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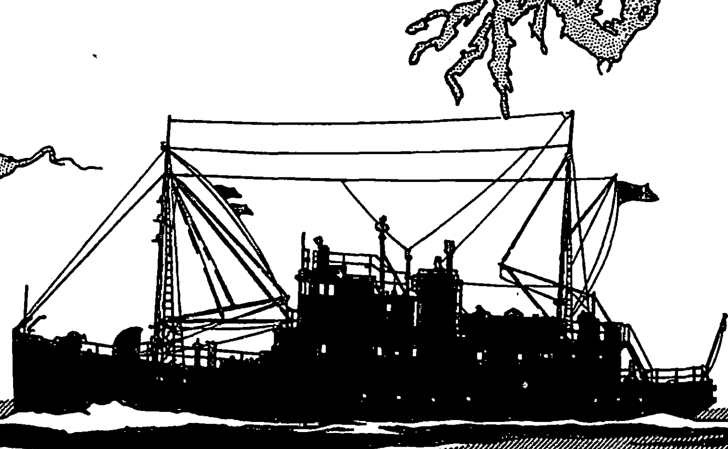

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CARBONATE DEPOSITS ON PLANTAGENET BANK NEAR BERMUDA, by M. Grant Gross. Geological Society of America Bulletin, 76:1283-1290. 1965.

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OXYGEN AND CARBON ISOTOPIC COMPOSITION OF LIMESTONES AND DOLOMITES, BIKINI AND ENIWETOK ATOLLS, by M. Grant Gross and Joshua I. Tracy, Jr. Science, 151(3714):1082-1084. 1966.

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TECHNICAL REPORT NO. 164

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Carbonate Deposits on Plantagenet Bank near Bermuda

Geological Society of America Bulletin, v. 76, p. 1283–1290, 2 figs., November 1965

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Carbonate Deposits on Plantagenet Bank near Bermuda

Abstract: Drilling operations on Plantagenet Bank, southwest of the Bermuda Islands, penetrated approximately 20 m of carbonate sediment and dolomite without reaching the substrate. To a depth of about 13 m the subsurface consists of fragments of calcareous algae, foraminifera, mollusks, and coral (listed in order of abundance). Carbonate fragments from 8 and 13 m were diagenetically altered and may be partially consolidated. Poorly ordered and Ca-rich (57 mole per cent $CaCO_3$) dolomite, containing recognizable fragments of coralline algae, was found at 20 m.

The C^{13} contents of the carbonates are within the range of values observed in the sediments and calcareous skeletal fragments of marine organisms from the Bermuda Islands. The undolomitized sediment is enriched in O^{18} with respect to the modern sediments near the Bermuda Islands; the dolomite is enriched in O^{18} by 3 to 3.7 per mil with respect to associated carbonate minerals in the cuttings. These differences in O^{18} content may be the result of reaction of the carbonate sediment with waters enriched in O^{18}.

CONTENTS

INTRODUCTION

Plantagenet Bank (lat. 32°00′ N., long. 65° 10′ W.) lies in the Sargasso Sea approximately 40 km southwest of the Bermuda Islands (Fig. 1). The Bank is assumed to be one of the extinct volcanoes forming the Bermuda Pedestal (Verril, 1905; Sayles, 1931).

Plantagenet Bank is submerged to a depth of about 30 fathoms (55 m) and is apparently covered by unconsolidated carbonate sand with nodules of calcareous algae up to 10 cm in diameter (H. A. Lowenstam, personal communication). Cores up to 8 feet (2.4 m) in length have recovered unconsolidated sediment (Ewing and others, 1960).

Approximately 20 m of carbonate sediment on Plantagenet Bank was penetrated by rotary drilling equipment in water depths of approximately 58 m, during construction of the Argus Island tower.

Inasmuch as Plantagenet Bank is separated from nearby Challenger Bank (Fig. 1) by water more than 600 fathoms (1100 m) deep, sediments now found on the Bank must have come from the volcano that presumably forms the Bank or from organisms living on the Bank or in water above it. There was no evidence that the boring completely penetrated the carbonate sediments; thus, here the volcanic substrate is more than 20 m below the water-sediment interface.

