Drilling on Bikini Atoll, Marshall Islands

H. S. Ladd and J. I. Tracey
U. S. Geological Survey, Washington, D. C.
G. G. Lill
Office of Naval Research

DURING a resurvey of Bikini Atoll (Operation Crossroads) carried out during the summer of 1947, five holes totaling 4,510 feet were drilled on Bikini Island (Fig. 1). One of these (No. 2B) was carried to 2,556 feet—the deepest hole yet drilled on a Pacific coral island. No materials other than calcareous sediments were encountered, and most of these were unconsolidated or very poorly cemented. Tertiary rocks have been identified from a depth of 925–935 feet, but the top of the system may lie considerably higher. A brief description of drilling operations, a preliminary statement of results, and suggestions for additional work are given below.

Drilling Operations

All drilling equipment and drilling crews were furnished by the Geo. E. Failing Supply Company under contract with the Navy Department. The drill was the "1500 Holemaster" rotary type, mounted on a truck and complete with all necessary tools and equipment, including about 2,500 feet of drill stem. Rock bits were used for straight drilling and hard metal bits for coring. After setting 6-inch surface casing, the holes were continued with $5\frac{7}{8}$-inch bits. In the deepest hole (No. 2B), 4-inch casing was set to a depth of 804 feet, the remainder of the hole being drilled with a $2\frac{7}{8}$-inch rock bit. Salt water was used with salt-water mud at the beginning of the operation but proved unsatisfactory. During the drilling of the deep hole, fresh water and fresh-water mud were substituted.

V. C. Mickle, assisted by Emmett Alexander, was in charge of two drilling crews of three each, and the drill was operated continuously in 12-hour shifts. A geologist was on duty at all times, and in this work the writers were relieved from time to time by John W. Wells and J. Harlan Johnson. Tanks of fresh water from the *U.S.S. Chilton* and other necessary supplies were furnished by Cdr. John R. Denny and his Construction Battalion Detachment.

As originally outlined, the drilling program called for a series of five holes, three to windward across Bikini Island and its reef, and two to leeward on opposite sides of one of the small southwestern islands. These holes were to be cored continuously to 300 feet and one of them carried by rock bit to 2,500 feet. When the first holes were put down, the core recovery was poor and the consumption of mud so great that changes seemed in order. The plan to drill on the cavernous reef flat was abandoned, and efforts were concentrated on completing the deep hole with as many core runs as time would permit.

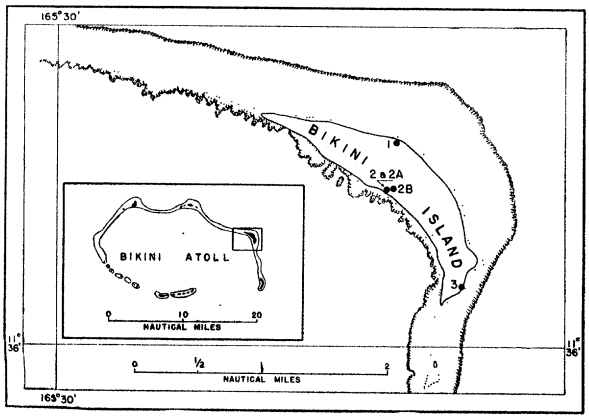

FIG. 1. Map of Bikini Island showing locations of drill holes.

A total of 812 feet was cored with a recovery of 135 feet (16.6%). The recovery was excellent in hard limestone and sometimes very good in the sand; it was poorest in loose or poorly consolidated material in which heads of hard coral were scattered in a matrix of softer sand. Cuttings were recovered at 5- to 10-foot intervals.

There was an appreciable loss of mud during all drilling, and, on occasion, cavities were encountered

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Expenses of the drilling were supported by the Bureau of Ships and formed a part of the geological work of the Bikini Scientific Resurvey. The scientific work was supported by funds provided by the Office of Naval Research and the Military Intelligence Division, Office of the Chief of Engineers. The 1947 operation was carried out under the leadership of Capt. C. L. Engleman, Project Officer. The writers wish to thank Capt. Engleman for enthusiastic cooperation in solving the many drilling difficulties as they arose. They also are indebted to Cdr. Roger Revelle, head of the Geophysics Branch, Office of Naval Research, for encouragement and support in planning and carrying out the entire program.

that stopped circulation completely. One such cavity was cemented and leakage at lower levels controlled by pouring a variety of absorbent materials, including rice hulls, sawdust, and corn meal, in the hole. Between 2,000 and 2,500 gallons of fresh water were used in each 24-hour period during the drilling of the deepest hole. Exact figures on depths, core recovery, etc. are included in Table 1.

