TEST DRILLING IN BASALTS,

LALAMILO AREA, SOUTH KOHALA DISTRICT, HAWAII

U.S. GEOLOGICAL SURVEY

OPEN-FILE REPORT 80-1299

Prepared in cooperation with the
DIVISION OF WATER AND LAND DEVELOPMENT
DEPARTMENT OF LAND AND NATURAL RESOURCES
STATE OF HAWAII

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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December 1980

UNITED STATES
DEPARTMENT OF THE INTERIOR
CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY
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CONVERSION TABLE

The following table may be used to convert measurements in the inch-pound system to the International System (SI) of units.

Multiply	By	To obtain
inch (in)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
cubic foot per minute (ft^3/min)	0.0004719	cubic meter per second (m^3/s)
pound (lb)	0.4535	kilogram (kg)
pound per square inch (lb/in^2)	6.895	kilopascal (kPa)
gallon (gal)	3.785	liter (L)

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ABSTRACT

Test drilling has determined that a downhole-percussion airhammer can be used effectively to drill basalts in Hawaii. When used in conjunction with a foam-type drilling fluid, the hammer-bit penetration rate was rapid. Continuous drill cuttings from the materials penetrated were obtained throughout the borehole except from extremely fractured or weathered basalt zones where circulation was lost or limited. Cementing of these zones as soon as encountered reduced problems of stuck tools, washouts, and loss of drill-cuttings.

Supplies and logistics on the Islands, always a major concern, require that all anticipated drilling supplies, spare rig and tool parts, drilling muds and additives, foam, and miscellaneous hardware be on hand before starting to drill. If not, the resulting rig downtime is costly in both time and money.

INTRODUCTION

In October 1978, initial plans were made by the U.S. Geological Survey to conduct a test-drilling study in Hawaii to (1) locate the water table in the Lalamilo area of the South Kohala District of Hawaii in the northwest corner of the island of Hawaii (fig. 1); (2) conduct experimental drilling in the basalts, using downhole airhammer and foam-drilling techniques; (3) collect continuous samples of the materials penetrated throughout the hole depth; and (4) obtain continuous basalt cores of selected bottom-depth intervals in the borehole by using a conventional core barrel equipped with a diamond coring bit. Drilling was to start as soon as possible after mainland coal-exploration drilling projects had been terminated for the winter season and the drilling rig and necessary support equipment could be loaded and shipped to Hawaii.

The purpose of this report is to present the methods and techniques used by the Survey to drill the basalt. Logistical and technical problems encountered while drilling are discussed. Although a major problem necessitated abandonment of the hole prior to reaching the water table, the study proved beneficial from the standpoint of the drilling experience gained in the attempt.