Geological Society of America Bulletin, v. 76, p. 1283–1290, 2 figs., November 1965

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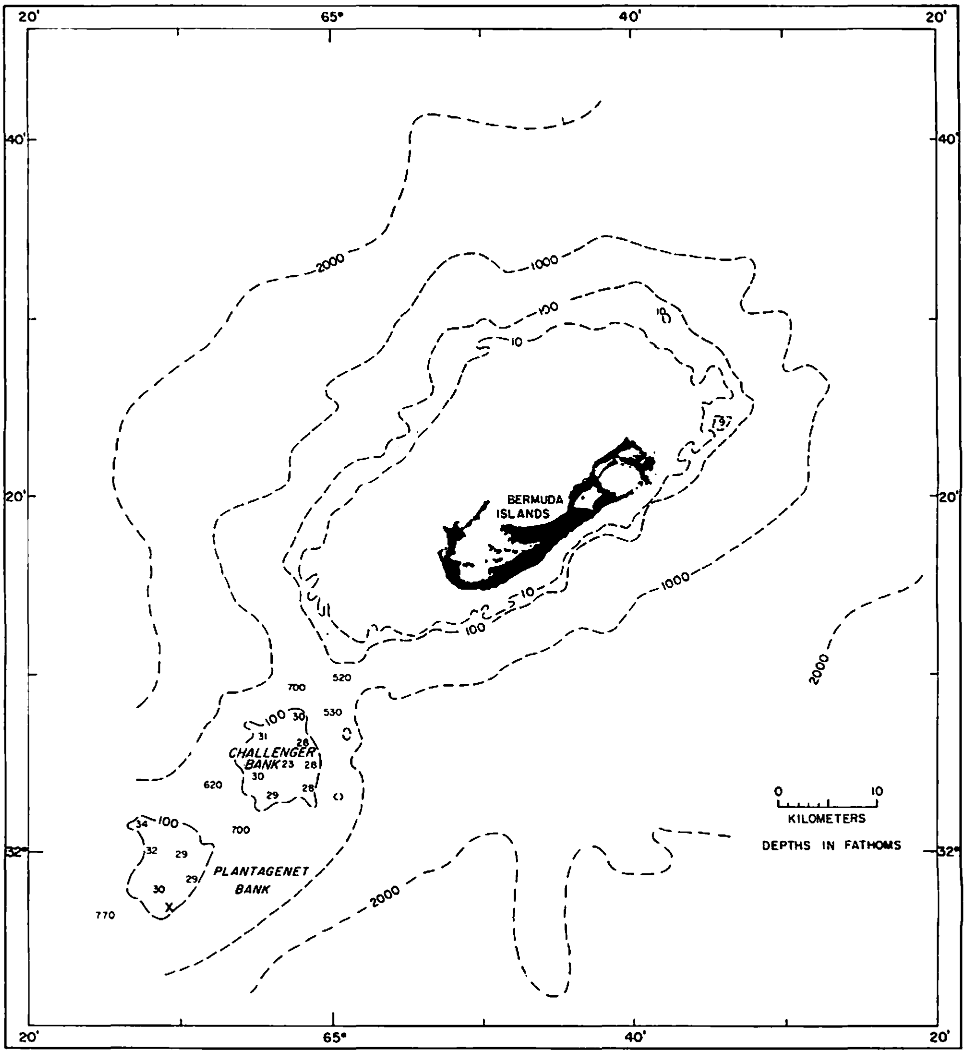

Figure 1. Bermuda Pedestal, showing the Bermuda Islands, adjacent banks, and the boring (X) on Plantagenet Bank

ANALYTICAL METHODS

Samples were collected from the cuttings that settled out in the trough through which the sea water, used as drilling fluid, returned to the ocean. These samples were taken when the bit was approximately 8 m (ABO24), 13 m (ABO-44), and 20 m (ABO66) below the water-sediment interface. Because the hole was uncased and no adequate means of sample collection was available, the actual depth in the boring from which the cuttings came is uncertain.

