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TECHNICAL REPORT

GEOTHERMAL GRADIENT DRILLING AND MEASUREMENTS ASCENSION ISLAND, SOUTH ATLANTIC OCEAN

prepared for

UNITED STATES AIR FORCE
EASTERN SPACE AND MISSLE CENTER
PATRICK AIR FORCE BASE , FLORIDA

and

UNITED STATES DEPARTMENT OF ENERGY
IDAHO OPERATIONS OFFICE
IDAHO FALLS, IDAHO

Earth Science Laboratory

University of Utah Research Institute
420 Chipeta Way, Suite 120
Salt Lake City, Utah 84108
(801) 581-5283

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by

Earth Science Laboratory
University of Utah Research Institute

Bruce S. Sibbett
Dennis L. Nielson
Michael C. Adams

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EXECUTIVE SUMMARY

This technical report on the Phase II geothermal exploration of Ascension Island documents the data collected during thermal gradient drilling and the subsequent thermal and fluid chemical investigations. It also documents the completion of the Phase II exploration strategy which was proposed at the end of our Phase I - Preliminary Examination of Ascension Island.

The thermal gradient drilling resulted in seven holes which range from 206 to 1750 ft (63-533 m) deep, with a cumulative footage of 6563 ft (2000 m). The drilling procedure and the problems encountered during the drilling have been explained in detail to provide information valuable for any subsequent drilling program on the island. In addition, the subsurface geology encountered in the holes has been documented and, where possible, correlated with other holes or the geology mapped on the surface of the island.

Temperatures measured in the holes reach a maximum of 130°F (54.4°C) at 1285 ft (391.7 m) in hole GH-6. When the temperatures of all holes are plotted against elevation, the holes can be classed into three distinct groups, those which have no thermal manifestations, those with definite geothermal affinities, and one hole which is intermediate between the other two. From consideration of this information, it is clear that the highest geothermal potential on the island is in the Donkey Flat area extending beneath Middleton Ridge, and in the Cricket Valley area. Because of the greater drilling depths and the remote nature of the Cricket Valley area, it is recommended that future exploration concentrate in the area around Middleton Ridge.

Hole LDTGH was a large diameter hole which was drilled to test for the presence of a fresh water aquifer beneath the island. The water encountered

was brackish. This is probably due to the high lateral permeability of the island which effectively disperses any precipitation to the sea. Fluid samples collected from this well have been chemically analyzed. Their chemistry indicates that they are derived from seawater reacting with rocks at elevated temperatures. Temperatures calculated from the chemical analyses indicate that the fluids have seen temperatures at least as high as 232°F (111°C) and may have experienced temperatures between 302° and 392°F (150° and 200°C). We believe that these fluids have been transported laterally from the higher temperature portions of a geothermal system and may not be the highest temperatures which could be discovered by a deeper drilling program.

In summary, our Phase II effort has found evidence of a high-temperature geothermal system beneath Ascension Island. The most prospective area is located in the vicinity of Middleton Ridge. We recommend additional exploration in this area which should consist of a short electrical resistivity survey to allow the siting of a deep thermal gradient test hole. The hole should be drilled to depths of 3000 to 5000 ft (914 to 1524 m), and should be designed to intersect and test fluids which are capable of generating electrical power.

INTRODUCTION

This report is the final technical report of the Phase II geothermal exploration of Ascension Island, South Atlantic Ocean. Previous reports on the Phase II effort discussed the results of electrical resistivity (Ross et al., 1984a) and aeromagnetic surveys (Ross et al., 1984b). This report deals with the results of thermal gradient drilling and subsurface temperature measurements which were completed in December of 1983 and March, 1984, respectively.

As part of the Phase I effort of this project, a preliminary examination of the geothermal potential of Ascension Island (Nielson and Sibbett, 1982) determined that the island had a suitably high potential for the occurrence of a geothermal resource and that more detailed exploration was warranted. At that time a strategy for the subsequent exploration was proposed, and that strategy has been carried out and reported to the USAF in this and the other Phase II technical reports.

This technical report goes into details of the drilling program that make for rather cumbersome reading, but which are necessary for proper documentation of the project and for the efficient handling of any additional geothermal or groundwater work on Ascension.

DRILLING

Seven thermal gradient holes, ranging from 206 ft (63 m) to 1750 ft (533 m) deep were drilled on Ascension Island between August 25, and December 12, 1983. The total footage drilled was 6563 ft (2000 m). The individual depths, surface elevation and descriptive locations are given in Table 1, and they are plotted on Figure 1. The drilling was conducted by Tonto Drilling Services of Salt Lake City, Utah using a skid-mounted, modified Longyear 44 core drill rig. Most of the drilling was done using HQ size core bits which cut a 3.85 in (9.78 cm) diameter hole and recover 2.5 in (6.35 cm) diameter core. In the two deepest holes (GH-2 and GH-6) the lower few hundred feet were drilled with NQ size bits (1.85 in core from a 3.04 in hole). Tricone rotary bits of appropriate sizes, which do not cut a core but return drill chips to the surface, were used to drill the hole required for casing and when thick sequences of trachytic ash and pumice were penetrated. Also the large diameter hole, LDTGH, was drilled to 622 ft with tricone bits.

Method and Completion

Core drilling was selected for the thermal gradient hole phase of exploration for several reasons. Anticipated subsurface conditions indicated that lost circulation of drilling fluids would be a major problem and this proved to be the case. Under these circumstance drill cuttings are washed into the formation, resulting in no stratigraphic information and the distinct possibility of sticking the drill rods if the cuttings fall back into the hole. In addition, the drill rig selected for the job was specially designed for transport to and operation in remote locations and could, if necessary, have been demobilized to Patrick AFB in a C-141.

The drill holes were generally started with a 5.63 in (14.3 cm) tricone

Table 1 - Summary of temperature gradient holes drilled on Ascension Island.

Hole #	Depth	Surface Elevation	Depth of Casing	Depth of Liner	Location *
GH-1	583 ft (178 m)	563 ft (171.5 m)	80 ft (24.4 m)	492 ft (150 m)	McTurk's Culvert
GH-2	1750 ft (533 m)	1570 ft (478 m)	180 ft (54.9 m)	1742 ft (531 m)	E. of Cricket Valley
GH-3	206 ft (62.8 m)	212 ft (64.6 m)	40 ft (12.2 m)	197 ft (60 m)	N. of Booby Hill, So. African dump
GH-4	723 ft (220.4 m)	586 ft (178.6 m)	120 ft (36.6 m)	712 ft (217 m)	S. of Bears Back, Northeast Bay Road
GH-5	892 ft (271.9 m)	515 ft (157 m)	60 ft (18.3 m)	886 ft (270 m)	Old Mountain Road, S. of Sisters Peak
GH-6	1294 ft (394.4 m)	620 ft (189 m)	60 ft (18.3 m)	1285 ft (391 m)	NASA Road, E. of Devils Riding Sch.
LDTGH	1115 ft (340 m)	570 ft (174 m)	619 ft (188.7 m)	1115 ft (340 m)	Midway between GH-1 and GH-6

* Drill sites are plotted on Figure 1.