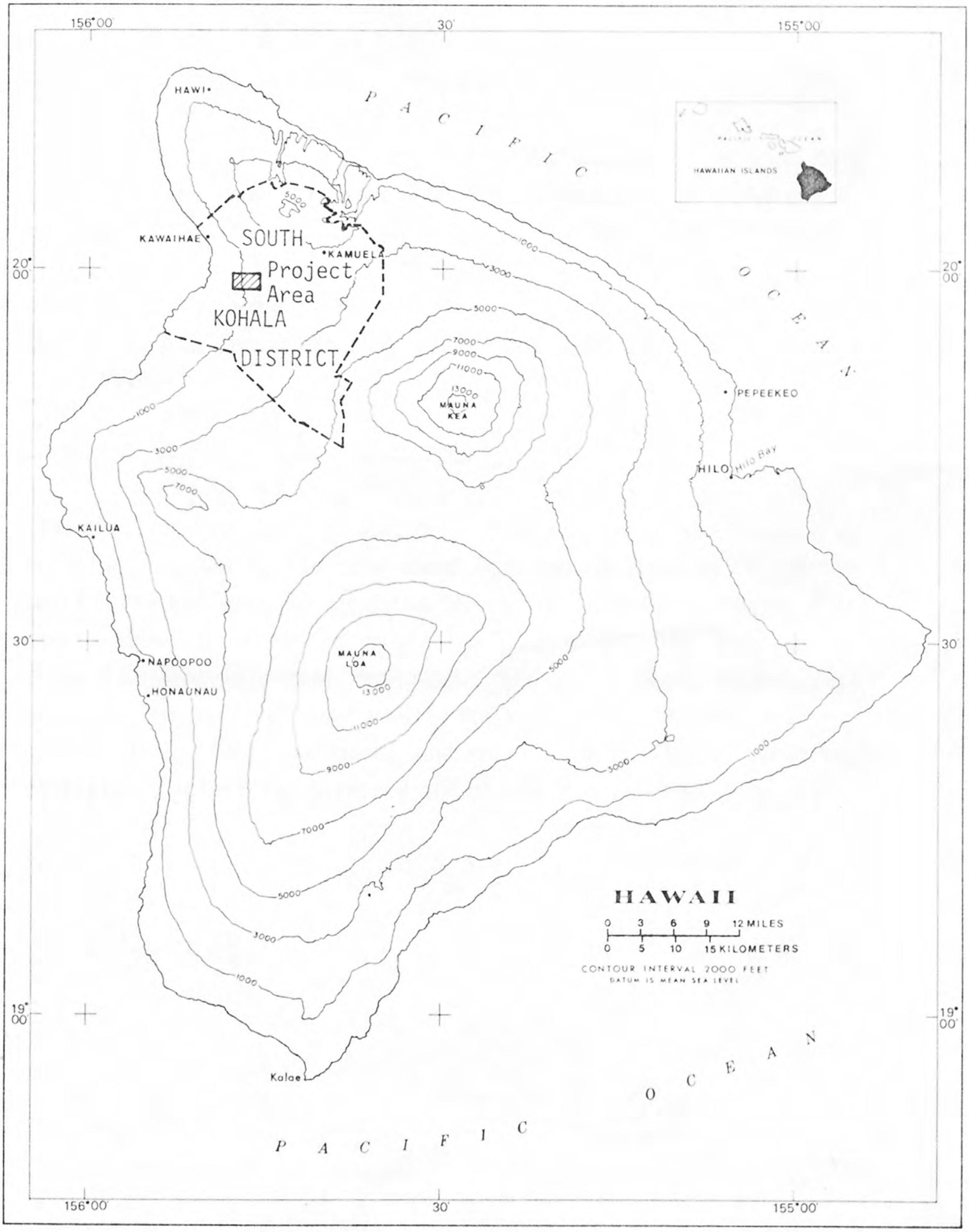


Figure 1. Test-drilling area, South Kohala, Island of Hawaii.

ACKNOWLEDGMENTS

Special thanks are directed to the following people for providing their cooperation, technical support, logistic support, and assistance in many ways throughout the project. Albert Ozaki, State of Hawaii, Department of Land and Natural Resources, Kamuela; Claude Jenkins, Waikoloa; Albert Fujiwara, and Kai V. Torngren, Jr., Hilo Transportation and Terminal Co., Inc., Hilo; E.D. Lohrer, American Mud Co., Grand Junction, Colorado.

LOGISTICS

The drilling rig, water truck, drill pipe, bits, support materials, and drilling supplies had to be shipped from the mainland to the Island of Hawaii. The two vehicles selected for use were loaded in Denver with equipment and supplies and driven to Oakland, Calif., for shipment to Hilo, Hawaii. The equipment took about 5 days to reach Hawaii, and several more days were required in Hilo for unloading. The drilling crew established local fuel, hardware, and miscellaneous charge accounts, rented field vehicles, and examined the proposed drill site (fig. 1).

EQUIPMENT

The drilling rig used on the project was a Gardner-Denver 17W mounted on an 8 ft x 4 ft crane-carrier (fig. 2). The rig was equipped with a two-stage screw-type air compressor and a duplex power pump, for air-rotary or mud drilling. The air compressor was capable of delivering a volume of 750 ft^3/min of air at a continuous pressure of 300 lb/in^2.

A flat-bed truck with a 1,200-gal tank carried the drill pipe, portable mud-mixing tank, and miscellaneous drilling bits and associated equipment. The drilling mud, polymer-type additives, and drilling foam also were loaded on the water truck. Several varieties of rotary bits were selected for the drilling. These included 6-3/4 inch and 5-1/8 inch carbide (button-type) tricone bits, 5-1/8 inch hard-formation (air-rotary type) tricone bits, 5-1/8 inch medium-formation (mud-rotary type) tricone bits, and a supply of downhole percussion bits for use in the air hammer. A 7-7/8 inch (air-rotary type) tricone bit was included for drilling a larger hole for setting the surface casing. The core barrel used for coring the basalts was a Christensen type, 4-5/8 x 3 inch, 10-foot conventional barrel.

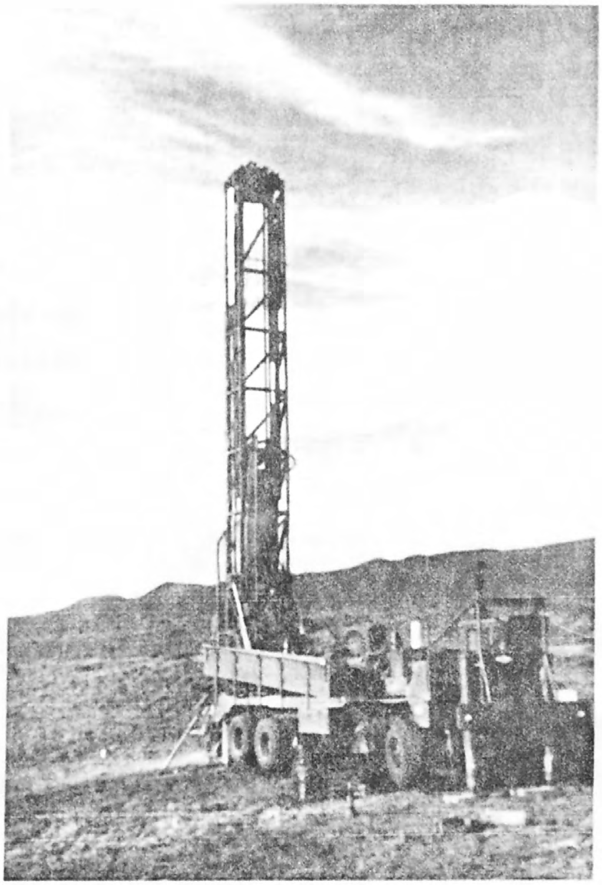


Figure 2. Gardner-Denver 17 W drilling rig.

