Manganese Pavements on the Blake Plateau

Abstract. *Dredge samples and photographs from the Blake Plateau, off the southeast coast of the United States, indicate that a layer of manganese oxide forms pavement that may be continuous over an area af about 5000 square kilometers. The manganese pavement grades into round manganese nodules to the south and east and into phosphate nodules to the west. The Gulf Stream probably maintains a very unusual environment that prohibits deposition of clastic sediment and permits accretion of manganese pavements.*

Round manganese concretions from the deep sea have been known since the Challenger Expedition in 1873–1876. The *Challenger Reports* (*1*) mention fragments broken from "huge concretionary masses especially near the top of volcanic sea mounts." Murray (*2*) is also credited with the first description of phosphate and manganese concretions from the Blake Plateau.

The Blake Plateau is an area of moderate depth, between the southeast continental shelf of the United States and the deep-sea basins to the east (Fig. 1). The original surveyors (*3*) realized that the bottom beneath the Gulf Stream was partly a rock pavement swept clean of sediment by the current. The plateau has been investigated extensively by ships of Woods Hole Oceanographic Institution since 1956. It is of exceptional interest for the study of manganese concretions because of the relatively shallow water, the nearness to land, and the great variety and abundance of the manganese and phosphate deposits. We now describe the manganese pavement covering much of the northern end of the Blake Plateau.

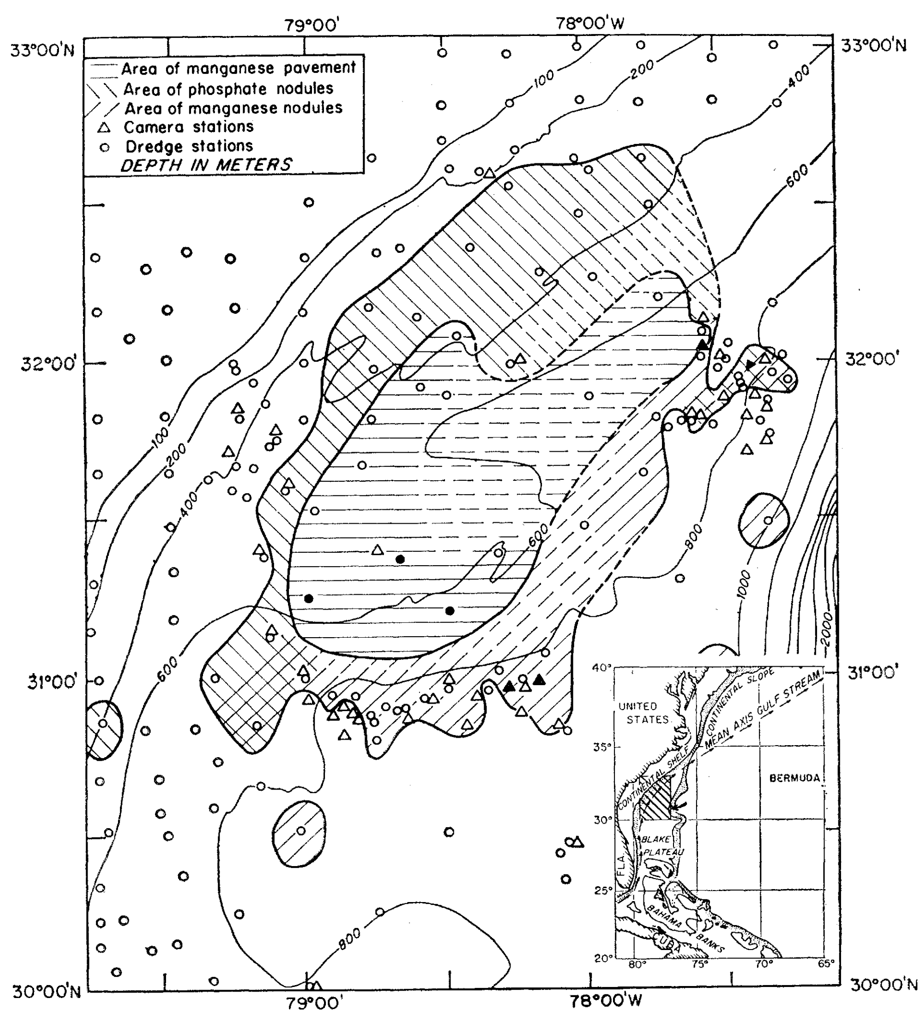

Fig. 1. Extent of the pavement. Estimates are based on a reasonable interpretation of available samples (circles) and photographs (triangles) of the bottom. The irregular boundary at the south and the northeast corners of the manganese nodule area is caused by irregular depression topography, not shown here by the generalized bathymetric contours.