TABLE 1

Hole No.	Depth (ft)	Casing (ft)	Drilling time (hrs)	Footage cored	Core recovery (ft)	Core recovery (%)
1	300	19 (6-inch casing)	46	281	33.5	12
2	190	41 (6-inch casing)	23	153	29.5	19.3
2A	1,346	190 (6-inch casing)	162	271	41.0	15.1
2B	2,556	28 (6-inch casing) 804 (4-inch casing)	190	None	None	None
3	118	6 (6-inch casing)	40	107	31.0	29
Total	4,510	284 (6-inch casing) 804 (4-inch casing)	461	812	135.0	16.6

All cores and cuttings are on deposit at the U.S. National Museum in Washington, D. C. Except for a few samples particularly rich in larger fossils, each will be split into two equal parts, one for study and one to be retained intact.

Geology

Lithology. Preliminary studies of the cores and cuttings reveal the following generalized lithologic zones:

(1) Unconsolidated calcareous sand and gravel from the surface to a level immediately below high tide.

(2) Bedded calcareous sandstone and conglomerate 2 feet or more in thickness at intertidal levels.

(3) Reef limestone extending to 65–75 feet, mainly sandy and poorly consolidated but in part compact and well cemented, showing reef corals in positions of growth. Occurrences of hard limestone at depths of from 35 to 65 feet suggest that the shallow terraces fringing the existing reef and the lagoon may be continued beneath the island.

(4) A zone of porous, poorly cemented, white to cream-colored coralliferous limestone with algae and other fossils, extending to about 425 feet. In the interval from 300 feet to the bottom of the zone (and downward at least to 575 feet) many of the corals and mollusks are preserved as molds, suggesting that this part of the section was above sea level for an appreciable time following deposition.

(5) A zone between 425 and 725 feet wherein the material grades from a white, poorly consolidated limestone to a tan, very porous sand with a variety of fragmentary fossils.

(6) A zone between 725 and 1,100 feet in which the material is sandy and poorly consolidated but shows layers containing well-preserved shallow-water Foraminifera, corals, and mollusks.

(7) A zone of fairly firm limestone from 1,100 to 1,135 feet.

(8) A section of medium to fine tan calcareous sand with a few identifiable fossils, extending from about 1,135 to 2,556 feet.

Very little magnesium carbonate is present in the samples analyzed to date. One sample from a beach sandstone core contains 8.27% magnesium carbonate, but 11 other samples at intervals down to 2,500 feet contain only .24–3.46%.

Age. Fossils are abundant in many of the cores and cuttings. The Foraminifera are now being studied by W. S. Cole; corals, by J. W. Wells; mollusks, by H. S. Ladd; and algae, by J. H. Johnson. The top of the Tertiary section has not yet been determined. Tertiary fossils have been identified from a depth of 930 feet, but the contact may lie above 725 feet and possibly as high as the 425-foot level.

Well-preserved upper Tertiary reef corals and mollusks are present in 2½ feet of sandy core recovered from a depth of 925–935½ feet. Many differ from the species now living in the Marshall Islands, some of them being new and others identical with forms occurring in the late Tertiary of the East Indies. A number of the mollusk shells show original luster and traces of color pattern. Foraminifera and echinoid fragments from this interval are not diagnostic with regard to age, but the entire assemblage suggests a depth considerably shallower than that where it is now found. Although many of the fossils show evidence of wear, it appears unlikely that they were transported appreciable distances either horizontally or vertically.

Diagnostic genera of Foraminifera indicating a Tertiary age have been identified from several levels below 1,020 feet. The section from 1,790 feet to the bottom of the hole is definitely lower Miocene, probably to be correlated with Tertiary *e* of the East Indian section.

Geophysical Observations. Seismic investigations made in 1946 indicated that Bikini is underlain at depths of 6,000–13,000 feet by hard material, presumably igneous rock having a seismic velocity of 17,000 feet/second (*1*). This basement surface is irregular. After the drilling of the deep hole in 1947, the Geotechnical Corporation made seismic velocity tests to obtain reliable data for the interpretation of the earlier records. A total of 72 seismic vertical

velocity measurements were made at intervals between 1,820 and 50 feet. A preliminary review of these data shows a break at a depth of about 800 feet. Above this level there are numerous intercalated bands with high velocities. The break at 800 feet correlates reasonably well with the geological data already presented. Below 800 feet the velocity increases relatively steadily with depth to a maximum of approximately 11,000 feet/second. It would appear, therefore, that the entire section above the basement—a section 1–2 miles in thickness—is sedimentary in nature, probably composed of calcareous sediments not unlike those found in the lower part of the deep hole.