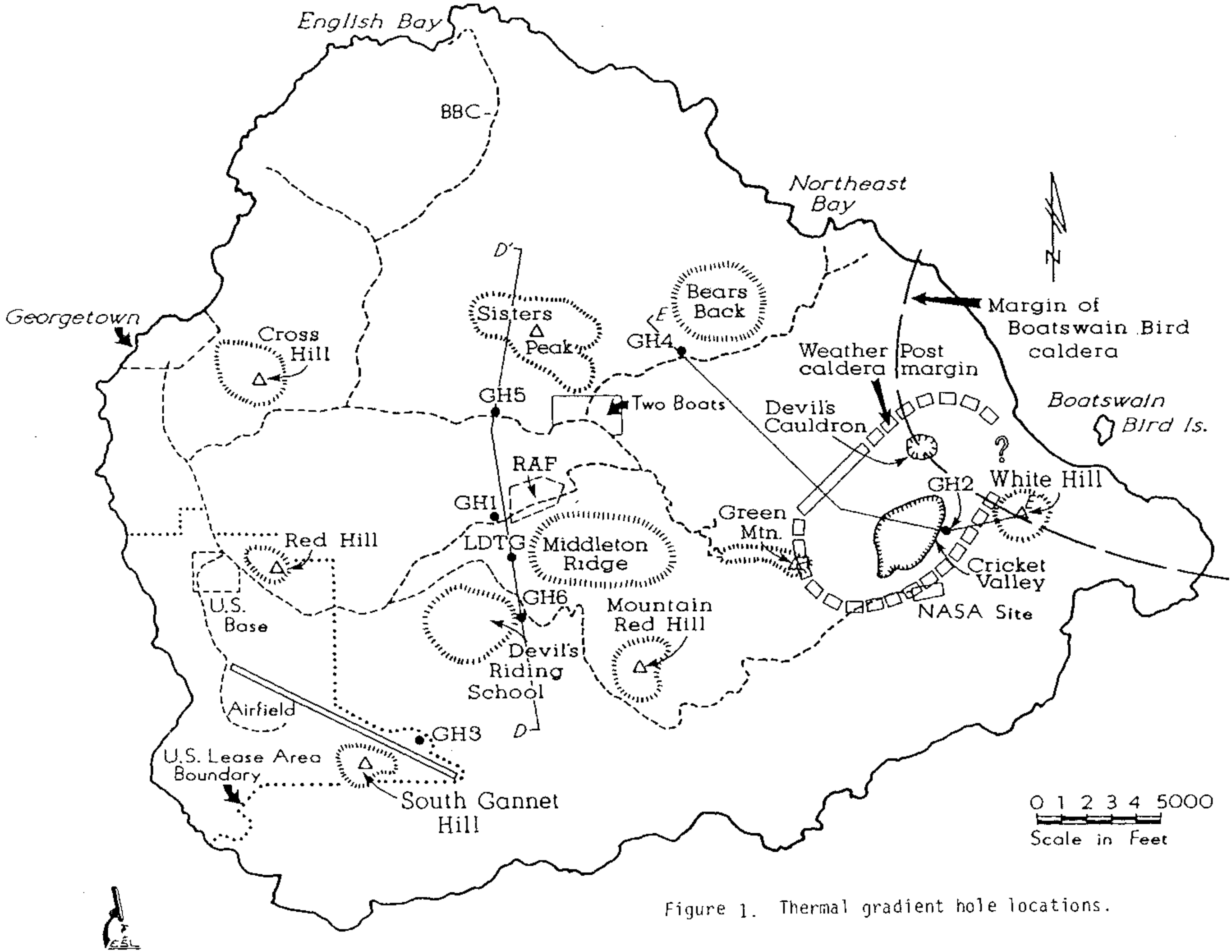


Figure 1. Thermal gradient hole locations.

mill-tooth bit to provide a large hole for the 4.5 in (11.4 cm) surface casing, which was set to a depth of 40 to 180 ft (Table 1). The 4.5 in casing was cemented in place to control near-surface caving and provide attachment for the blow out preventer (BOP). After surface casing was set, the holes were drilled with HQ-size diamond core bits or tricone bits depending on ground conditions as discussed below. After a hole reached total depth, 1.5 in, (3.8 cm) steel liner pipe was set to preserve the hole for temperature surveys.

Ground Conditions and Drilling Problems

From surface mapping it was known that massive lava flows, fragmental flow breccia, volcanic breccia and ash deposits would be encountered in the subsurface. The fragmental rocks can be very difficult to drill because of lost circulation, variable hardness and caving. During drilling it was found that the combination of drilling agitation and adding water to the dry formation destabilized the fragmental deposits and caused caving. The continual lost circulation intensified the caving problem because caved material could not be lifted out and the drilling mud often did not stand high enough in the hole to help hold it open. Coring worked well in hard, competent rocks such as massive basalt flows, rhyolite lava flows and consolidated pyroclastic rocks. Loose hard rocks, particularly basalt flow breccias and cinders were very difficult to core because the clasts would roll around under the bit, preventing the diamond bit from cutting, abrading the bit and breaking off the diamonds. The loose material would wedge in the core barrel, requiring pulling the core barrel many times to remove a small amount of breccia. While the core barrel was being pulled or the drill string raised to add a drill pipe, the flow breccia would cave into the hole. Prior to drilling it had been hoped the basalt flow breccias above and below each lava flow would be infilled with ash and stabilized. However, above sea level the flow breccias were found to be unconsolidated and very open. Intensely fractured zones, loose ash and some clay zones also proved very difficult to core. Breccias and ash zones were therefore often drilled with 3.87 in (9.84 cm) tricone bits. The bit was past through the caved zone a number of times until all the material falling into the hole was ground up and washed into the formation. The tricone bits would penetrate soft ash units fairly fast but made very slow progress in the hard lava flows. Drill bits and drilling methods have been designed to work in most ground conditions but rapidly changing heterogeneous lithologies encountered on Ascension Island are very difficult to drill.

Drilling Mud and Rod Grease

Lost circulation of drilling mud was the normal drilling condition on Ascension Island. The permeability of dry ash, scoria and especially flow breccias was too high to seal even with large quantities of lost circulation material. In addition to cottonseed hulls, vermiculite and Chemstop (Drillgel) were used as lost circulation material. LDTGH was the only hole where returns were maintained long enough to fill the mud pit. Pumice lapilli floating in the mud pit from the pit walls clogged the mud pump when this mud was used. At a depth of 135 ft (41 m), while drilling a massive rhyolite flow, 3 bags of cottonseed hulls, 2 bags dry Quikgel, 80 empty mud bags and a treatment of Chemstop were used to regain circulation. All returns were lost again after drilling six feet deeper. After the LDTGH hole was cased to 50 ft (16 m) below sea level, 1000 gal (3,785 l) of fresh water were pumped down the hole in about 2 minutes time without filling the 622 ft of 6.62 in casing (190 m x 16.8 cm).

Two different mud programs were tried during the drilling. GH-1, GH-3, GH-4 and GH-5 were drilled with sea water using Zeogel (attapulgite) and polymer (Pac-R or Drispac). This provided a very thin, low viscosity drilling fluid which only cooled and lubricated the drill bit and pipe. Because all fluids were generally lost near the bottom of the hole, friction between the drill rods and the hole wall and caving were major problems. To reduce both of these problems, large quantities of rod grease were applied to the drill pipe as it was run in the hole. The rod grease seemed to help stabilize the dry holes and reduce friction. In GH-6, however, the rod grease caused buildup and caking of cuttings on the drill pipe and its heavy use was discontinued.

The second mud program consisted of standard bentonite drill mud (Quick-gel) and a reduced amount of polymer mixed in fresh water to expand the montmorillonite (which won't expand in the cation-rich salt water). This was then mixed with 2 parts of sea water to extend the volume of drilling fluid. This fresh water and salt water mud program was used for the drilling of GH-6, GH-2 and LDTGH. The switch from a straight salt water-Zeogel mud to a mixed water-bentonite mud was made to reduce consumption of the expensive Drispac polymer and make a thicker, more viscous mud to improve hole conditions. The drillers felt that the fresh water + salt water mud system helped the drilling program and that caving frequency was reduced. However, because an increased volume of drilling fluid was used on the last three holes in an attempt to prevent problems, and the last three holes were drilled deeper than the salt-water drilled holes, it is not easy to compare directly the performance of the two mud systems. The drillers concluded that the Zeogel had no value, and if a straight salt water system were used in the future, only polymer should be added.

Logistics and Equipment

Logistics is a major consideration in a remote location like Ascension Island. Heavy equipment and large volume shipments are brought in by boat. Harbor conditions require materials to be moved from ships to barges, then lifted off the wave-tossed barges onto the dock by mobile cranes. The lift limitation of the dock crane is 20 to 30 tons depending on the crane used. This would require a truck-mounted drill rig to be dismantled for shipment and loading onto the dock. Relatively small equipment and emergency supplies can be brought in on the regularly scheduled U.S. Air Force C-141 flights. Because of military mission priorities, needed drilling supplies could not be assured to get on the next available flight, however.

An account for fuel and other support was set up with Pan Am, the support contractor for the U.S. air base on the island. Pan Am supplied a water truck for drilling water, and crane and trucks for moving the drill rig from site to site. A front end loader and bulldozer were also supplied as needed.

The drilling equipment provided by Tonto Drilling Services was of excellent quality. Not a single shift was lost to a major breakdown of the drill rig, reflecting on the quality of the equipment and the skill of the drillers.

A large inventory and selection of both diamond core bits and tricone bits was taken to the island to provide for the unknown drilling environment and expected variable rock types to be drilled.

Cost and Drilling Rate

Footage was drilled on 80 days of the project. An additional 17 days, when no footage was drilled, were spent moving from site to site, working on stuck drill pipe, setting casing in LDTGH, airlifting water from LDTGH and unpacking and packing the drill rig. Three days were lost waiting for a shipment of drill mud. Daily penetration rate was highly variable, ranging from 3 ft to 224 ft (1 to 68 m). However, the average rate per hole was fairly uniform and close to the overall average for the 80 drilling days of 82 ft/day (25 m/day), or 68 ft/day (21 m/day) for the 97 days worked. Overall footage cost, exclusive of mobilization and unused materials, was $75/ft ($246/m). Total bit cost was $44,004 or $6.70/ft.