The manganese pavement lies between latitude 31°00′ and 32°10′N and longitude 77°30′ and 79°00′W and may be continuous over an area of 5000 km^2. The depth to the pavement varies between 400 m (to the north) and 800 m (to the south). Topographically the area lies along a broad east-west flexure that forms the north end of the monotonously flat plateau. This probably continuous pavement grades toward the south into an area of slabs, plates, and round manganese nodules and to the north and west into an area of phosphate nodules. The sea floor in the pavement area was investigated by dredging, photography, echo sounding, and seismic profiling.

Dredge stations were made with a chain bag dredge (for nodules and rock), 83 cm wide, to which was attached an 8-cm pipe dredge closed with fine mesh (to obtain sediment). In August and September of 1965, 112 sites were sampled with this dredge combination. At most of the stations on the pavement, large slabs of manganese were recovered without any sediment, and at one station nothing was recovered in three attempts. The lack of sediment in even the small pipe dredge suggests that these pavements are free of significant sediment. A similar failure to recover sediment from the pavement and phosphate nodule area had been noted for some van Veen stations during previous cruises. Proof that the chain dredge dragged over rock bottom was shown by scrape and polish marks on the steel dredge, the recovery of a few sessile sea fans and sponges, and the action of the ship's tensiometer.

Several hauls in the pavement area produced large slabs of manganese pavement (Fig. 2). The largest piece measures 73 by 69 by 4 cm (about the maximum size the dredge could contain). Thickness of the eight largest slabs averages 6.8 cm. The slabs have an irregular tabular to discoidal shape with occasional holes and indentations near the edge. The upper surface is typically flat but not always smooth, while the bottom is rounded and smooth, and often phosphatic, as indicated by the color (brown). Irregular phosphate nodules occasionally project from this lower surface. The undersides also have a few worm tubes and foraminiferans attached, while the upper sides have a few old bases from coral and hydroids and occasional living sea fans, sponges, bryozoans, and other small, sessile organisms. Manganese concretions have relatively sparse sessile populations and are thus distinguished from the scoured limestone bottoms farther south on the Blake Plateau. Both the phosphate and manganese concretions rest in an environment of indurated globigerina sand (calcarenite), as demonstrated by a few nodule samples imbedded in the underlying calcarenite. Some small slabs were encrusted with sponges and other organisms on both sides; hence they projected above the bottom as tilted, broken slabs or as flat-lying, undercut slabs. Photographs do show undercutting of the pavement by current scouring. Such undercutting probably explains why some of the slabs were recovered.

The manganese slabs' broken edges show a laminated or layered internal structure, often with thin interlayers of brown phosphate between the coal-black manganese. Calcitic interlayers and cross-cutting veinlets are occasionally present. Several slabs have remnants of embedded phosphate nodules; in some cases replacement of phosphate by manganese, as well as simple accretion of manganese oxide, may have taken place. The geochemistry of these manganese-phosphate relationships is not yet known.

Photographs were taken in conjunction with current measurements, with single-shot and multiple-exposure cameras. Unfortunately the only multiple-exposure photographic sequence that shows continuous pavement is at the northeast edge of the area in which approximately half of the 508 pictures show a sequence of unbroken pavement (Fig. 3). In contrast, the pictures taken in the area characterized by loose nodules show beds of various-sized nodules interspersed in and surrounded by rippled globigerina-pteropod sand. Bottom current in the area averages about 30 cm/sec.

Echo soundings, when used in conjunction with samples and photographs, help to define the extent of the pavement area. Sounding profiles in the area have very sharp, smooth bottom traces, but profiles of some of the adjacent areas have fuzzy traces and crescent-shaped echoes indicating, respectively, the presence of sediment and coral growths. The pavement seems to be confined to this smooth, well-defined bottom. The limits are partly determined by abrupt scour depressions to the south and east and by a generally rough bottom with small depressions in the phosphate nodule area to the west. However, whether the flat manganese pavement formed over an area of smooth rock bottom or the bottom is smooth because the pavement has resisted scouring is an unresolved question.