Comparison With Other Drill Holes

Funafuti Atoll, Ellice Islands. In 1896–98 the British cored to a depth of 1,114 feet on the seaward margin of Funafuti Island 500 feet from the reef edge (Fig. 2). They obtained an over-all core recovery of

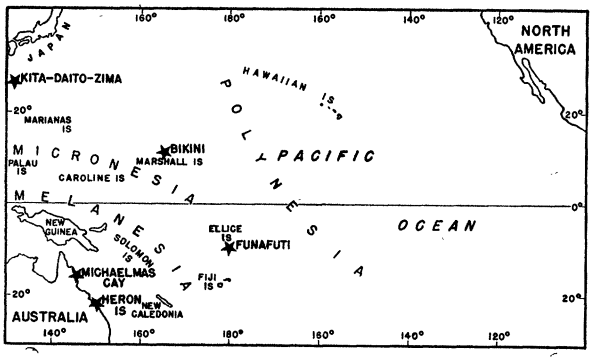

Fig. 2. Map of a part of the Pacific showing locations of drill holes on coral islands.

34% and described their findings in a detailed report (*8*). The section from 0 to 637 feet consisted of porous, friable limestone containing corals, calcareous algae, mollusks, and Foraminifera. From 637 to 748 feet was a white, soft and earthy dolomitic limestone with fossil remains less conspicuous. From 748 to 1,114 feet the rock was a hard and compact dolomitic limestone, 85% of which was recovered as a solid rock core. No fossils other than Recent species were reported, and shallow-water forms only were found.

Magnesium carbonate was generally 1–5% to a depth of 637 feet, with the exception of a maximum of 16% between 15 and 25 feet. Below 637 feet, in the white, earthy limestone, the magnesium carbonate rose rapidly to a maximum of 40%, this being maintained to the bottom of the hole with the exception of two intervals, 819–875 feet and 1,050–1,097 feet, where dolomitization was less. The lower third of the Funafuti boring thus differs radically from that of Bikini in age, induration, and chemical composition.

Kita-Daito-Źima. In 1934–36 the Japanese cored a hole to a depth of 431.67 meters (1,416 feet) on Kita-Daito-Źima (North Borodino), a small island lying south of Japan and to the east of Okinawa (Fig. 2). According to figures given by Endo (*3*), a core recovery of about 28% was obtained above 240 meters; in the lower part of the hole Sugiyama states (*7*) that recovery was lower but averaged above 10%. Study of the cores by Hanzawa (*4*) revealed that down to a depth of 103.49 meters (340 feet) there was cavernous, indurated, dolomitic limestone, containing reef-building corals, calcareous algae, and Foraminifera; from 103.49 to 116.41 meters (340–382 feet), grayish-blue calcareous mud with some limestone; from 116.41 to 209.26 meters (382–687 feet), white granular limestone; from 209.26 to 394.98 meters (687–1,296 feet), coarse-grained calcareous sand; and from 394.98 meters (1,296 feet) to the bottom of the hole at 431.67 meters (1,416 feet), fine-grained calcareous sand. From his studies of the Foraminifera, Hanzawa refers the material above 103.49 meters to the "Plio-Pleistocene," the interval 103.49–394.98 meters to the Aquitanian (lower Miocene), and the lowest zone (below 394.98 meters) to the Chattian (upper Oligocene). Dolomitization was high in the upper levels, ranging from 78.87 to 90.45% dolomite for the interval 0–103.49 meters. Below this interval the dolomite content dropped abruptly to 1.07–6%, with a few intervals having a much higher percentage (41.31–87.56%).

The dolomitic limestones of the upper part of the section in the Kita-Daito-Źima hole have no counterpart in Bikini, but the section below 209.26 meters is much like that of Bikini, both sections being unconsolidated, nonmagnesian, foraminiferal sands.

