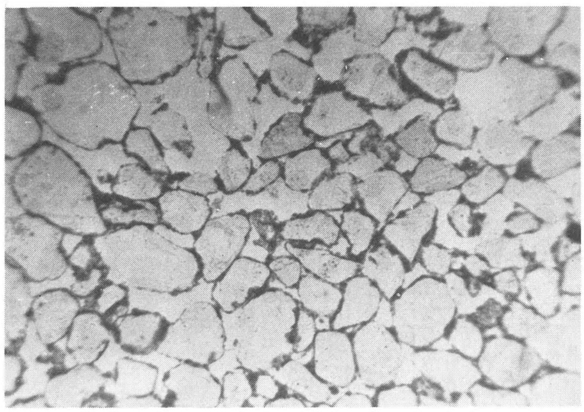

Fig. 2C
Sample 18: calcareous quartz sandstone. Scale 10/0.25-8x.

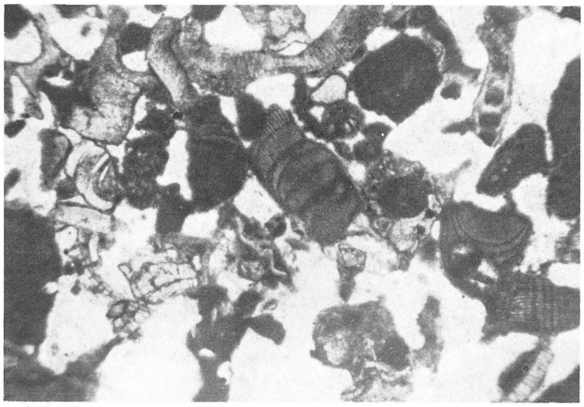

Fig. 2D
Sample 1: foraminiferal intrabiosparite. Scale 10/0.25-8x.

occurs, it appears to be sparry clacite. Aragonite growth has not been observed. The sediment can be classified as *a foraminiferal intra-biosparite* (fig. 2D).

ORGANISMS

Microfauna

The study of the foraminifera present in the limestones has been effectuated, as far as the sample could be desaggregated, by Miss Eva B. Caldas (fellowship of C.N.Pq.; internal report, 1970). Five groups of foraminifera could be distinguished:

group I
benthonic forms with arenaceous test – dominant species: *Textularia agglutinans* d'Orbigny; others: species of *Textularia, Spiroplectamina* and *Clavulina.*

group II
benthonic forms with perforated calcareous test – dominant species: *Cibicides robertsonianus* (Brady) and *Eponides antillarum* d'Orbigny; others: species of *Falsocibicides, Cibicides, Eponides, Poroeponides, Nonion, Cassidulina, Hanzawaia, Discorbis, Gyroidina, Siphonina, Lenticulina* and *Spirilina*.

Group III
benthonic forms with non-perforated test – dominant species: *Quinqueloculina lamarckiana* (d'Orbigny); others: species of *Quinqueloculina, Triloculina, Articulina, Massilina* and *Pyrgo*.

group IV
big foraminifera – dominant genera: *Amphistegina* and *Peneroplis*; others: species of *Amphistegina, Borelis, Peneroplis, Archaias, Amphisorus* and *Heterostegina*.

group V
planktonic foraminifera (in very small quantity, except in sample 1 in which they dominate) – dominant genus: Globigerinoides; others: species of *Globigerinoides, Globorotalia, Globigerina* and *Globigerinella.*

In table I has been mentioned the group which dominates in each sample. It appears that the limestones and calcareous sandstones reflect the foraminiferal assemblage of the bottom deposit at that place. The only exception is sample 14, collected at a depth of 140 m, showing a dominance of *Amphistegina*. This can be explained by the fact that the sample was found near a bank off the shelf, with a steep slope, causing a downward slide of the material from smaller depths.