Seismic profiles (*4*) have insufficient resolution to define the distribution and thickness of manganese pavements. They do indicate that the shallow sedi-

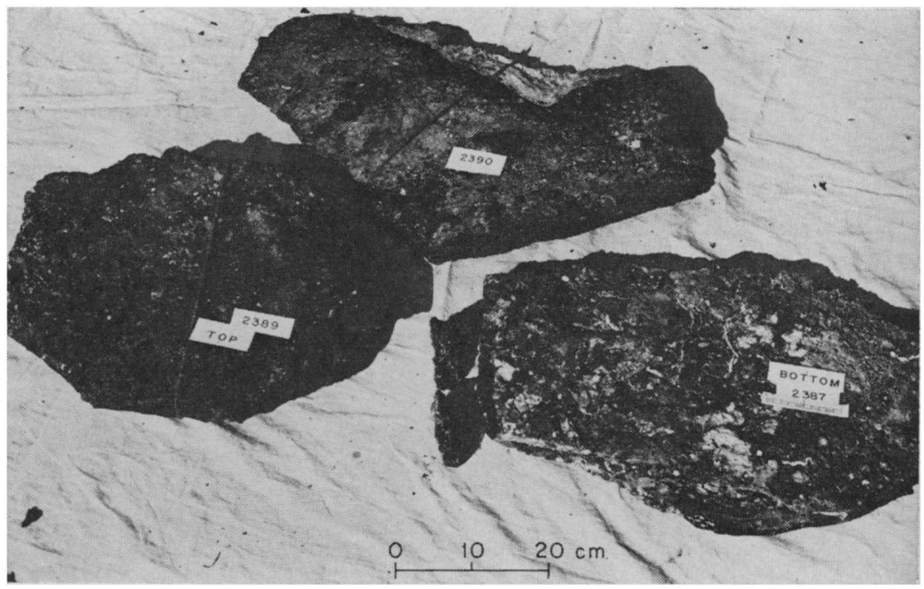

Fig. 2. Representative dredged samples of the manganese pavement. All samples taken on *Gosnold* cruise No. 74. Station 2387, 31°15.2′N, 78°59.0′W, depth 546 m. Station 2389, 31°23.0′N, 78°40.0′W, depth 512 m. Station 2390, 31°12.8′N, 78°29.0′W, depth 648 m.

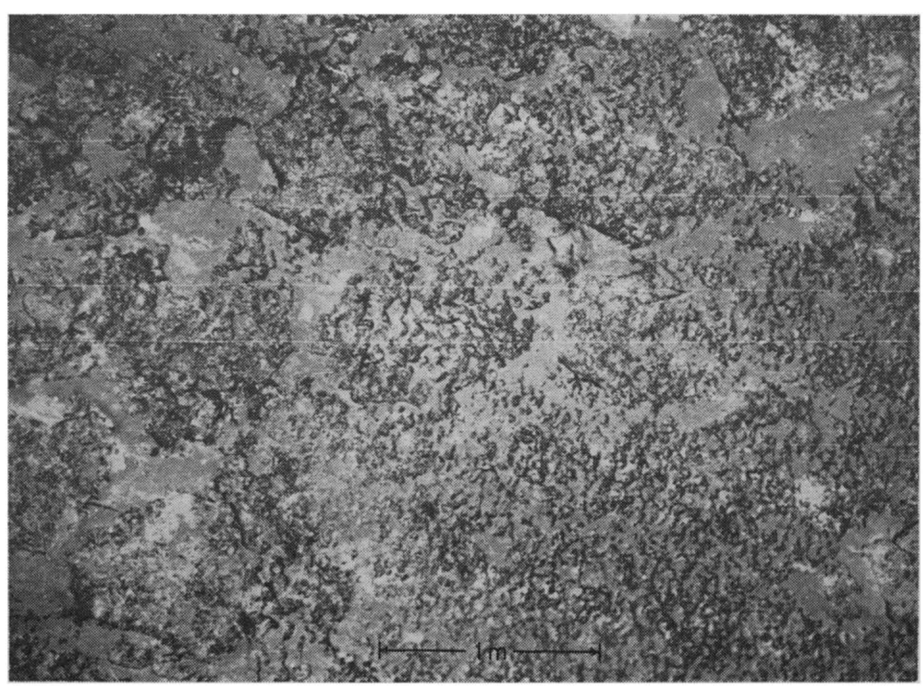

Fig. 3. Continuous manganese pavement on the bottom. This is one of a long series of photographs taken in sequence, all showing the same type of bottom. Station 11, *Atlantis* cruise 266, 32°03′N, 77°37′W, depth 750 m.

mentary strata beneath the pavement are rather flat lying and are discontinuous where cut by scour depressions.

The general tendency for manganese oxides to precipitate out of sea water was recognized by Murray (*1*). Recent summaries indicate that the geochemical precipitation of the manganese as nodules is not unusual (*5*). On the Blake Plateau, however, the Gulf Stream appears to be the special environmental factor that promotes the deposition of manganese oxide in the pavement form. Not only does the Gulf Stream replenish the sea bottom with a constant large volume of sea water, but its associated currents prevent the deposition of clastic sediments. Another factor which might be important in the formation of the manganese pavement is the presence of small, closely spaced phosphate nodules as solid nuclei which could initiate manganese deposition. However, this suggestion is weakened by the facts that an extensive area with phosphate nodules north of the pavement has no manganese and that most of the area of roundish manganese nodules south of the pavement has no phosphate. Also, extensive crusts of manganese oxide cover some of the New England seamounts (*6*) which have the same Gulf Stream environment but no phosphate nodules.