TABLE 1. ABUNDANCE OF SKELETAL FRAGMENTS IN PLANTAGENET BANK SEDIMENT

Sediment-contributing organisms	ABO24 (8 m) (per cent)	ABO44 (13 m) (per cent)
Algae		
Halimeda	0.9	3.7
Coralline	26.1	23.1
Amphiroa	1.2	0.3
Foraminifera		
Homotrema rubrum	7.1	9.2
Amphistegina	4.0	4.0
Other foraminifera	7.2	7.9
Mollusca	11.4	14.7
Coral	9.3	5.8
Bryozoa	0.6	0.9
Echinoid		
Spines	1.6	0.3
Tests	0.3	0.6
Crustacean	0.3	0.9
Alyconarian spicules	0.3	0.3
Quartz	0.6	0.0
Volcanic material (?)	0.9	2.5
Unidentified	28.2	25.8
Total	100.0	100.0

Portions of the cuttings, including all size fractions, were impregnated with plastic and sectioned for analysis (Ginsburg, 1956); the abundance of recognizable skeletal fragments of marine organisms was estimated by counting approximately 500 points on each thin section (Table 1). The source of the abundant fine-sand- and silt-sized particles could not be determined.

Mineral composition was estimated by X-ray diffraction analysis, and the amount of $MgCO_3$ in solid solution in calcite was estimated by measuring the displacement of the X-ray diffraction peaks (Chave, 1954). The amount of aragonite, low-Mg calcite (less than 4 mole per cent $MgCO_3$), high-Mg calcite (more than 4 mole per cent $MgCO_3$), and dolomite in each sample was calculated by comparing the intensity of the main diffraction peak of each mineral phase and applying appropriate corrections (Lowenstam, 1954; Gross, 1961, Ph.D. thesis, Calif. Inst. Tech.). The results (Table 2) are probably reliable to within 20 per cent of the amount reported.

Carbonate sediments were reacted with 100 per cent H_3PO_4 at 25°C (McCrea, 1950) to obtain carbon dioxide gas for analysis in an isotope-ratio mass spectrometer (McKinney and others, 1950). The sediment from approximately 13 m (ABO44), containing a mixture of dolomite, calcite, and aragonite, was prepared by extracting the carbon dioxide after 30 minutes and again after 72 hours (Degens and Epstein, 1964). The first carbon dioxide sample is considered to be a mixture of calcite and aragonite; the second, dolomite. Isotope ratios (Table 3) are reported as per mil (‰) deviations (δO^{18} or δO^{13}) from the Chicago belemnite standard, PDB-I, with appropriate correction factors applied (Craig, 1957).

COMPOSITION OF THE SEDIMENTS

The surface sediment from Plantagenet Bank was not extensively studied. One grab sample of carbonate sand was found to contain a few fragments of volcanic rock but consisted mainly of the calcareous skeletal fragments of marine organisms, predominately calcareous algae, mollusks, and foraminifera. The *Amphistegina* tests are generally unbroken, but many appear frosted, unlike tests of recently dead organisms. Fragments of *Homotrema* are pale pink rather than the deep red common to the organisms living on the Bermuda Banks.

Cuttings from 8 m (ABO24) and 13 m (ABO-44) in the boring are similar in their abundance of identifiable fragments (Table 1). Fragments of coralline algae, foraminifera, mollusks, and corals are most abundant; the most common foraminifera are *Homotrema rubrum* and *Amphistegina* sp. Large amounts of the cuttings recovered in the two samples may have slumped from the same part in the upper portions of the boring, and the cuttings collected in these two samples may be largely derived from the same zone.

The type and abundance of skeletal fragments in these sediments are similar to those in the modern beach sands and near-shore marine sediments from the southeast coast of the Bermuda Islands. From the abundance of coralline algae and *Homotrema rubrum* in the sediments, one may infer that the sediment-contributing organisms grew near the sea surface in an open-ocean environment (Kuenen, 1950; Emiliani, 1951). The algae must have grown within the photic zone, and probably at depths less than 150 m (Holmes, 1957, p. 123).

Although most of the sediment particles from the upper part of the boring are identifiable, many appear to be diagenetically altered. Fragments of *Homotrema*, some overgrown with coralline algae, retain little of their original red color, and the microstructure of the tests was largely obliterated. The *Amphistegina* tests commonly contain some sparry calcite in the still unfilled, internal cavities; also the microstructure of the tests is not as distinct as in living individuals. Several mollusk-shell fragments from the 8- and 13-m cuttings retain little or none of their original microstructure.

The altered fragments at 8 and 13 m suggest that at least some of the sediment is partially consolidated. However, the scarcity of skeletal fragments obviously cemented together suggests that any aggregates were destroyed during drilling. It is possible that the sediment is similar to the friable, partially consolidated eolianites exposed on the Bermuda Islands (Gross, 1964).