To compare the two mud systems, footage costs and penetration rates were calculated separately for the holes drilled with sea water and those drilled with fresh water and sea water. To break the cost out among holes, the figures from the daily cost estimates, which do not include some indirect costs, were used, and the cost per foot is therefore lower than the overall cost figure given above. The fresh water + sea water holes which were the deep holes (GH-2, GH-6 and LDTGH), cost $74/ft and penetration averaged 80 ft/day. Cost per foot tends to increase with depth due to increased time to pull the core barrel and trip for a new bit. For a meaningful comparison, the upper part only of the fresh + sea water drilled holes (average of 652 ft per hole, taken to the nearest complete day) was compared to the sea water drilled holes (GH-1, GH-3, GH-4, GH-5, average of 600 ft per hole). The sea-water drilled holes cost $67.50/ft with a penetration rate of 85.8 ft/day. The fresh + sea water holes cost $65.50/ft with a penetration rate of 85 ft/day. The upper 622 ft (190 m) of LDTGH were drilled using only 12.25 and 8.75 in diameter tricone bits at a penetrate rate of 89 ft/day and a cost of $64/ft if the cost of casing and the 12.25 in bit are not included.

The above analysis suggest that average cost per foot was about the same for both the Zeogel and bentonite drill muds. Also, the penetration rate was about the same for both mud systems. The penetration rate and cost per foot for drilling with the 8.75 in tricone button bit was comparable to diamond core drilling.

DRILLING HISTORIES

GH-1

GH-1 was the first hole drilled in the thermal gradient program. It is located north of the Sloan Freeway at McTurk's Culvert. Drilling of GH-1 started on August 25, 1983 with a 5.25 in tricone mill-tooth bit, and it was drilled to a depth of 83 ft (25 m) by noon, August 26. Eighty feet of 4.5 in surface casing were set in the hole. Below 83 ft, GH-1 was drilled with HQ, coring hard basalt to 118 ft (36 m). Below the basalt, volcanic ash was drilled to 310 ft (94 m), but core recovery was very sparse below 134 ft (41 m) due to the soft ash washing away. An HQ impregnated core bit was used from 83 ft to 146 ft (24 m - 44.5 m). At 146 ft a new HQ set bit was run in the hole and the bit crown came off before any additional footage was drilled. A new HQ impregnated bit was run in the hole on August 28, and the hole drilled from 146 ft to 254 ft (44.5 m - 77.4 m), at that point cuttings accumulation between the core tube and bit stuck the core tube in the drill pipe requiring pulling the drill string out of the hole. A 3.87 in tricone bit (same diameter as HQ) was then run in the hole to ream and drill down to 310 ft (94 m), where a harder rhyolite lava flow was encountered. A hard, HQ impregnated bit was then used to core to 364 ft (111 m), after which a softer HQ impregnated bit was used because the rock was not abrasive enough to expose the diamonds in the harder bit. Rod grease was used to control caving and all drilling fluid was lost in the hole throughout the drilling described so far. On August 29, at a depth of 445 ft (135.6 m), penetration into blue clay, sandstone and volcanic breccia require switching from the impregnated bit to a stone-set bit. At 462 ft (141 m) the harder rock of a basalt dike required switching back to an impregnated bit. The hole was cored through broken basalt to 583 ft (178 m) by August 31, then the drill rods became tight, and hung up 47 ft off bottom. While trying to free the drill string, the rods broke off at 292 ft, leaving 220 ft of rods in the hole. Attempts to enter the broken off HQ rods with the smaller NQ rods were unsuccessful and drilling could not be continued in GH-1. The 1.5 in liner pipe was placed in the hole to a depth of 492 ft (150 m), at the bottom of the lost drill rods. Below the drill rods the hole had caved.

GH-2

GH-2, the sixth hole drilled, is located on the east rim of Cricket Valley, at an elevation of about 1570 ft (478 m), due north of the NASA station. The hole took 26 days to drill to total depth.

The drill rig was moved onto the GH-2 site during the afternoon of October 17, 1983 and was ready to start drilling soon after midnight, but water was not delivered until 7 PM on October 18. This delay was primarily due to problems preparing a new water transport system. The access road was too steep and rough for the old water truck to be used. After difficulties with caving in the upper part of the hole, casing was set to 180 ft on October 21. Lost circulation and caving were recurring problems throughout the drilling of GH-2.

On October 23 caving and tight hole conditions combined to break 10 ft of drill rods off at 368 ft (112 m). Fishing out the lost drill rods and bit (a tricone) was attempted on October 24, but this effort failed, so the hole was wedged to drill past the lost rods, continuing with HQ rods after cementing. The sharpness of the deflection at the wedge caused subsequent problems with pulling the core barrel and vibrations during drilling.

On November 2, with the hole at a depth of 1163 ft (354 m), the core tube became stuck in the core barrel. As the drill rods were being pulled to recover the core tube, the rods became stuck with 716 ft of rods still in the hole. After considerable effort and hammering the rods were worked free on November 3.

At a depth of 1177 ft, the HQ rods were stuck again on November 4. At this point the decision was made to reduce to NQ rods rather than trying to free the HQ rods. Three feet below the bottom of the HQ rods, circulation was lost again. GH-2 had reached a depth of 1750 ft by November 11 and was stopped at that depth because the drilling budget had been spent and a temperature check the day before had indicated a downhole temperature of only 104°F.

The bottom 60 ft of the stuck HQ rods were cut off and the rest came free and were recovered. Cutting the HQ rods, running the 1.5 in liner pipe and pulling NQ and HQ rods out of the hole took until Saturday, November 12. The move to the next hole could not be made until Monday, so Sunday was a standby day. The drill rig was moved off the GH-2 site on November 14, 1983. In addition to getting the drill string stuck, the large volume of drilling mud used added to the high drilling cost.

GH-3

GH-3 is located west of Booby Hill, and northeast of the runway. It was started on September 2 and completed on September 4 for a total drilling time of 3 days. The hole was planned to go to a depth of 500 ft (152 m), but loss of the bit and core barrel at a depth of 206 ft (6.28 m) terminated drilling. The hole was started with a 5.25 in mill-tooth tricone bit, which cut very slowly in the hard basalt flows. Circulation was lost at a depth of 12 ft (3.7 m) and the hole was triconed to 20 ft (6 m), then cored to 54 ft (16.5 m). Because the hole was caving at 34 ft, it was reamed with a 5.25 in tricone to 42 ft (13 m) and 40 ft (12 m) of casing were set.

The hole was cored with an impregnated diamond bit through massive basalt flows centers 3 to 34 ft (1-10 m) thick with 3 to 18 ft (1-5.5 m) of flow breccia between flows. The flow breccia caved continuously and after the core barrel twisted off, caved rock covered it, preventing fishing for the lost core barrel and bit. In light of the bad caving conditions in the hole, it was decided not to continue the hole by wedging. Liner pipe was set to 197 ft (60 m).

GH-4

GH-4 is located along the Northeast Bay Road, southwest of Bears Back. The hole was started on September 8 and completed on September 16 for a drilling time of 9 days. GH-4 was drilled to 120 ft. (36.6 m) through ash deposits in one 12 hour shift using a 5.25 in tricone. Casing was set to 120 ft and cemented on September 9. A thicker drilling fluid, using more Zeogel and polymer than was used in GH-1 and GH-3, was used in GH-4 to control caving and improve drilling. The thicker drilling fluid helped, but caving flow breccia was still a problem. Starting with GH-4, we decided to core competent formations such as massive flow centers and consolidated ash, but loose material which caved was drilled with a tricone bit. This required frequent trips in and out of the hole to change bits, however, a lower cost per foot was achieved. The bottom hole temperature was 96°F (35.5°C) on September 15, at a depth of 710 ft (216 m). Because the temperature was not encouraging and the drilling costs were still running above budget goals, it was decided to stop the hole the next day, and move, rather than drill to the original target depth of 1000 ft and wait until Monday to move. GH-4 was drilled to 723 ft and 1.5 in liner was set to 712 ft (217 m), about 126 ft (38 m) below sea level.