Among the other micro-organisms and small-size components may be mentioned the following: calcareous algae (often *Halimeda* stems), micro-molluscs, and not more exactly determinable fragments of other organisms such as bryozoans, grouped together with grapestone, grewn-together fragments believed to be of algal origin. The relative abundance of these components has also been mentioned in table I.

Macrofauna

The bigger-sized fauna, chiefly the mollusks, of the shelf of northern and northeastern Brazil is actually being studied by Mr. M. Kempf (Oceanographical Institute of Federal University of Pernambuco). The area is almost unknown so that the major part of the species has still to be determined. Therefore, only some general observations can be given at the moment.

It appears that the recent limestones and calcareous sandstones show the same faunal groups as the surrounding sediment. Almost all samples occurring eastward of the Parnaiba river delta, up to the São Francisco river mouth, show a dominance of calcareous algae. Another group which is present in considerable quantities, is that of the bryozoans as encrusting as well as branching forms. Molluscs are abundant in all samples which show a high percentage of biodetritical material, whereas in the samples with a high quartz content they become less frequent. Corals constitute a considerable amount in those areas where they occur frequently (between Cape São Roque, N of Natal, and the São Francisco river mouth; L a b o r e l, 1968). Other organisms are present in smaller quantities, becoming rare W of the Parnaiba river delta where the shelf bottom is more quartz sandy.

The limestones and sandstones collected from the shelf possess the very same fauna as the surrounding bottom sediment. Besides, they show borings of living organisms whereas within the sponges and algae many detrital sediment has been trapped. Possibly these organisms serve as a nucleus for limestone formation.

MINERALOGICAL COMPOSITION

As determined chiefly by chemical and microscopical analyses the minerals present prove to be aragonite and high-Mg calcite (fig. 3). The low-Mg calcite content is very low to almost zero, with the exception of sample 1 from the continental slope. Two groups of sediment can be distinguished. Group I, with 90-100% of high-Mg calcite ($MgCO_3$ in high-Mg calcite 12,1-19,4%), contains the samples of the algal facies and the sandstones with an algal crust. The algae are in this case almost entirely lithothamnioids. Where the algal bottom shows an accumulation of *Halimeda,* the aragonite content increases. Samples from such areas occur in group II, together with those from the shelf edge and the deeper waters of the banks off the platform which contain more fragments of other organisms with an aragonitic skeleton (bryozoans, solitarian corals, mollusks). Only sample 1, from a depth of 370 m, with its high content of planktonic foraminifera, shows a considerable percentage of low-Mg calcite.

The high content of high-Mg calcite in the samples from the Brazilian tropical shelf is surprising. Studies made in other areas (Florida, Bahama Banks – S t e h l i & H o w e r, 1961; Campeche Bank-Mexico, Heron Island Reef-Great Barrier Reef, Bermuda, Bahamas – F r i e d m a n, 1964) show generally a higher aragonite content as well as a certain amount

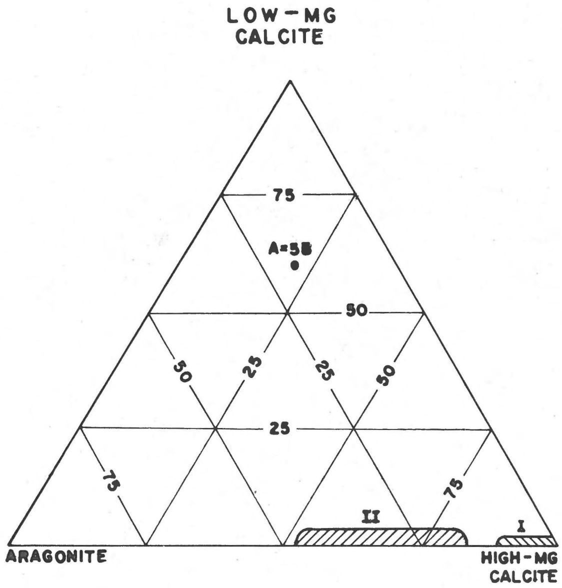

Fig. 3
Mineralogical composition of studied limestones; explanation in text.

of low-Mg calcite. Only the Heron island sediments and a few from Campeche Bank have more or less the same composition as the limestones of group II from the Brazilian shelf.