Dolomite was detected by X-ray diffraction analysis (Table 2) in all cuttings; at 20 m below the interface the sediment is completely dolomitized. No dolomite was recognized in thin sections of the cuttings from 8 and 13 m, so it must occur in unidentifiable small fragments or in small crystals. There is no compelling evidence to indicate that dolomite and aragonite coexist in the same fragments.

Cuttings from approximately 20 m consist of interlocking, anhedral to subhedral crystals with some poorly formed dolomite rhombs. Despite the prevalent destruction of textural features, recognizable fragments of coralline algae preserving the original cell outlines cemented together by dolomite are common. Tests of foraminifera and one echinoid plate fragment were also recognized. Apparently the dolomite formed from a carbonate sand consisting largely of coralline algae.

The dolomite is Ca-rich with an enlarged unit cell corresponding to a $CaCO_3$ content of approximately 57 mole per cent, as indicated by X-ray diffraction techniques (Goldsmith and Graf, 1958) and confirmed by a partial chemical analysis (Dr. A. D. Maynes, analyst) of the dolomite ($CaCO_3$, 56.5 mole per cent).

TABLE 2. CARBONATE-MINERAL COMPOSITION OF PLANTAGENET BANK SEDIMENT

Sample number (approximate depth in boring, in meters)	Aragonite (per cent)	Dolomite (per cent)	Calcite: Low-Mg* (per cent)	Calcite: High-Mg† (per cent)
ABO24(8)	30	5	15	50
ABO44(13)	30	15	15	40
ABO66(20)	0	100	0	0

* Less than 4 mole per cent $MgCO_3$ † More than 4 mole per cent $MgCO_3$

The solutions causing the dolomitization may have come from volcanic activity or from brines locally produced by the evaporation of sea water. Although the possibility of volcanic activity cannot be excluded, there is no direct evidence of recent activity. On the other hand, if Plantagenet Bank stood above sea level, evaporation of sea water in isolated basins might produce hypersaline brines which could form dolomite by interacting with the carbonate sediments. This process has been postulated by Deffeyes and others (1964) for the dolomite on Bonaire in the Netherlands Antilles, and for the mid-Pacific atolls (Berner, 1965). This hypothesis requires that at some time Plantagenet Bank was at or above sea level.

CARBON AND OXYGEN ISOTOPIC COMPOSITION OF THE SEDIMENTS

The Plantagenet Bank carbonate deposits are similar in their C^{13} content to the modern sediments of the Bermuda Islands (Gross, 1964) suggesting that little or no change in the isotopic composition of the carbon occurred during the alteration of the sediments (Fig. 2; Table 3).

The enrichment of O^{18} in the dolomite can be explained by assuming that it formed as the result of interaction of the carbonate sediments with hypersaline brines (Deffeyes and others, 1964) enriched in O^{18} by evaporation (Berner, 1965), and that the dolomite retains its original oxygen isotopic composition. Epstein and others (1964) showed experimentally that even at temperatures of 400° to 500°C, dolomite is less susceptible to isotopic exchange with the surrounding fluids than is calcite.

It is obvious (Fig. 2) that the sediment from

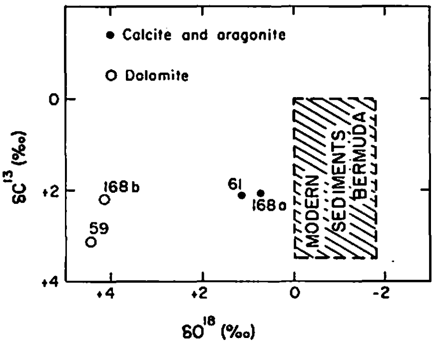

Figure 2. Carbon and oxygen isotope ratios of carbonate sediments on Plantagenet Bank (Table 3) compared with the modern marine sediments from the Bermuda Islands (Gross, 1964)

the upper part of the section is enriched in O^{18} relative to the recent sediments from Bermuda. This enrichment is too large to be explained by the presence of small amounts of dolomite in unaltered sediment. One explanation for the O^{18} content of these sediments is that they still retain their original O^{18} content but that they formed under conditions no longer prevailing in the region. Two possibilities must be considered: (1) the carbonates were formed in isotopic equilibrium with sea water having its present O^{18} content, $\delta O^{18} = +0.8‰$ (Epstein and Mayeda, 1953), but at temperatures lower than those now prevailing in the region; (2) the carbonates were formed in isotopic equilibrium with sea water considerably enriched in O^{18} at temperatures comparable to those now observed in the Bermuda Islands.