GH-5

GH-5, located along the road to Two Boats, between Sisters Peak and Lady

Hill, was started on September 16, 1983. A total of 11 days was spent drilling. On September 17, casing was set to a depth of 60 ft. The upper 171 ft of this hole penetrated alternating hard basalt flows and flow breccias. Below the flows, thick ash and cinder zones were drilled. Caving, short core runs and no circulation returns throughout the hole added to drilling time and problems. Several times the drill rods became stuck for a short time before they could be freed, and a few times the core tube was stuck in the core barrel by fines, requiring the pulling of all the drill pipe out of the hole to free the core tube. Much of the hole between 171 ft and 375 ft deep was drilled with a tricone bit because the rock was too broken to drill with a core bit.

A maximum-temperature thermometer was run down the hole at a depth of 660 ft (201 m) on September 23, and gave a reading of 86°F (30°C). These maximum reading thermometers were not very accurate and gave only a rough indication of down-hole temperature. Also, it should be noted that the drilling fluids used had a temperature of about 83°F before going down the hole. It appeared that the hole was cold, the cost was over budget and the condition of the hole was poor. There was a good possibility of getting the drill string stuck. It was therefore decided on Friday, September 23, to arrange for moving the drill rig on Monday, September 26, and to stop the hole at whatever depth was reached at that time, if no encouraging temperatures were encountered by then.

The hole reached 892 ft (272 m) on September 25 and liner pipe was set to a depth of 872 ft, 357 ft (109 m) below sea level on September 26.

GH-6

The drill rig was moved onto the GH-6 site by the Devil's Riding School along the NASA road on September 26, 1983. Drilling started on the 27th and continued until October 17 for a total of 22 days. Surface casing was set to a depth of 60 ft (18 m) in a trachyte flow. Drilling with a fresh water + sea water mixed system was started on this hole. The mud, Quik Gel and the polymer (Pac-R or Drispac) were first mixed in fresh water, which enables the Quik Gel to expand. This thick mud was then mixed 1:2 with sea water for drilling. This mud program reduced by one half the consumption of the polymer and the resulting mud reduced caving and generally improved drilling. While the cement was setting, large mud tanks were built to facilitate the new mud program.

On 28 September, the HQ rods were stuck at 82 ft (25 m) in a clay bed at the base of the Devil's Riding School trachyte flow. Later the same day the drill rods were freed and a total of 138 ft was drilled that day with a tricone bit. A thick ash unit was drilled during the next few days and minor caving and tight hole conditions existed.

By October 4 the hole had been drilled to 894 ft (272 m). On hand drilling mud ran out at this time, and drilling stopped while awaiting mud on the plane due in the next day. The plane arrived late on the evening of the October 7, and drilling resumed on the October 8. When the hole reached 1053 ft (321 m) on October 9 the drill rods and tricone bit became stuck 270 ft off bottom. Liner pipe could not be set to bottom and the hole could not be continued by reducing to smaller NQ rods because of the tricone bit. It was therefore decided to cut the HQ rod 50 ft above the bit (normally rods are stuck near the bit), wedge off around the stuck rods and continue the hole. When the rods were cut, the bit and 50 ft of drill rods fell to the bottom of the hole and the drill string was still stuck higher in the hole. A wedge was built to deviate the hole above the bit and below the stuck rods, continuing the hole with smaller NQ rods. After two cement jobs, the hole was wedged off the original hole at 945 ft (288 m) on October 12. A temperature of 112°F was measured at 1007 ft (44.8°C at 307 m) on October 10 aiding in the decision to continue the hole.

On October 14 the NQ rods became stuck 14 ft off bottom, with the hole at 1136 ft. The drillers start pulling rods out of the hole when they felt it get tight. The next day on October 15, the NQ rods were freed after much effort. The hole was considered dangerous at this point and loosing NQ rods could prevent the drilling of the deep Cricket Valley hole (GH-2). However, because the rig could not be moved off site until Monday, October 18, drilling was resumed. The ash on which the drill rig sat was unstable, and all the pushing and pulling on the stuck drill rods had moved the drill rig. This added to difficulties and required releveling and realigning the rig several times.

GH-6 was completed at a depth of 1294 ft (394.4 m) on October 16 and on the next day liner was set to 1284 ft (391 m). 410 ft of HQ rods were retrieved from the hole by resining all joints and back rotating the drill rods several times to unscrew the loose rods off the stuck rods. However, 370 ft of rods were lost in the hole.

LDTGH

After the six thermal gradient holes were completed, a large diameter thermal gradient hole (LDTGH) was drilled in an attempt to find a fresh-water lens which could be used for culinary purposes. Fresh-water lenses have been successfully developed on many islands, such as Guam (Abplanalp, 1945) and in the Caribbean (Mather, 1975; Bugg and Lloyd, 1976). However, most of these islands have much higher rainfall than Ascension, and in addition have a limestone and sand composition. The main controlling factor for the thickness of a fresh-water lens, which is lateral permeability, is unknown on Ascension Island.

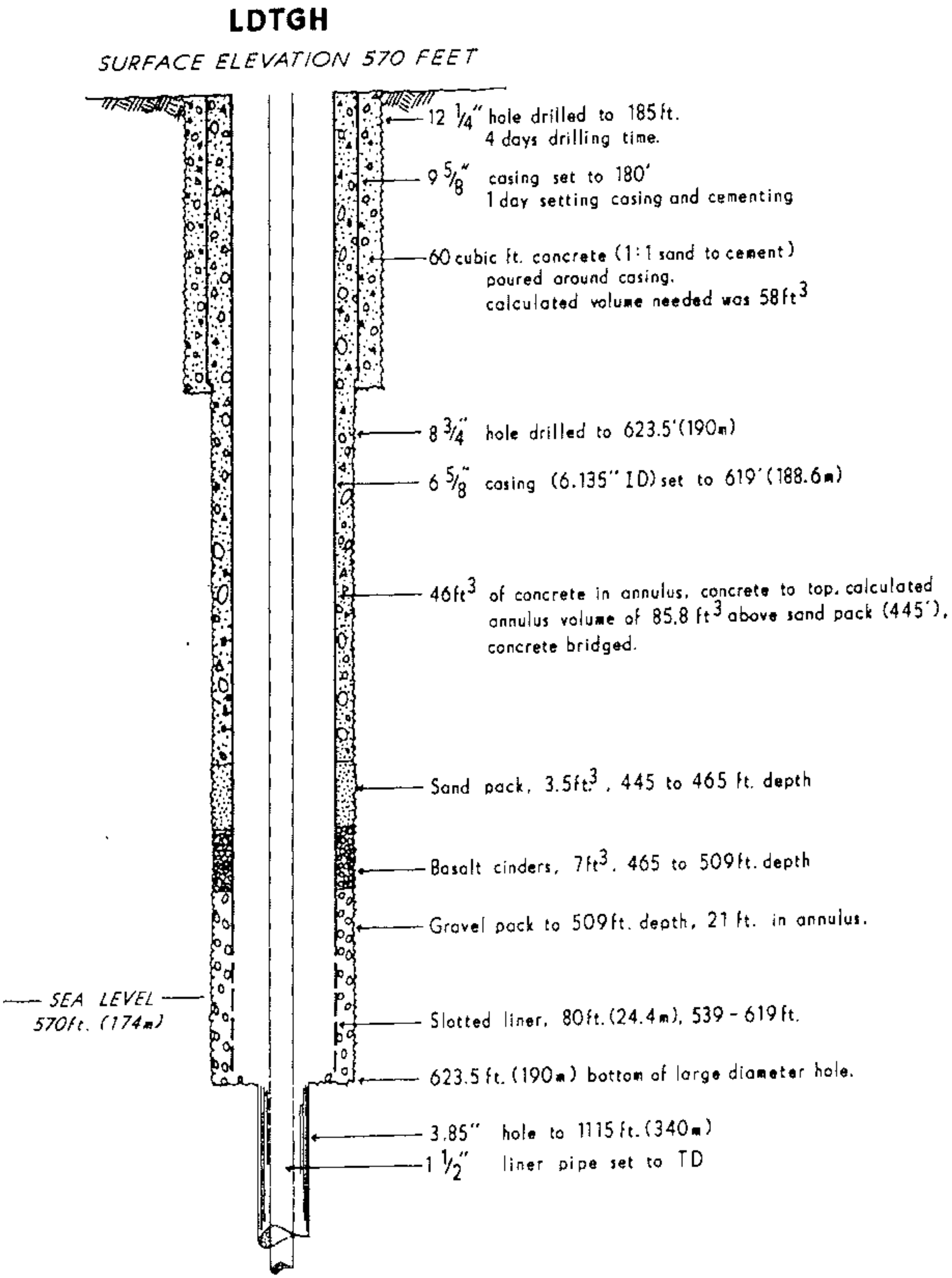


Figure 2. Completion diagram of LDTGH.