Airhammer

A Bakerdrill Model D-2 airhammer was used for the drilling (fig. 3). It is a valveless pneumatic tool with all air feed that provides the up-and-down strokes taking place through a plastic feed tube in the center of the piston and through other air passages in the piston. Exhaust occurs through undercuts in the hammer case and, then, out through piston passages. The airhammer runs at cyclic frequency of approximately 1,650 blows per minute at an operating pressure of 250 lb/in^2.

Hammer Bits

Two types of hammer-bit configurations were tested during the drilling. These were the flat-face (Y type) and the drop-center (D-C type). Both types have spherical carbide buttons on the cutting face of the bit. The spherical buttons were selected over conical buttons because they do not tend to catch and twist the hammer in fractured formations as the bit is rotated.

The drop-center bit proved to be the most effective for drilling in the basalts. A more uniform cutting action was maintained while using this bit, and the basalt cuttings were circulated up the hole more readily, resulting in a cleaner hole. The flat-face bit did not penetrate as well, and the return volume of drill cuttings was substantially less.

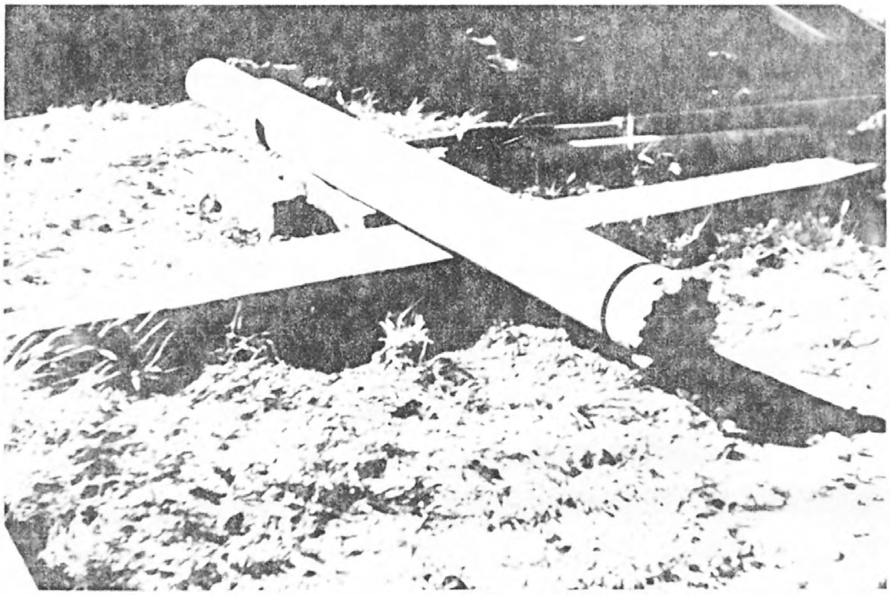


Figure 3. Model D-2 airhammer equipped with a Y-type flat-face bit.

TEST-DRILLING OPERATIONS

Lalamilo No. 1 Site

The first drilling attempt was at the Lalamilo No. 1 site. It was air drilled with the 7-7/8 inch tricone bit to a depth of 13 feet. Because of a cracked feed tube in the air hammer, drilling was continued with a 5-1/8 inch carbide tricone bit until new hammer-feed tubes could be shipped from Denver. At a depth of 35 feet, drilling had to be stopped because of material caving from the upper part of the hole. Surface casing was shipped by air freight from Honolulu, as large-diameter casing was not available on the Big Island. A 9-inch, carbide button-type tricone bit was ordered from Denver; it arrived several days later. The hole was reamed to a diameter of 9 inches and a depth of 16 feet, and the surface casing was installed and cemented in place. After several days of setting, in order to allow the cement to cure, drilling was resumed, using the airhammer equipped with a 6½-inch drop-center hammerbit. At a depth of 65 feet, hole-cleaning problems were encountered with using the hammer and only air to circulate the cuttings to the surface. The hammer was replaced with a 5-1/8 inch tricone bit, a mixture of water and drilling foam was injected to regain circulation, and the hole was deepened to 95 feet. Another attempt was made to use the airhammer; however, the hole was crooked at the depth where the smaller bit had been used. Because the drift was enough to cause the hammer to bind, and reaming attempts proved to be futile, Lalamilo No. 1 was abandoned.