If the surface sea water had the same isotopic composition as the present surface sea water at Bermuda (Epstein and Mayeda, 1953), and if the sediment-contributing organisms had formed their skeletons in isotopic equilibrium with the water (Epstein and others, 1951; 1953), they must have grown at temperatures between 16° and 18°C. Similar calculations for sediment (Gross, 1964) from the Bermuda Islands indicate temperatures between 21.5° and 25.0°C, which is close to the temperature of modern shell deposition (Epstein and Lowenstam, 1953). Also, ocean water with temperatures lower than 18°C occurs at present at depths greater than 300 m in this region (Schroeder and others, 1959).

The similarities in type and abundance of the skeletal fragments in the sediments of Plantagenet Bank and the Bermuda Islands, however, suggest that the sediments in these areas formed under similar climatic conditions, with a mean annual temperature greater than 20°C (Epstein and Lowenstam, 1953, p. 435). The presence of *Halimeda* and coral fragments in the cuttings is consistent with this hypothesis (Lowenstam and Epstein, 1957; Wells, 1957, p. 609).

If the sediment-contributing organisms formed their skeletons in isotopic equilibrium with ocean water when temperatures were near their present values, and if the skeletal fragments still retain their original oxygen isotopic composition, the ocean water must have had δO^{18} values of $+1.5‰$ or greater. This is substantially enriched in O^{18} with respect to present surface ocean waters near Bermuda (Epstein and Mayeda, 1953) and probably outside the range of variation in the O^{18} content of

TABLE 3. CARBON AND OXYGEN ISOTOPIC COMPOSITION OF PLANTAGENET BANK SEDIMENT

Sample number	Description (approximate depth in boring, in meters)	δC^{13} (‰)	δO^{18} (‰)
61	Total sediment (8)	+2.1	+1.1
168a	Calcite and aragonite fraction (13)	+2.0	+0.7
168b	Dolomite fraction (13)	+2.1	+4.1*
59	Total sediment, dolomite (20)	+3.1	+4.4*

* These values not corrected for differential acid fractionation

ocean water during Pleistocene times (Emiliani, 1955, p. 543).

Thus, there is no compelling evidence that any of the analyzed sediment samples from Plantagenet Bank retain their original oxygen isotopic composition. Instead it appears likely that much of the observed alteration of the sediments occurred in waters substantially enriched in O^{18}.

Assuming that the dolomitization and diagenetic alteration occurred in isotopic equilibrium with waters having essentially the same O^{18} content and at approximately the same temperature with no isotopic exchange afterwards, we find an apparent fractionation of O^{18} of 3.0 to 3.7‰ between the dolomite and the undolomitized sediment. Obviously the validity of these assumptions cannot be checked with the data available. It is interesting to note, however, that the apparent fractionation agrees more closely with the results of Clayton and Epstein (1958) and Engel, Clayton, and Epstein (1958), who predicted a large fractionation at surface temperatures, than with the results of Friedman and Hall (1963), who found little fractionation between calcite and dolomite. It is evident that to solve this problem we need additional data on the isotopic composition of co-existing calcite and dolomite formed under known conditions.

CONCLUSIONS

(1) Drilling operations on Plantagenet Bank indicate that the carbonate sediments on the Bank are more than 20 m thick. The sediment from the surface and cuttings from 8 and 13 m consists of fragments of calcareous algae, foraminifera, mollusks, and coral. Cuttings from fragments from the boring are diagenetically altered; part of the sediment penetrated may be somewhat consolidated.

(2) Poorly ordered, Ca-rich (57 mole per cent $CaCO_3$) dolomite occurred in all cuttings. The sediment at 20 m was composed entirely of dolomite and apparently formed from carbonate sands containing abundant coralline algae.

(3) The C^{13} contents of the carbonate sediments are within the range of values observed in the calcareous sediments and skeletal fragments from the Bermuda Islands.

(4) The undolomitized sediment and the dolomite are enriched in O^{18} relative to the modern carbonate sediments of the Bermuda Islands. The variations in O^{18} content can be explained as the result of reaction between the carbonate sediment and waters enriched in O^{18}.

(5) Diagenetic alteration and dolomitization of the carbonate sediments most probably occurred when part of Plantagenet Bank was at or above sea level.

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