Not included in fig. 3 are the calcareous sandstones which carbonate content may be as low as 3%. The chief cementing material is in this case also high-Mg calcite.

COMPLEMENTARY OCEANOGRAPHICAL DATA

During the various cruises, bottom temperatures, salinity, and pH measurements have been made.

In the range of the South Equatorial Current, the temperatures vary between 25 and 28°C, the lower temperatures occurring at greater depths. Salinity is always between 35,5 and 36,5 $^0/_{00}$, whereas pH values range between 8,1 and 8,4.

In the area where the Brazil Current is found, the temperatures are generally not higher than 27°C, whereas salinity and pH show almost the same values as along the coast of northern Brazil.

INTERPRETATION OF THE ANALYSES

First, although it could not be proved by C-14 data, it may be concluded that the consolidated limestones and calcareous sandstones are of fairly recent age. Especially the fossil content does not show any difference from the actual one on the surrounding bottom. No species of older ages have been determined thus far.

The rocks are composed of the same material as the bottom sediment at the sampling locality. This means that they must have been formed *in situ*, by cementation of the present loose sediment.

The mineralogical composition reflects that of the organisms determined in the sediment. As has been reported by Blackmon & Todd (1959) and by Neumann (1965), warm sea benthonic foraminifera, lithothamnioid algae, echinoderms and ostracods are almost entirely composed of high-Mg calcite. *Halimeda*, corals and gastropods are chiefly aragonitic, and bryozoans and lamellibranchs show a variable amount of aragonite and high-Mg calcite. Because the mineralogical analysis showed the presence of nearly 100% of the two unstable carbonates mentioned this means again the relatively young age of the studied limestones.

The cementation occurred by microcrystalline carbonate matter (micrite) and proves to be high-Mg calcite, low-Mg calcite and aragonite. Often the latter mineral can be observed as needles in the thin sections. The lithification occurred *in situ*, because the sediments do not show any evidence of their being exposed to subaerial conditions. The same has been found for recent marine limestones on the New Providence Platform of the Bahamas (Taft & others, 1968) and in the Persian Gulf (Shinn, 1969). The Brazalian shelf proves thus to be a real tropical organic reef environment. The bulk of the material is composed of calcareous algae; corals have only a local importance.

Early diagenesis has already been observed in thin section. Many algal structures show a tendency of transformation in micrite, exhibiting a more or less gradational change to microcrystalline calcium carbonate (Wolf, 1965). This is especially the case with the pure *Lithothamnium* limestones. This is, however, the only process observed. Transformation of unstable carbonate minerals into stable low-Mg calcite apparently did not yet happen.

The environment of occurrence and formation is that of a tropical sea, without strong current action, at depths generally between 10 and 80 m with a few exceptions. The temperature is high, as is the salinity of the water, whereas the pH values are basic. There is a certain action of organisms and it is supposed that living algae and sponges play an important role in the beginning of the limestone formation. A few samples collected from the bottom, showed sponges and algae in which loose calcareous sediment was trapped, and where incipient cementation could be already detected.

The recent sandstones show a high-Mg calcite, micritic cement, deposited rim-like around the subangular to rounded quartz grains. Not all pore space has been filled up yet so that the sediment is still very friable. This fact, together with the shallow burial or even occurrence at the bottom surface, causes a lack of compaction and therefore a high porosity. The quartz grains appear to be somewhat corroded by the cement which presents an irregular inner margin and a more sharp outer margin against the adjacent voids. In some samples, broken fragments of shells and calcareous algae as well as entire foraminifera can be found. The determined species are the same as occur actually in the surrounding environment.