Lalamilo No. 1-a Site

Drilling of the Lalamilo No. 1-a hole used the large-diameter casing bit to a depth of 20 feet. A 12-foot length of 8-inch PVC casing was installed in the hole and cemented to within 5 feet of land surface. After the cement hardened for a day, drilling was resumed with a 6-3/4 inch tricone bit (fig. 4). Upon reaching the basalt, the casing bit was replaced with the airhammer (equipped with the 6½-inch drop-center bit). By use of a mixture of drilling foam and water or, on occasions, just drilling foam to increase cutting returns, the hole was drilled to 110 feet. A zone of cinders, encountered slightly above this depth began caving in around the drill tools and binding them, making further penetration impossible.

It became apparent that the technical services of a commercial mud engineer with special expertise in foam-drilling techniques were needed on the project. The American Mud Co. was contacted and a mud engineer (foam specialist) from Grand Junction, Colo., arrived the next day. He advised the use of a "stiff" foam to condition the hole. The stiff foam recommended had the consistency of shaving cream and was prepared in the following manner: About 15 pounds of an extra-high-yield bentonite (such as, American Mud's Red Devil Gel, Baroid's, Quik Gel, or Magobar's Kwik-Thik) and 4 to 5 pounds of a polyanionic, cellulosic, and long-chained polymer of high molecular weight, used to control fluid loss (such as, American Mud's, Drispac, Baroid's, Drispak, or Magobar's Drispac) were mixed in about 3 gallons of diesel fuel. The reason for using the diesel fuel was that the polymer mixes more readily in it than in water. When mixing in water alone, the polymer has a tendency to form a sticky, translucent, and jellylike substance unless mixed very slowly and in very small quantities at a time. The bentonite-polymer gel

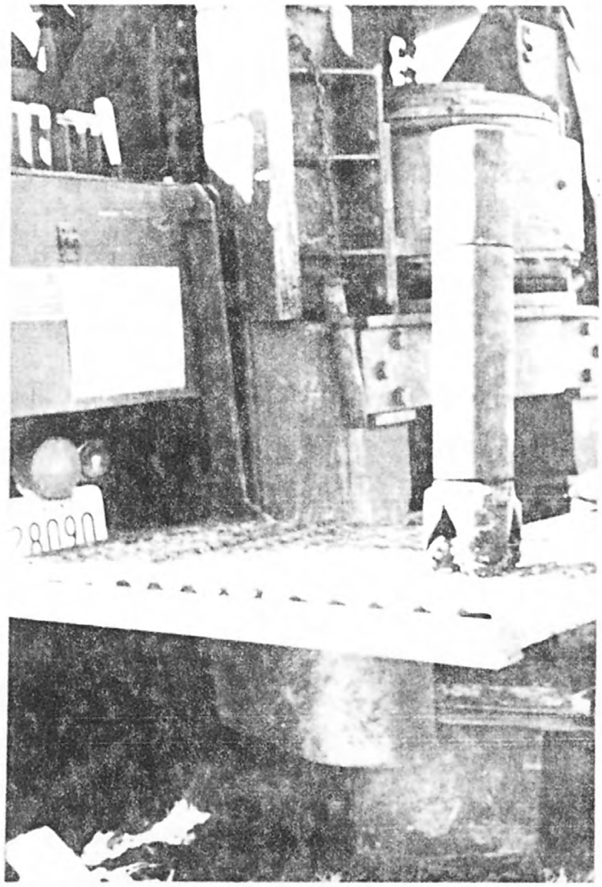


Figure 4. One of the larger tricone drilling bits.

mixture was then circulated through the intake hose of the drilling-rig mud pump (fig. 5) and discharged into the portable mud tank (fig. 6) containing about 350 gallons of freshwater. Circulation was continued until the water and the gel mixture became thoroughly mixed. After all materials were well mixed, about 2 gallons of drilling foam (American Mud's Stafoam 202, Baroid's Quik Foam); were poured directly into the mixture in the mud pit and then circulated just enough to mix it into the solution. (Note: If too high a pump circulation rate is used, the mixture may foam over the mud pit.)

Drilling was resumed, using the stiff foam drilling fluid. Circulation in the borehole was excellent and provided very good cuttings. However, the volume of cuttings returned as compared to downward penetration rate and hole diameter was indicative of a washout occurring just above the 130-foot depth.

Cementing Process

The drill pipe was pulled from the hole and the airhammer was replaced with a 5-1/8 inch drag bit. A nearby cement plant was contacted and a slurry of cement (a mixture containing about eight parts of water to one part of cement without any aggregate) was ordered for use at the drill site (fig. 7). When the cement arrived, the hole was drilled, to the bottom of the cinder zone (137 feet) using the drag bit. Cement slurry was then pumped through the drill pipe and out the drag bit, pressure cementing the caving formation through pressure. To avoid cementing the drill pipe in the hole, it was pulled and removed while the cementing took place, and the borehole was completely cemented to the top of the casing. The cement was left to cure for 1 day and drilling was then resumed.