Great Barrier Reef. In connection with the comprehensive studies of the Great Barrier Reef of Australia, two holes were put down, one on Michaelmas Cay, the other on Heron Island (*6*). These sites are 700 miles apart, Michaelmas Cay being at about the central point in the length of the reef and Heron Island at the southern end (Fig. 2). The Michaelmas Cay hole, lying 14 miles from the seaward margin of the barrier, was carried to a depth of 600 feet; the Heron Island hole, 10 miles from the reef edge, was drilled to 732 feet. In each hole the material encountered for practically the entire depth was loosely coherent, and none of it was dolomitized. The northern hole passed through 378 feet of coralliferous limestone into quartz-foraminiferal sand; in the southern hole the calcareous material extended to 506 feet before entering the sand. Neither hole reached the basement rock. Core recovery was poor, a small fraction of 1% being recovered below 20 feet. It was concluded that the limestone section was accumulated at depths never greater than 25 or 30 fathoms. Mollusks were found

in the Heron Island hole to depths of 696 feet, all apparently being littoral species. Some of the foraminiferal assemblages, however, both in the calcareous section and in the sands below, consisted of worn and broken larger, shallow-water species mixed with well-preserved, smaller, deeper-water species. No extinct species were found, and it was concluded that the entire section is Recent in age.

The limestone section is similar in many ways to that of Bikini, but detailed comparison has not yet been made.

Borneo Shelf. Kuenen (*5*) has reported briefly on two holes recently drilled on Maratoea, described as a horseshoe-shaped elevated atoll, 30 by 7–8 kilometers, lying northeast of Borneo near the seaward edge of the shelf that extends from Borneo to the Celebes Sea (shelf close to island lies at a depth of 270 meters). Highest point on the island is 110 meters; the lagoon is 5–10 meters deep. The drilling was on an islet 2–2½ kilometers inside the outer margin of Maratoea and presumably close to sea level. The first hole was alternately cored and drilled to a depth of 261 meters (856 feet); the second was cored and drilled to 373 meters (1,224 feet), then cored continuously to 429 meters (1,407 feet). A core recovery of 19% is recorded from 51.25 meters (168 feet) of sampling from the 250- to 368-meter interval. Coral limestone alternating with a mixture of pieces of coral limestone and coral sand was found to 189 meters (620 feet); from that level to 261 meters (856 feet) there was no hard limestone but mainly cemented reef detritus and soft, marly limestone merging into an olive-green limy marl. Below 260 meters (853 feet) was an irregular alternation of coral limestone detritus and soft, amorphous, nonfossiliferous limestone. No evidence is given of the content of magnesium carbonate, but preliminary studies of some of the finer samples show a lime content of 83–98%. The age of the sediments penetrated is not stated. The section, except for the greenish marl reported in the first hole, is not unlike that found on Bikini. As Kuenen points out, had the hole been carried 100 meters deeper, the Borneo platform would probably have been encountered and the maximum thickness of "coral growth" in that area would thus have been established.

Suggestions for Additional Work

The establishment of a thick Tertiary section beneath Bikini is very significant in connection with the geologic history of the Pacific Basin,[1] but of even greater interest are the indications that the sedimentary section continues downward for many thousands of feet. The determination of the geological time-span of this unknown section and the environments of deposition which it records should reveal much about the evolution of the Pacific Ocean.

The character of the unknown basement rock is also a matter of prime importance. It may be a basaltic mound, but this is not certain. Other possibilities involving the fundamental structure of the Pacific should be considered. In this connection it should be noted that the atolls of the Marshall Islands, including Bikini, are aligned in two arc-like series. In this area also there are numerous flat-topped sea mounts[2] which rise to levels 700–900 fathoms below the surface. One of these structures adjoins Bikini as a terrace-like feature extending northwestward for 20 miles (*2*).

It is believed that the drilling of a hole to a depth of 8,000–10,000 feet and subsequent exhaustive studies of cores from such a hole would result in significant contributions in several diverse geological fields, including stratigraphy, structural geology, paleontology, petrology, and tectonophysics. Moreover, much information of great interest to zoologists and students of paleoecology is likely to be obtained from a study of the fossils.

Such a hole should be located near the center of Bikini lagoon, where the geophysical evidence indicates that the depth to the basement is slightly more than 8,000 feet. Although the average depth of the lagoon is about 180 feet, the floor is dotted with relatively flat-topped coral knolls, some of which rise to within 12 feet of mean sea level. The tops of these knolls are about 100 feet in diameter and are covered with a rich growth of corals. A substantial foundation for a drilling platform could thus be provided, since a barge could be sunk on such a knoll and a portable drilling rig mounted on top of the barge. Engineers and drillers with whom the plan has been discussed foresee no major difficulties.