We conclude that the accretion of manganese oxide into the extensive pavement at the north end of the Blake Plateau is primarily the result of an environmental situation in which the impingement of the Gulf Stream currents against the sea bottom is an important factor.

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References and Notes

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7. Work supported under contract 2196-6 with ONR and by the U.S. Geological Survey. Woods Hole Oceanographic Institution contribution No. 1473.

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Oxygen and Carbon Isotopic Composition of Limestones and Dolomites, Bikini and Eniwetok Atolls

Abstract. *Aragonitic, unconsolidated sediments from the borings on the Eniwetok and Bikini atolls are isotopically identical with unaltered skeletal fragments, whereas the recrystallized limestones exhibit isotopic variations resulting from alteration in meteoric waters during periods of emergence. Dolomites and associated calcites are enriched in* O^{18}*, perhaps because of interaction with hypersaline brines.*

The Cenozoic history of Bikini and Eniwetok atolls has been one of slow subsidence—more than 1200 meters since late Eocene time—interrupted by several prolonged periods of emergence during which the atolls stood above the sea as high islands (*1, 2*). The emergences are inferred from subsurface zones of vuggy, calcite-cemented limestone.

Petrographic evidence indicates that the limestone zones resulted from the partial solution of original skeletal material and the addition of crystalline calcite cement. This alteration of originally unconsolidated sediment to lithified rock is believed to have taken place through the agency of percolating meteoric water. Aragonite in these zones is largely or completely replaced by calcite. The zones of calcite-cemented limestone grade downward to unaltered aragonitic sediments; these zones are truncated and overlain with apparent unconformity by unaltered aragonitic sediments. The aragonitic sediments are considered to represent parts of the section that were not long exposed to meteoric waters. These unconformities, called solution unconformities by Schlanger (*2*), at depths of 90, 330, and 820 meters, were formed in Pleistocene, late Miocene, and early Miocene time. Dolomite occurred below the Miocene solution unconformities at Eniwetok (*2*); none was detected at Bikini (*1*).

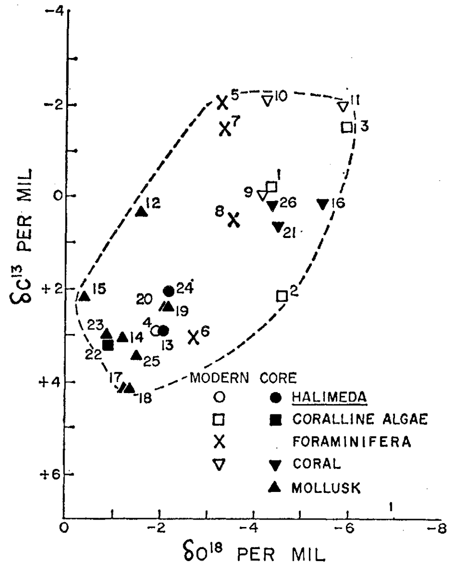

Fig. 1. Oxygen and carbon isotopic composition of skeletal fragments of the dominant carbonate-secreting organisms. The numbers are sample numbers.

The interpretation that the solution unconformities developed during periods of emergence is reinforced by the finding of fossil land snails of genera whose living representatives are usually found only on high islands, and of pollen that appears to be more closely related to present floras from high islands than to those from atolls (*3*).

We determined the oxygen and carbon isotopic composition of samples from the cores and cuttings (*4, 5*) in order to learn more about the processes causing lithification of carbonates in isolated, mid-ocean atolls, and in order to ascertain whether emergences of the atolls could be verified by the isotopic composition of the recrystallized limestone. The initial isotopic composition of the carbonate sediments was obtained by analysis of selected skeletal fragments of the dominant carbonate-secreting organisms now living in the area, as well as apparently unaltered skeletal fragments from the cores (Table 1 and Fig. 1). The results indicate little difference in the C^{13} and O^{18} contents of the skeletal fragments, except for the mollusks, from either source; no modern mollusks were analyzed.

The isotopic compositions of the recrystallized limestones, the altered skeletal fragments, and the coarsely crystalline calcites from the borings on the two atolls show striking variations in C^{13} content as compared to the unaltered skeletal fragments or to the unconsolidated sediments (Table 2 and Fig. 2). The unconsolidated calcareous