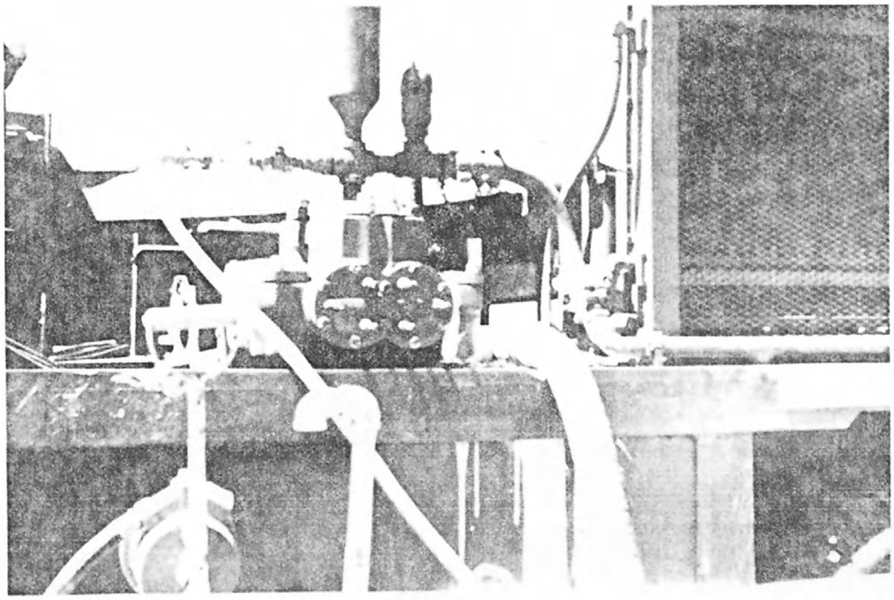


Figure 5. Mud pump on drill rig.

Figure 6. Preparation of a "stiff" foam mixture in the portable mud tank.

Figure 7. Neat-cement slurry being pumped from a hopper tank into the borehole.

Continuation of Drilling

The drag bit used during the cementing was replaced by a carbide-button tricone bit, as the cement was still not hardened enough to be drilled with the airhammer, and drilling of the cement progressed rather slowly. The air compressor was set for 125 lb/in^2, and as drilling progressed in the borehole, the circulating air helped to cure the cement. The next day, airhammer drilling was resumed. All caving of the washout area had been stopped, full air-foam circulation had returned, and the drilling progressed favorably. Intermittent zones of scoria and (or) fractured basalt were found at various depths throughout the borehole (fig. 8). Good circulation could be maintained in most of the problem zones by injecting heavy slugs of stiff foam at 300 lb/in^2, followed by periodic slugs of straight foaming agent. Drilling progressed very well to a depth of about 270 feet, when lost circulation again became a problem. The drill pipe was pulled and about six sacks of Quik Gel were emptied into the hole, followed by about 35 gallons of water, and allowed to harden overnight.

Circulation could not be regained the next day and the zone was cemented off by use of a neat-cement slurry containing seven sacks of cement in a 9:1 water-to-cement ratio mixed in a stock tank (fig. 9) and then pumped into the hole. Just prior to pumping the slurry into the borehole, about 2 pounds of calcium chloride was added to the mixture in order to hasten the curing time of the cement. However, because of a rig breakdown and the difficulty in locating a replacement compressor shaft bearing, drilling was not resumed for several days. After repair work was completed on the compressor driveshaft assembly, the drill pipe was returned to the borehole. A slug of heavy foam was used to regain circulation, and drilling went well to a depth of about 545 feet. Here, another badly fractured or weathered basalt zone was encountered and had to be cemented off before proceeding.