LDTGH was started on November 14, at a site 570 ft (174 m) above sea level, near the center of the island, where a fresh water lens would presumably be thickest and favorable aquifer rocks were present. The hole was started with a 12.25 in mill-tooth bit, and circulation was maintained to a depth of 118 ft (36 m). The large hole was drilled to 185 ft (56 m) on November 18, and 180 ft of 9.62 in conductor pipe was set. A plug was placed at the bottom of the conductor pipe and held in place with water pressure. Concrete (1:1, cement to sand mix) was run down the outside of the casing, about 60 cu ft being used to fill the annulus.

After the surface conductor was set, drilling continued with an 8.75 in button bit. Returns were lost again at 219 ft, 39 ft (12 m) below the casing. At a depth of 323 ft (98 m) the drill string was pulled because the stabilizers were sticking. At this time 100 empty mud bags, 2 full bags of bentonite and a bag of cottonseed hulls were put in the hole. Circulation was not obtained. At a depth of 391 ft (119 m) over 100 empty bags, 2 bags bentonite and the last bag of cottonseed hulls were put in the hole without gaining returns. The large diameter hole was completed to 623.5 ft (190 m) on November 22, and the next day 6.62 in casing was set to 619 ft. The bottom 80 ft of casing were slotted, and 21 cu ft of quartzite gravel were washed down the annulus forming about 110 ft (23 m) of gravel pack around the slotted liner (Fig. 2). The gravel was followed by 7 cu ft of cinders, then 3.5 cu ft of sand to prevent cement from entering the gravel pack. This filled the annulus up to a depth of about 445 ft (136 m). Forty-six cubic feet of concrete filled the annulus to the surface. This is only 2/3 of the calculated volume, therefore the concrete bridged the annulus and some gaps in the cement job remain.

On November 24 to 25, the hole was airlifted by injecting air at the bottom of the hole for 19 hours, producing 3 to 4 gallons per minute. The airlift system was the limit on production rate. The salinity increased from 25,000 mg/l to 27,000 mg/l NaCl in the last four hours of the airlift. It was therefore concluded that a usable fresh water lens was not present.

After cleaning loose gravel from the bottom of the hole, PQ rods (4.5 in diameter) were set to the bottom of the large-diameter hole to contain drilling fluids and cuttings and provide a guide for the HQ rods. A slim thermal gradient hole was then drilled out the bottom of LDTGH using HQ rods. The slim hole was drilled to 1115 ft (340 m) on Nov. 30, without major difficulties. Circulation was lost at 635 ft, 12 ft (3.7 m) below the PQ rods and never regained. Liner pipe (1.5 inch) was set to 1115 ft (340 m) and water was airlifted from 600 ft for 4 hours to clean drilling mud and cuttings out of the gravel pack and slotted liner. Cuttings from grinding out the gravel pack at the bottom of the hole had blocked the slots and the hole would not produce at first. In two minutes time, 1000 gal of fresh water was pumped down the hole to wash these cuttings out and thin the drilling mud. The hole was then airlifted. The muddy water produced was fresh at first, but after one hour salinity was up to 17,000 mg/l and was 23,000 mg/l after 2.5 hours of airlift.

To allow for possible removal of the liner pipe from the 6.62 in casing, a well greased, loosely attached coupling was placed just below the bottom of the large diameter hole. All couplings above this (upper 623 ft of the hole) were screwed tight without grease. If the liner pipe is unscrewed from the top, it should disconnect just below 623 ft (190 m) for removal. Sloughing of the deep hole and cuttings settling will prevent the entire length of liner pipe from being removed after the hole has set for a few months.

SUBSURFACE GEOLOGY

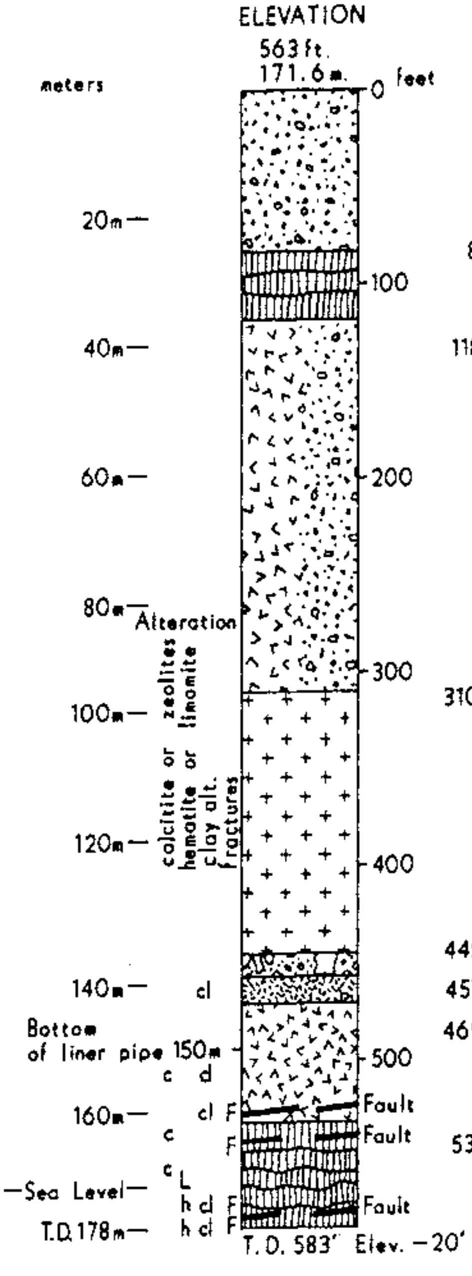
Lithologic Logs

Recovered core was logged on site as the thermal gradient holes were drilled. Core recovery was generally good, with 90 percent or greater recovery for the intervals cored. In flow breccias and ash units, core recovery was much less but a large part of the flow breccia and ash were drilled using a tricone bit. Representative samples were taken from each significant lithologic unit as the core was logged. Collected samples were shipped back to the U.S. for petrographic study and chemical analysis. The bulk of the core is stored on Ascension Island for possible future reference. Generalized logs were drafted from the field logs and are presented as Figures 3 through 9.

Thermal gradient holes, GH-3, GH-4 and GH-5, penetrated mostly basalt flows and a few basaltic cinder zones. Each basalt flow has a top and basal flow breccia around the massive flow center. The contact between massive flow and flow breccia is more significant for drilling than flow units, and different breccias are difficult to distinguish because of the low phenocryst content. Massive flows were therefore logged separately from flow breccias, and adjoining breccias were grouped on the generalized logs. Correlation of basalt flows between holes was not possible because of the non-uniqueness of flows and the wide spacing of the holes.

The holes drilled on or near the trachyte platform of the island (GH-1, GH-2, GH-6 and LDTGH) penetrated mostly rhyolite lava flows, thick trachyte pyroclastic units and dacitic ash-flow tuffs. Stratigraphic correlation of the Middleton ridge rhyolite flow and pyroclastic units above and below it can be made between GH-1, GH-6 and LDGTH (Fig. 10). However, the pyroclastic intervals were drilled mostly with tricone bits, so little information is

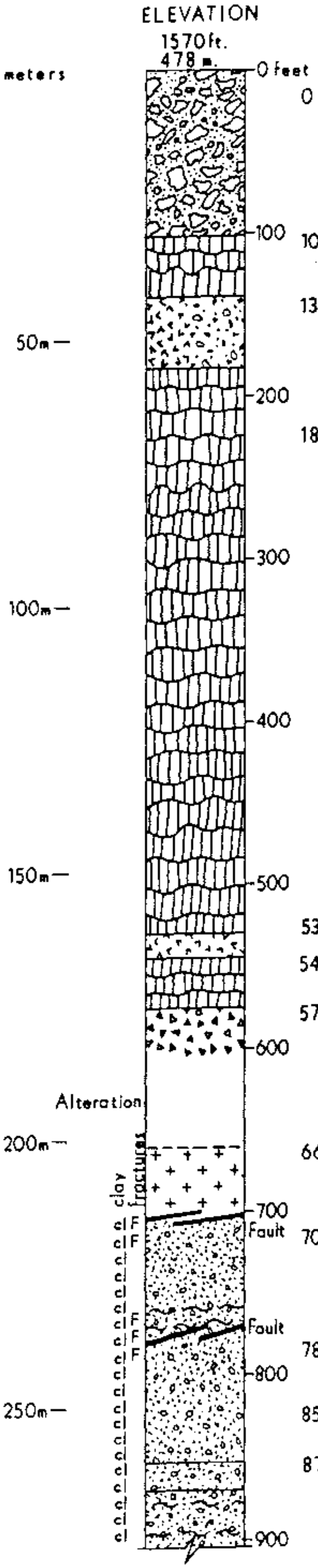
GH1



0-83'	No sample, probably pumice lapilli and ash.
83-118'	Basalt flows, massive to 99', lower flow vesicular 99-118'.
118-310'	Mixed basaltic ash and trachyte ash and pumice lapilli.
310-445'	Rhyolite flow, probably Middleton Ridge flow, gray to pale green, fractures. Basal flow breccia 435-445'.
445-457'	Volcanic sandstone and breccia.
457-469'	Basalt dike.
469-531'	Basaltic ash, cinders, blocks, vesicular.
531-583'	Basalt flows, vesicular, porphyritic flow breccia or scoria 554-557'.