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[1] The discovery of such a section was not entirely unexpected, as H. Yabe and R. Aoki (*Jap. J. Geol. Geogr.*, 1922, **1**, 40–44, Pl. 4) had previously found pellets of limestone containing *Lepidocyclina* in a Recent reef conglomerate on Jaluit, an atoll lying southeast of Bikini in the Marshall Group.

[2] These are called guyots by H. H. Hess in a recently published study that gives much information on the form, distribution, and possible origin of such structures in the areas between Hawaii and the Marianas (*Amer. J. Sci.*, 1946, **244**, 772–791).

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Association Affairs

Officers for 1948

At the recent annual meeting of the Association in Chicago, E. C. Stakman, of the University of Minnesota, St. Paul, was named president-elect. The two newly-elected members of the Executive Committee, replacing Dr. Stakman and Arthur H. Compton, are Roger Adams, of the University of Illinois, and Edwin B. Fred, president of the University of Wisconsin. Those elected vice-presidents of the American Association for the Advancement of Science are: Section A (Mathematics), R. L. Wilder, University of Michigan; Section B (Physics), F. W. Loomis, University of Illinois; Section C (Chemistry), Lee Irvin Smith, University of Minnesota; Section D (Astronomy), Alfred H. Joy, Mount Wilson Observatory; Section E (Geology and Geography), Henry R. Aldrich, Geological Society; Section F (Zoology), Alfred S. Romer, Harvard University; Section G (Botanical Sciences), E. N. Transeau, Ohio State University; Section H (Anthropology), Wilton M. Krogman, University of Pennsylvania; Section I (Psychology), Edwin R. Guthrie, University of Washington, Seattle; Section K (Social and Economic Sciences), Talcott Parsons, Harvard University; Section L (History and Philosophy of Science), Alexander Pogo, Harvard University; Section M (Engineering), William R. Osgood, U. S. Navy, Washington; Section N (Medical Sciences), Shields Warren, Harvard Medical School; Section O (Agriculture), H. K. Hayes, University of Minnesota; and Section Q (Education), Francis D. Curtis, University of Michigan.

Section on Geology and Geography (E)

The program of Section E at the Chicago meeting was made up of a symposium on "Problems of Mississippian Stratigraphy and Correlation," organized by J. Marvin Weller, which met for morning and afternoon sessions on Friday, December 26, and a symposium on "Methods of Ground-Water Investigation," organized by E. J. Schaefer, which met for two sessions on Saturday, December 27. A joint session with Section D (Astronomy), a symposium on "Origin of the Earth," was held on Saturday afternoon, December 27 (to be reported upon under Section D).

Geologists from many parts of the country working on Mississippian problems were present to describe the results of their work and take part in the discussions. In his introduction to the Mississippian Symposium, Prof. Weller, of the University of Chicago, indicated the general problems to be considered. The papers are to be published as a special issue of the *Journal of Geology.* In discussing the status of Mississippian stratigraphic knowledge in the Appalachian region, B. N. Cooper, of Blacksburg, Virginia, emphasized the need for detailed studies. P. B. Stockdale, of the University of Tennessee, discussed Mississippian stratigraphy of the southern Appalachians, including results of recent facies studies and problems of defining the Mississippian-Pennsylvanian boundary. D. H. Swann, of the Illinois Geological Survey, presented his and co-author Elwood Atherton's work on subsurface studies of Chester strata in the Illinois basin. L. R. Laudon, of the University of Kansas, described studies indicating that the Osage-Meramec boundary constitutes a major break throughout the Upper Mississippi Valley and in a large area to the west and northwest. E. L. Selk, Oklahoma City, took up the problem of the "Mayes" in Oklahoma. There was vigorous discussion of each of these papers.

During Part II of the Mississippian Symposium, on the afternoon of December 27, J. S. Williams, of the U. S. Geological Survey, Washington, D. C., discussed Mississippian-Pennsylvanian boundary problems in the Rocky Mountain region, and E. C. Reed, of the University of Nebraska, presented subsurface data from Nebraska and surrounding states which indicate that the Mississippian seas were not continuous between the mid-continent region and the northern Rocky Mountain region. Paleontological problems of the Mississippian were taken up in four papers: A. K. Miller, University of Iowa, described Mississippian ammonoid zones; C. A. Arnold, University of Michigan, the Mississippian flora; and C. L. Cooper,