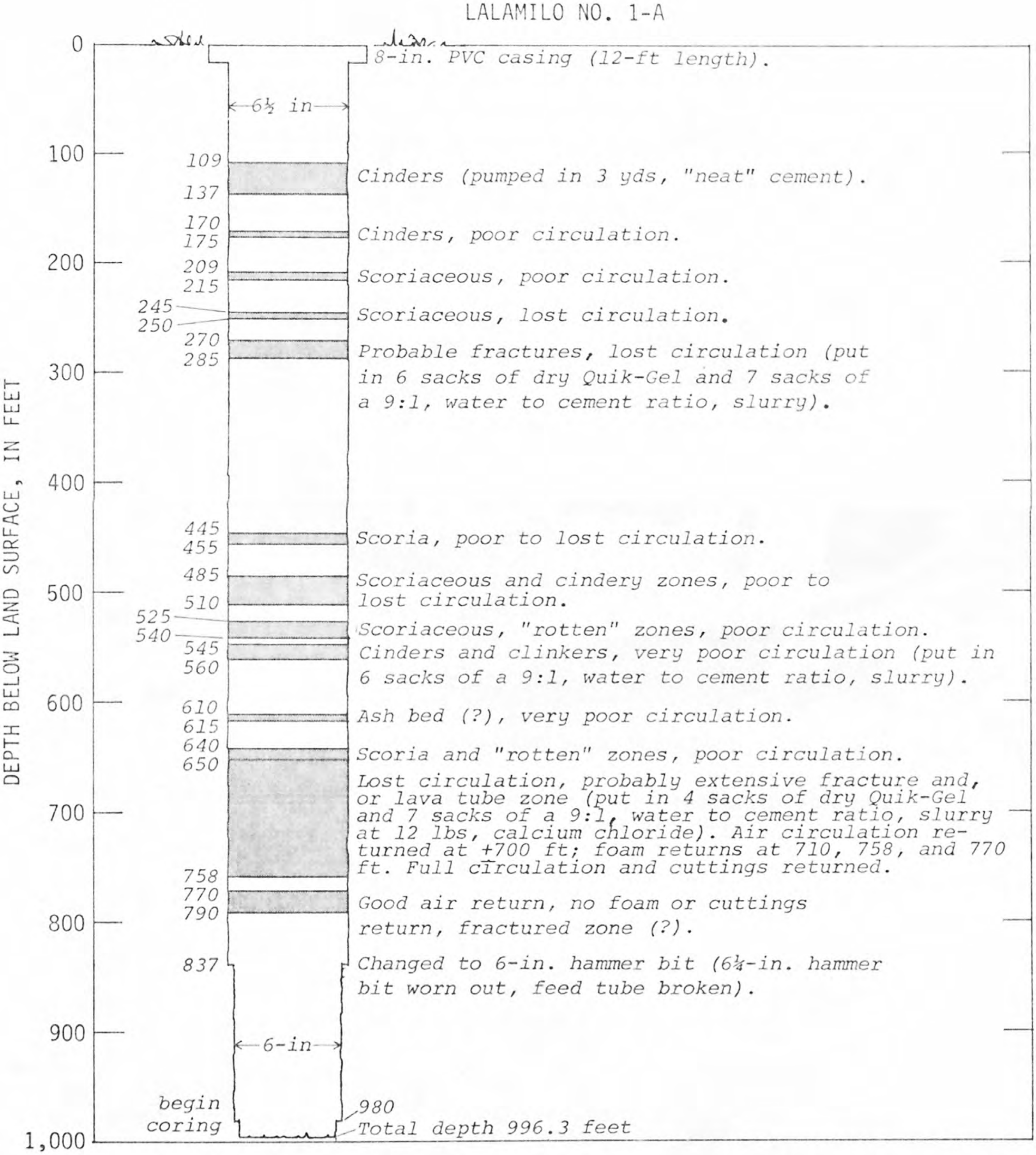


Figure 8. Zones of poor or lost circulation in Lalamilo No. 1-a borehole.

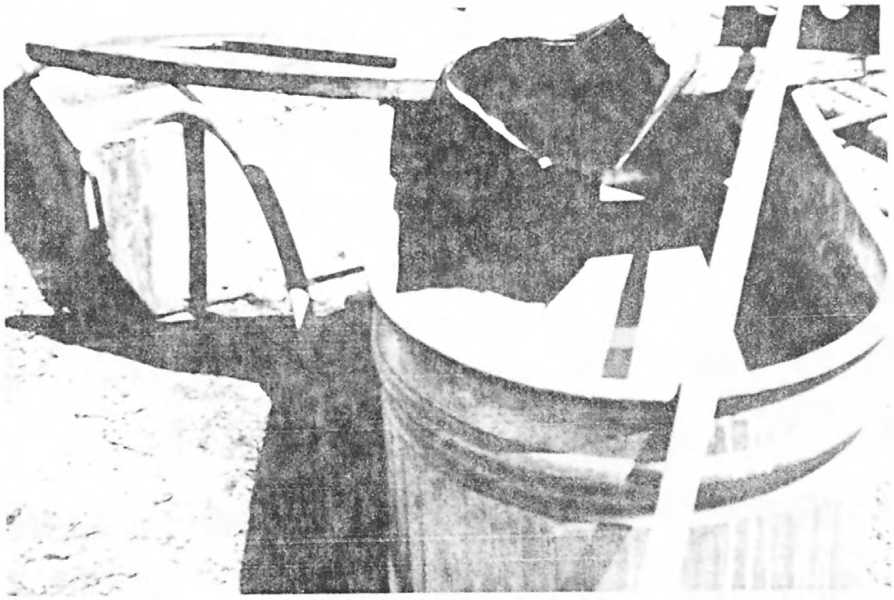


Figure 9. Stock tank used for batching neat cement slurries.

The hole was deepened to 595 feet the next day and then the supply of foaming agent was exhausted. A supply had been ordered from the mainland but, owing to shipping problems, drilling was delayed for several days pending arrival of the material in Hilo. Drilling with the foam went well to a depth of about 640 feet. Circulation of return cuttings became poor at this depth, and the small quantity of materials that was brought up appeared to be scoriaceous, broken, and possibly weathered.