Figure 3. Lithologic log and alteration of GH1, sited at McTurk's culvert and RAF base.

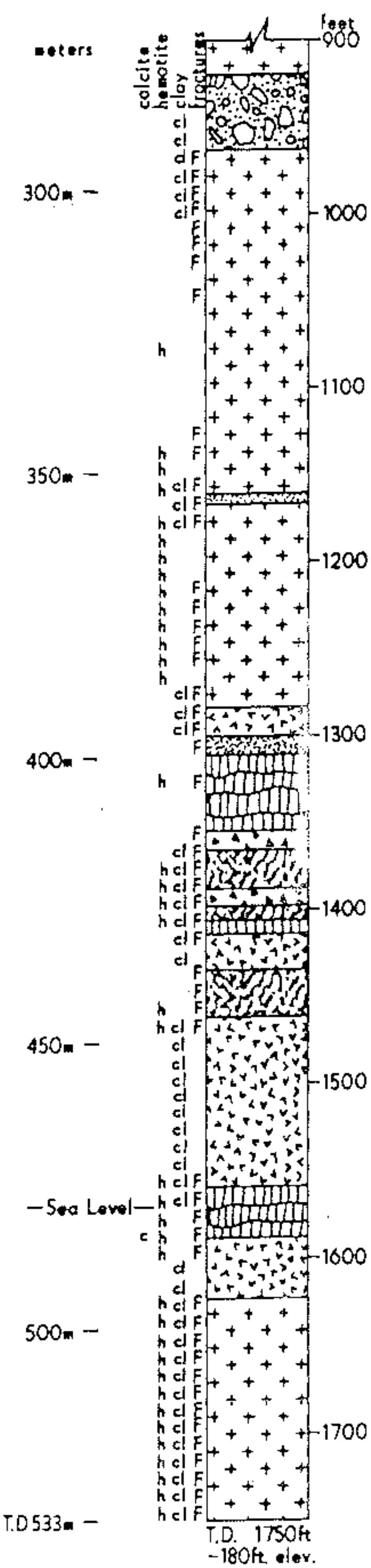
GH2



0 - 102	Trachyte breccia and ash, volcanic breccia, mixed lithologies of trachyte and basalt blocks with fine trachyte ash matrix.
102 - 139	Basalt flow, 2% 3 mm plag. crystals, dk gray-brn, 30% 3-10 mm vesicles in upper 2/3.
139 - 182	Ash, trachyte and basaltic, no recovery, but triconed easy, trachyitic ash exposed to the north and basaltic ash to the south.
182 - 530	Olivine basalt, poss. lava lake, phenocrysts of pyroxene, plagioclase, few xenoliths of dioritic rock and vesicular basalt. Light green to red-brown. Vesicular zones and fracturing present. This unit forms most of the cliffs around the south side of Cricket Valley. Thin sec. contains labradorite, olivine and pyroxene, Chem: 50.7% SiO_2.
	2' thick baked zone under basalt's base.
530 - 545	Ash and cinders altered to clay, red.
545 - 574	Basalt flow, vesicular, 5% plagioclase crystals.
574 - 672	Triconed without recovery, probably flow breccia in upper part with ash below.
	Upper contact of rhyolite flow lost by triconing.
660 - 702	Rhyolite lava flow, gray-grn, flow banded, porphyritic, contains lithic inclusions, pumice base 696-702.
702 - 780	Pyroclastic sandstone grading to welded ash flow tuff below 758'. Volcanic sand is probably upper non-welded zone, clay alt.
780 - 853	Pyroclastic ash and cinders, pumice lapilli, black grading to gray at 802, dacite ash & pumice.
853 - 870	Volcano-clastic-pyroclastics, red-brn, compaction features.
870 - 901	Ash flow tuff, non-welded 853-870, welded below 870'. Lithic rich pyroclastic flow, few fiamme, light brnish-gray.

Figure 4. Lithologic log and alteration of GH2, sited on the east rim of Cricket Valley, near the NASA station.

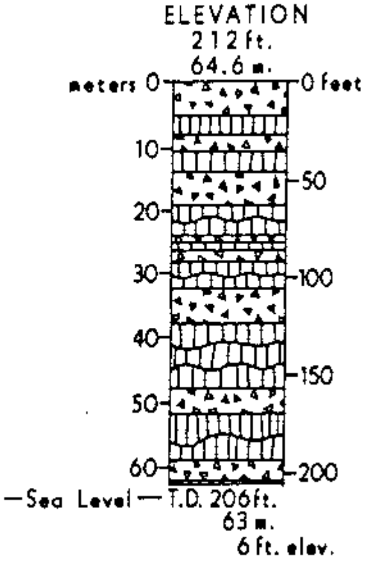
GH2 CONTINUED



901 - 917	Trachyte lava flow? gray, flow brec., sheared.
917 - 961	Pyroclastics, clay alt., mottled colors of li. gray, pinks, yellows, brns, pebbles to blocks.
961 - 1160	Dacite flow or dome, light brnish-gray 1% 1 mm feldspar phenocrysts, euhedral. Color grades to grayish-red then to purplish-gray.
1160-1164	Sandstone, coarse grain volcanic, clay-rich, possibly a sand dike cutting the dacite.
1164-1282	Dacite flow, massive, grayish-red, 1% 1 mm feldspar crystals. Probably the same dacite as 961-1160.
1282-1300	Basaltic ash & cinders, scoria, reddish-brn.
1300-1310	Basaltic dike(?), red, no vesicles, non-porphy. possibly andesite.
1310-1354	Basalt flows, black, vesicular.
1354-1366	Basalt flow breccia, scoria.
1366-1387	Andesite dikes, flow banded, clay seam at 1374.
1387-1398	Basaltic flow breccia, scoria.
1398-1407	Andesite dike, flow banded vertically.
1407-1414	Basalt flow, vesicles, flow breccia.
1414-1434	Basaltic ash, red-brn, lapilli.
1434-1461	Andesite dike, fine grain, dk gray, flow banded. Lower contact intrudes ash.
1461-1558	Basaltic ash and lapilli, red-brn, clay matrix. Same unit as 1414-1434. Possibly pyroclastic flow or lahar, very colorful reds, black, pinks, brown. A few trachyte clasts present.
1558-1588	Basalt flow, 5% large irregular vesicles. Sparse mafic xls. Flow breccia top & bottom.
1588-1623	Basaltic ash or lahar as above (1461-1558). Multi-colored lapilli to sand in red-brn matrix.
1623-1750	Rhyolite flow or dome, 5% 1 mm feldspars, grayish-red, strong limonite-hematite on abundant fractures, also strong hem. stain spread through rock. Clay and sand thick in fractures.

Figure 4 (continued). Lithologic log of GH2.