ORIGIN OF THE LIMESTONES

When the data obtained for the tropical Brazilian shelf are compared with those for the Persian Gulf (Shinn, 1969), the similarity between the features is striking. No sedimentary structures are found; all particles, even the coarsest shells, are random orientated. The only difference between the limestone and the surrounding bottom deposit is that the first is cemented. Borings made in the cemented sediment, are frequent in both calcarenite and algal limestone. Also the recent limestones studied by Taft & others (1968) at the Bahamas (Yellow Banks) show a similar aspect.

One important difference is, however, the depth at which the Brazilian limestones have been collected. Whereas Taft & others (1968) found no evidence of lithification below a depth of 19 feet (about 6 m) and Shinn (1969) below a depth of about 30 m, the Brazilian samples came from depths between 10 and 140 m, with 50% from depths between 50 and 75 m. If it is true that no lithification occurs below 30 m, the Brazilian recent limestones should be of a somewhat older age, possibly formed during the last sea level rise. But then the unstable carbonates should have been transformed at least partly in low-Mg calcite, which is evidently not the case. Our evidence is thus that lithification may occur also at greater shelf depths, when the environmental conditions are favourable, at least the same as at the shallower depths. The entire shelf area up to the edge which is found between 70 and 100 m, has a fairly uniform temperature, salinity and pH. The only exception, sample 14, from a depth of 140 m, shows evidence of being formed at shallower depth; its content of organisms reflects this, as does its proper occurrence at the top of a rather steep slope.

The process of cementation of the calcarenite seems to be favoured by the medium to coarse grain size of the loose bottom sediment, the abundant pore space, and the presence of algae and sponges which constitute the nuclei for incipient lithification. The decomposition of the organic material and the partial solution of lime debris cause the subsequent precipitation of aragonite and high-Mg calcite as a microcrystalline cement.

The pure algal limestones are nothing more than accretions of lithothamnioids and due to direct organic growth. Grains and fragments of other organisms may become trapped in the open spaces and consequently be cemented within the accretion. Generally such limestone fragments are relatively small in size.

The limestone sample from the continental slope, with its sparitic cement and its content of low-Mg calcite, may be of less recent age as well. The organism content is not indicative for age. However, the faunal content is very characteristic for the depth of occurrence (370 m): almost only planktonic forms. This provides a strong indication for the limestone formation *in situ*, although it may be favoured by the character of the underground. The intraclasts may as well be fragments of an older limestone cropping out on the continental slope, thus creating an environment in which limestone formation is favoured.

ORIGIN OF THE CALCAREOUS SANDSTONES

It is supposed that the carbonate cement in the recent sandstones has the same origin as that of the recent limestones. High-Mg calcite cement seems to be more common than once supposed, and has been mentioned, for instance, from the Mediterranean (Alexandersson, 1969). The sources of the high-Mg calcite may be not only direct precipitation from the interstitial sea water in the sediment but also from high-Mg calcite organisms such as foraminifera and the lithothamnioids of very common occurrence within the sediment.

In the influence area of the Parnaiba river, were salinity values are somewhat lower (although not more than 0,5 $^0/_{00}$, the deposits are sandstones with a very low carbonate content and thus very friable. In the area more westward towards the Amazon mouth, the salinity is normal for the area. This means that salinity is not an important factor in the cementation process. Also in this case, though it could be still not be proved, the interstitial water must create the conditions for lithification of the bottom sands.

CONCLUSIONS

Our conclusions are that the limestones and calcareous sandstones from the shelf of northern and northeastern Brazil are recent formations, composed of the same material as the surrounding bottom. The presence of unstable calcium carbonates, due to the mineralogical composition of the organisms, confirms this recent age. The rocks do not show evidence of having been exposed to subaerial condition so that lithification must have occurred under the sea water level and even at a considerable depth, up to about 100 m. The environment of formation is an open ocean shelf, with not very strong currents, high temperature and salinity, basic pH, and a bottom of biodetritical calcareous sediment.

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