At 650 feet, all returns ceased. The hammer was pulled out, and the drag bit used for the cementing operation was installed into the hole to 660 feet. A cement slurry, having a volume of about 16 ft^3, was pumped into the zone of lost circulation and the drill pipe was removed from the hole.

The cement was allowed to cure for 1½ days. When drilling was resumed, circulation could not be regained. The material drilled like a dense basalt, but the cuttings apparently were being lost into the formation. The borehole may have transected an extensively fractured zone or lava tube(s). Since the drill cuttings were not binding the hammer or drill pipe in the hole, blind drilling was continued. Periodic slugs of stiff foam were injected at 300 lb/in^2, and at depth of about 710 feet some foam and air returns appeared; however, the mixture did not contain any drill cuttings.

At a depth of 758 feet, full foam circulation, containing pebble-sized cuttings of dense, scoriaceous red and gray basalt, returned. Another fractured basalt zone was encountered at 770 feet, and most air circulation was lost until a depth of about 790 feet had been reached.

Upon regaining full circulation, the drilling was continued through relatively dense basalt sections, and at 837 feet the tools were removed from the borehole in order to check the hammer. Two of the carbide buttons were broken and chipped and the bit showed signs of overall wear. The plastic feed tube had become brittle and cracked. It was replaced and a new 6-inch drop-center hammerbit was installed in the hammer. Hammer drilling was resumed until the first selected coring depth of 980 feet had been reached.

Before removing the drill pipe and replacing the hammer with the core barrel, the hole was thoroughly flushed and cleaned of drill cuttings.

Coring of Lalamilo No. 1-a Well

The 3-inch cores were taken with a 10-foot Christensen 4-5/8 x 3-inch conventional core barrel equipped with a diamond coring bit. A part of the core taken on the first core run is shown in figure 10. A total of three continuous core runs were made, coring the borehole from 980 to 996.3 feet. One of the diamond coring bits used to core the basalt is shown in figure 11.

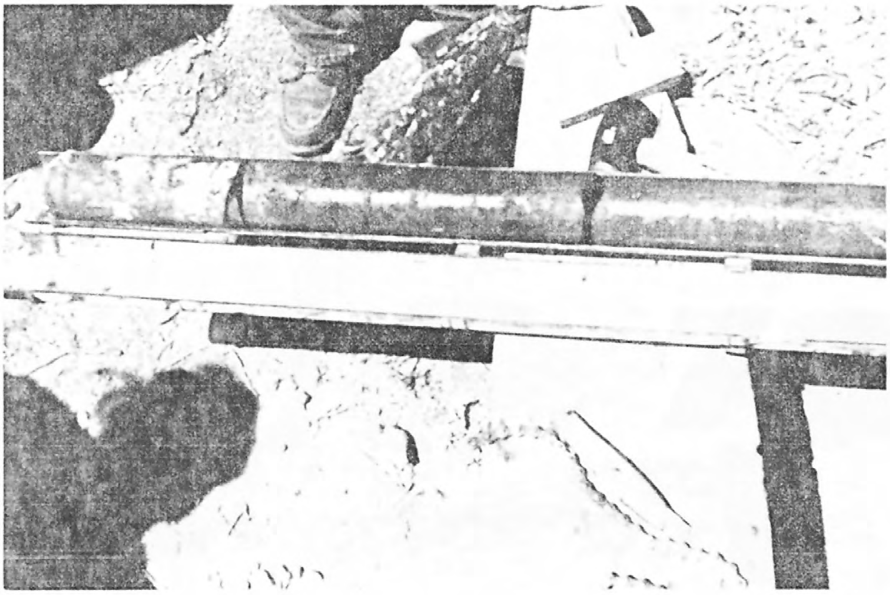
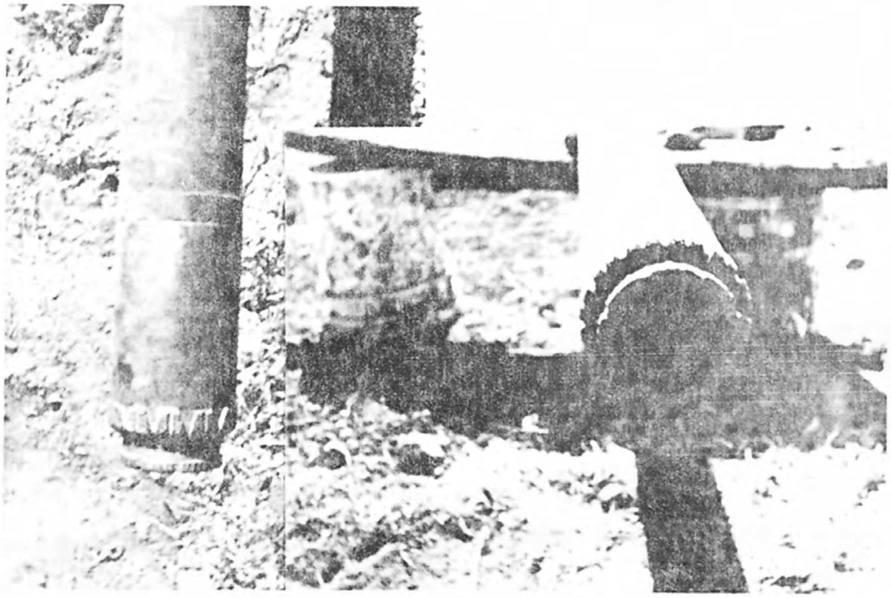


Figure 10. Part of basalt core taken in Lalamilo No. 1-a.