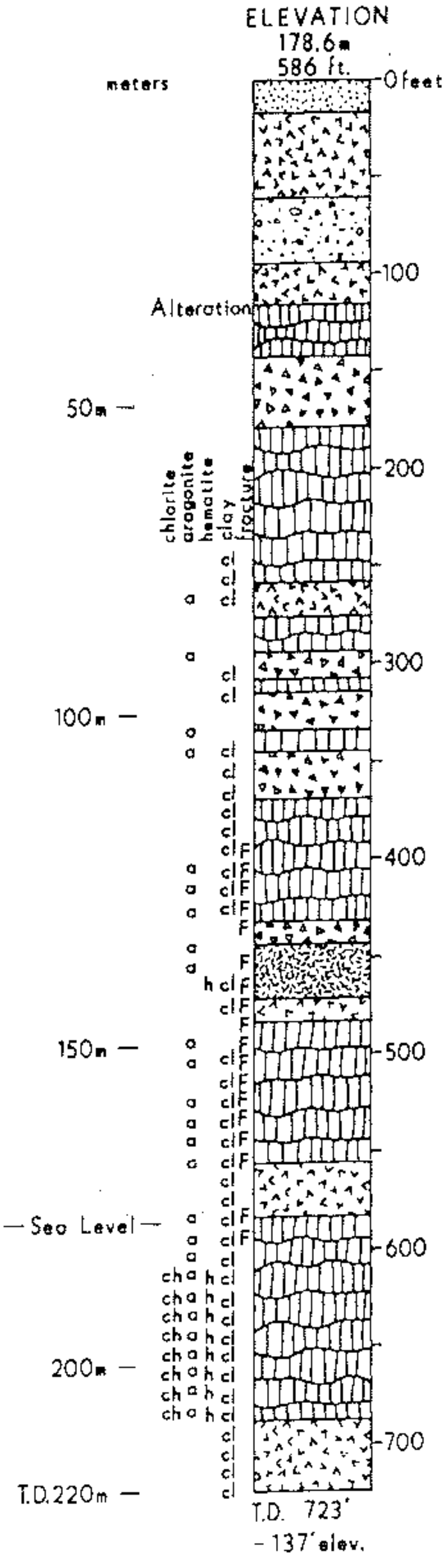
GH3



0 - 18	Flow breccia, vesicular basalt.
18-28 & 34-45	Basalt flow, dense centers.
28 - 34	Flow breccia, vesicular basalt scoria.
45 - 63	Flow breccia, vesicular basalt, scoria.
63 - 78	Basalt flow, dense flow center.
92 - 106	Basalt flow center, vesicular.
106 - 124	Flow breccia and thin solid zones.
124 - 158	Basalt flow, solid, vesicular.
158 - 170	Flow breccia, scoria.
170 - 194	Basalt flow, solid, vesicular.
194 - 202	Flow breccia, scoria.
202-206	Basalt flow, scoria.

Figure 5. Lithologic log of GH3, sited north of Booby Hill in the South African dump. No alteration was present in the core.

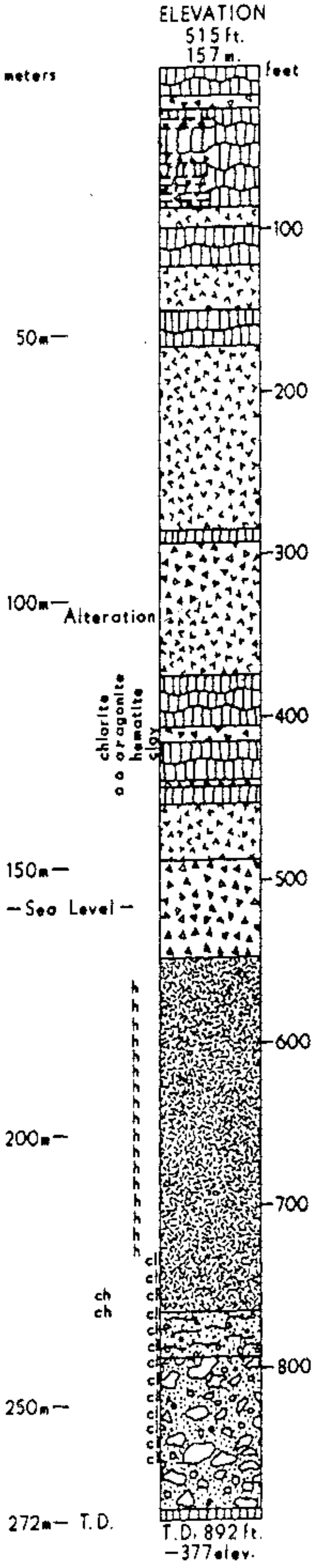
GH4



0-17'	Alluvium, fine sand and silt.
17-60'	Basaltic cinders, ash few boulders. 2' trachyte ash at top.
70-94'	Trachyte ash, light gray with pumice, also basaltic ash caving.
94-115'	Basaltic ash, and poss. lahars.
115-141'	Basalt flow, non-porph., vesicular.
141-177'	Flow breccia, basaltic, scoria, rust red, 0.5-5 inch clasts.
177-258'	Basalt flow, black, non-porph., few vesicles, scoria autoliths. Minor blk coating on joints. Honey colored, soft zeolite?
258-369'	Basalt flows and flow breccias interbedded, vesicular, some red clay. Alteration clays in fault breccia. Aragonite crystals are white or colorless, small round growths. Vesicular to dense flow centers.
369-431'	Basalt flow, ~ 40% vesicles, reddish-gray to med. gray. Possibly an andesite flow?
431-443'	Fused breccia, few vesicles.
443-471'	Dike, basaltic, black, non-vesicular, non-porphyritic, very fine grain.
471-481'	Cinders and ash, basaltic, scoria.
481-567'	Basalt flows (2), dk gray, few vesicles, flow lineations near parallel to core. Light blue-gray coating on fractures, probable clay alteration.
567-584'	Ash, basaltic, mostly alt. to red clay. Core dry at 572, no formation water.
584-688'	Basalt, black, fine grain, non-porph. grayish-red with a few large vesicles near upper contact, 10' into flow the color is dk gray with crystal grain size increasing to coarse aphanitic. Large aragonite crystals present in vesicles and on joints throughout unit, horizontal flow lines and normal flow base.
688-723'	Basaltic ash, cinders and sand with red clay alteration. This unit includes lahars with cobbles and light gray rholitic zones, and alluvial material, med. reddish-brown.

Figure 6. Lithologic log and alteration of GH4, sited near Bear's Back.

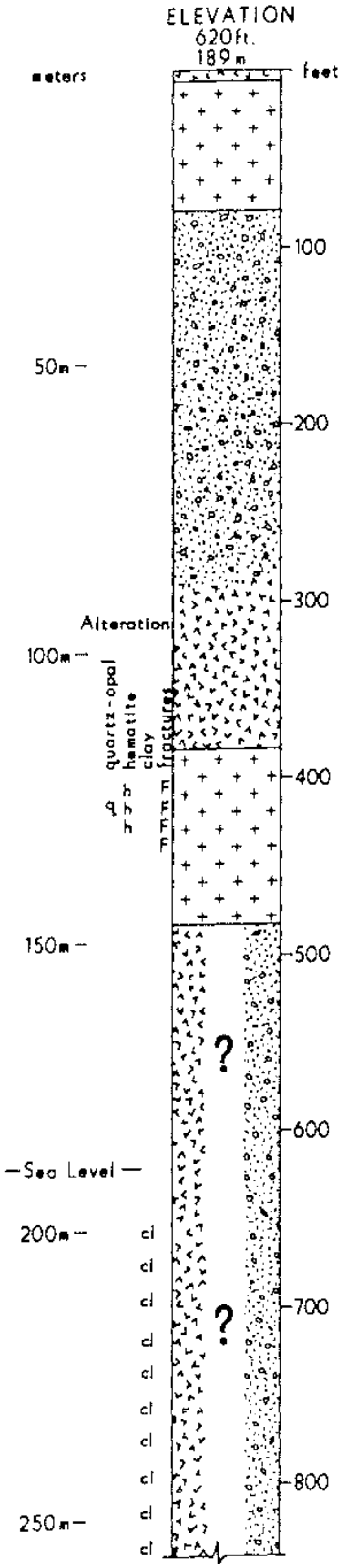
GH5



0 - 171	Basalt flows and interbedded flow breccias and ash beds. Basalt flows are dark gray, vesicular, non-porphyritic, with upper and lower scoria grading into flow breccias. Basaltic ash zones are dark reddish gray with minor alt. to red clay.
171 - 285	Ash, cinders, scoria with a few "hard" spots. This interval was triconed without returns. Some trachyte ash may be present.
285 - 292	Basalt flow, dark gray, non-porphyritic.
292 - 375	Flow breccia and ash, triconed from 296-375, with no returns.
375 - 452	Basalt flows with flow breccia separations. Flows are dark gray to black, 20% porphyritic with plagioclase pheno. to 6 mm. Pyroxene 3 to 6 mm and 3 mm olivine crystals partly altered. Dense flow centers.
452 - 476	Flow breccia and ash grading to volcanic sandstone.
476 - 488	Alluvium, Ss, ash, gravel, trachyte pumice.
488 - 548	Flow breccia, basaltic, black scoria, sparsely porphyritic, few dk. olive to grn streaks. Tricone soft breccia or ash from 492 to 548'.
548 - 765	Basalt dike, dark gray, 5% 6 mm plag. phenocrysts, high angle flow lines, few fract. Minor hem. on fractures and trace hem. stain through rock. Grain size remains very fine aphanitic throughout. Color grades to grnish-blk or dk-grnish-gray below 600'. Green clay(?) filling flow fractures at 732', med. bluish-gray below 740'. 760' - alteration increases, dark grnish gray.
765 - 792	Welded lithic ash flow tuff, with 3 to 8 cm collapsed, pumice, black, very lithic rich with andesite(?) clasts. Yellowish-brn alt. matrix, with pumice not evident in some zones.
792 - 886	Lahar or volcanic rubble, unsorted, reddish brn. matrix of clay alt. ash. Clasts are ash to block size, aphanitic basaltic and andesite(?) Tricone below 801 thru soft lahar-ash type rock.
886 - 892	Basalt flow, fine grain, fresh, nonporphyritic, dark gray.