A
side view

B
end view

Figure 11. Diamond coring bit used to core basalt.

Coring Problems

Although the basalt cores obtained were of good quality and recovery was excellent, there were some problems in the coring operation. One of the major difficulties was the lack of a tool weight indicator on the rig. Because it was not possible to determine and thereby control the exact downward pressure on the tools, excessive bit pressure caused the matrix containing the diamonds on the coring bits to quickly erode, rendering several bits useless. Another characteristic of the rig, which was not suitable for hard-rock coring, was the extremely slow spindle rotation (about 106 revolutions per minute). Ideally, the basalt should have been cored by using a bit down-pressure of 600 to 1,000 lb/in^2 and a spindle rotation between 400 and 700 rpm. A previous drilling project conducted by the author on the island of Maui, using a small mud-drilling and coring rig, had shown this type of rig to be effective using wireline coring equipment.

The last coring bit was damaged upon completion of the third core run, and, in order to avoid any further delays in the drilling program, the decision was made to complete the hole with the downhole hammer.

Attempt at Hole Completion

The depth to water in Lalamilo No. 1-a had been estimated as slightly greater than 1,000 feet below land surface. This estimate was made by using depth-to-water data obtained from a nearby well and the drill site elevation above mean sea level (msl). The downhole hammer was inserted in the borehole to a depth of 980 feet--the depth at which the coring had begun. It was soon discovered that the bit in the hammer could not be used for reaming, as it became wedged in the smaller hole and would not function properly. Since a regular pilot-type (self-centering) reaming bit was not available to replace the drop-center bit, reaming would have to be attempted with a conventional tricone bit. However, while the drill pipe was being pulled, about 30 sections of drill pipe, two drill collars, and the downhole airhammer had become unthreaded and dropped several hundred feet. The entire string was lodged in the bottom of the hole. Several weeks of retrieval efforts, using overshots, grapples, jars, and washover casing only succeeded in recovering 20 sections of twisted and bent drill rod. The rest of the tools could not be retrieved and further fishing operations would have been costly in both time and money.

CONCLUSIONS

The downhole airhammer and stiff foam are effective and efficient tools for drilling in basalt. Penetration rates varied generally between 2 and 5 ft/min. The greater penetration rate occurred in the extremely vesicular or weathered basalt zones. Circulation and drill cuttings returns are important factors to consider whenever the penetration rate is to be increased in order that the hammer doesn't become buried in cuttings. Also, when hammer drilling relatively incompetent materials, the downward movement and rotation of the drill tools should be stopped at frequent intervals while continuing stiff foam circulation to clean the hole. Check for tool binding in the borehole by "deadsticking" the kelly and tools up and down several feet and noting any tool hangup or wedging. If wedging occurs, begin slow rotation, keep on circulating until the obstruction is cleared and there is a good return of cuttings, and then continue drilling according to the aforementioned techniques.

When drilling through cindery or extremely fractured zones where circulation return of the drill cuttings becomes a problem, stop drilling and cement the zone. If this is not done immediately, caving usually occurs, particularly in cinders. In badly fractured basalt, the drill cuttings merely fall back around the hammer and drill string and wedge the tools in the borehole. In either case, if the sealing off of these problem zones is not done, much time and possibly even the drilling tools can be lost. Whenever the hole is to be reamed or enlarged (after coring, for example), use the proper reaming or pilot-type bit. This precaution will greatly reduce the possibility of wedging the hammer and drill tools in the hole.

Drilling supplies, casing, repair parts, and many other materials are very difficult, if not impossible, to obtain in the Hawaiian Islands. Items and spare parts ordered from the mainland may take as long as 4 weeks to arrive by ship, or even by air. Shipping strikes and lost or damaged shipments caused even longer more costly delays to the project. Because of these and other problems in logistics, anticipated and emergency supplies should be obtained prior to beginning an Island project. However, unexpected breakdowns do occur, and these situations can be handled only as quickly as conditions allow.

Although the borehole was not completed, other objectives of the program were fulfilled. The downhole airhammer and foam-drilling techniques worked very well in the basalts. Drill cuttings representative of the materials penetrated were obtained for a major part of the borehole, and several cores of the basalt were taken with a conventional core barrel. The information gained on techniques and methodology used to accomplish the drilling should prove beneficial to others drilling under similar lithologic conditions and location circumstances.