Figure 7. Lithologic log and alteration of GH5, sited along Old Mountain Road.

GH6



0 - 7 Basaltic ash and cinders, black, vesicular.

7 - 80 Trachyte Flow, med-gray, non porphyritic, Increasing auto-breccia near base. Devil's Riding School trachyte flow.

80 - 382 Trachyte pumice lapilli, gray, orange-yel. baked zone in upper 10'. Below ~ 280 poss. Transition to basaltic ash, cinders and/or lahar and alluvium.

This unit triconed with no returns but it is exposed 1000 feet (305 m) to the south.

382 - 482 Rhyolite Flow of Middleton Ridge, med.-gray. ~ 5% feldspar pheno., 1-2mm, irregular, light-gray mineral traces along flow lines. Hematite spread along flow lines and heavy on fractures, 410'-poss. fault, with chalcedony on surface.

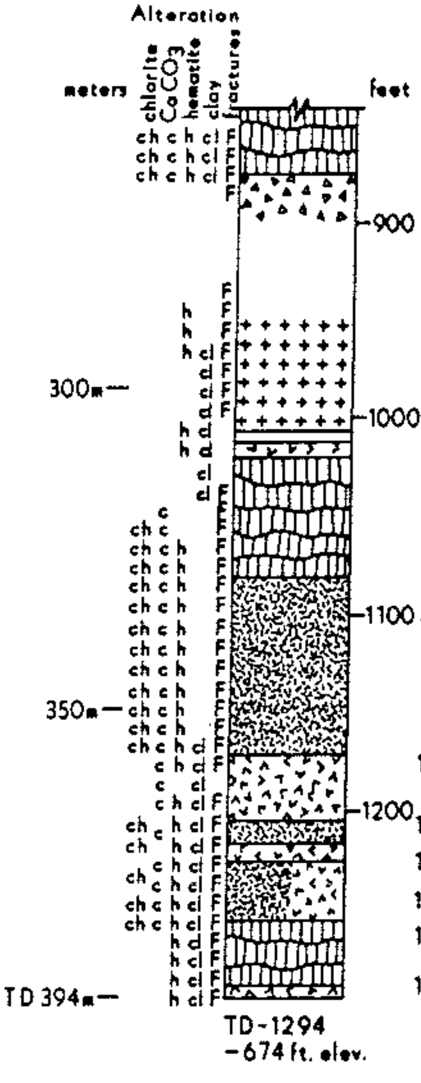
482 - 840 Ash and cinders? "Soft drilling" with tricone, no returns.

Tricone, no returns.

Much of this may be altered rock, pink to orange clay stuck to bit.

Figure 8. Lithologic log and alteration of GH6, Devil's Riding School.

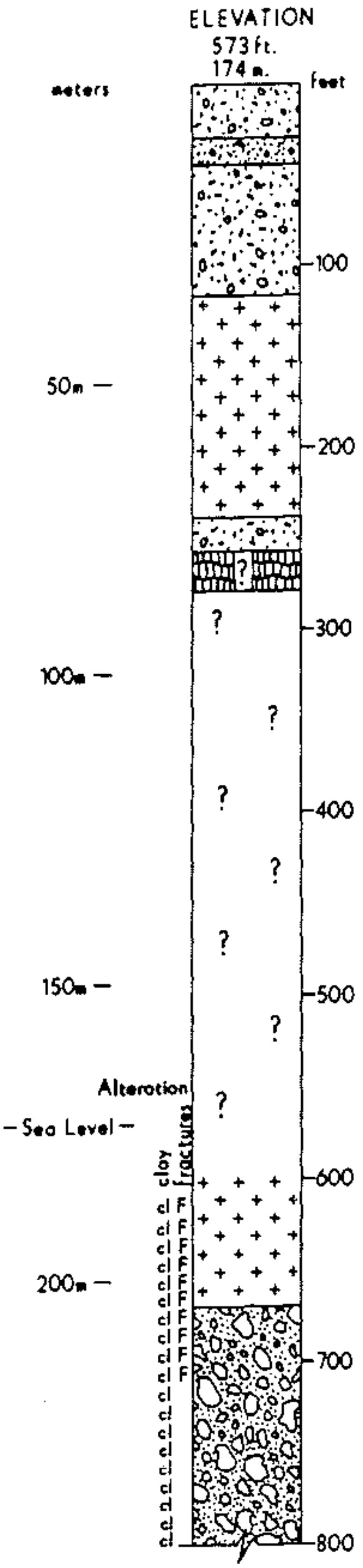
GH6 CONTINUED



840 - 876	Basalt, porphyritic, 10% 1-3mm plag. dark gray, calcite cemented fractures, hematite stained, non-vesicular, pyrox. & olivine.
876 - ?	Basaltic Breccia, Base of this unit not known due to triconing and no returns. 894-945' Triconed with no returns.
? - 966	Dacite, porphyritic 2% 3mm feldsp. xls., plag. brown-gray, to grayish-red purple with flow breccia below 959.
966-1007	Dacite flow, 2% porphyritic, 2mm feldsp. flow breccia & scoria, clay alteration.
1007-1011	Pyroclasitic or Lahar (?) flow, lithic rich, grayish-red brn. w/yellow-pk zones
1011 - 1019	Basaltic ash, reddish-brn, clay alt.
1019-1080	Basalt flow, abund. 2mm vesicles, flow breccia zones, chlorite on slicken sides.
1080-1171	Basaltic Dike, Intrusive upper contact, med. gray, fault breccia & alt. pyrox. ~2% 1mm crystals of plag. & alt. mafics. Dense, tight fractures filled with chlorite & $CaCO_3$
1171-1204	Basaltic cinders, dk reddish-brn, scoria, clay matrix, Dk grnish-yellow palagonite.
1204-1217	Dike (?) basaltic, non-vesicular, non-porphyritic
1217-1225	Basaltic cinders, med. brn, scoria
1225-1256	Basalt Dike (flow?) non-vesicular, non-porph.
1256-1288	Basalt Flows, vesicular, 2% alt. plag. red-brn. yellow clay alt.
1288 - TD	Basaltic Flow Breccia, scoria, red pink

Figure 8 (continued). Lithologic log and alteration of GH6 Devil's Riding School hole.

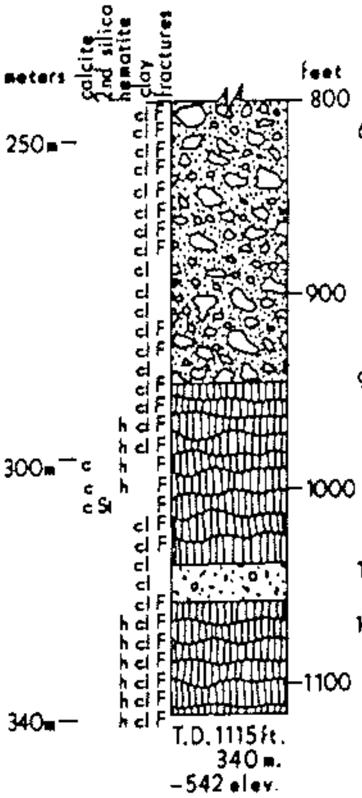
LDTGH



0 - 30	Trachyte pumice lapilli and ash
30 - 43	Fused Pyroclastic flow breccia
43 - 118	Ash, trachyte pumice, gray
118 - 239	Rhyolite Flow of Middleton Ridge? med-gray to med. dk-gray, fine grain, fresh rock peppered with mafics.
239 - 257	Ash? soft rock, no samples recovered.
257 - 279	Hard rock, possible basalt flow. Caving zone below flow.
279 - 622	Triconed with no recovery, generally soft rock but unknown.
?? - 670	Trachyte Flow, flow banded with yellowish-gray to brn.-gray. ~5% 1-2mm feldspar crystals.
670 - 945	Volcanic Breccia and Pyroclastics, Rhyolitic but with mixed colors, lapilli to block size fragments with coarse to med grained ash matrix and some cm size cavities. Multi-hued yellow, gray, brnish gray. Secondary black psilomelane or manganite coating and cementing breccia at 678-694'.

Figure 9. Lithologic log and alteration of LDTG, sited west of Middleton Ridge between GH1 and GH6.

LDTGH (continued)



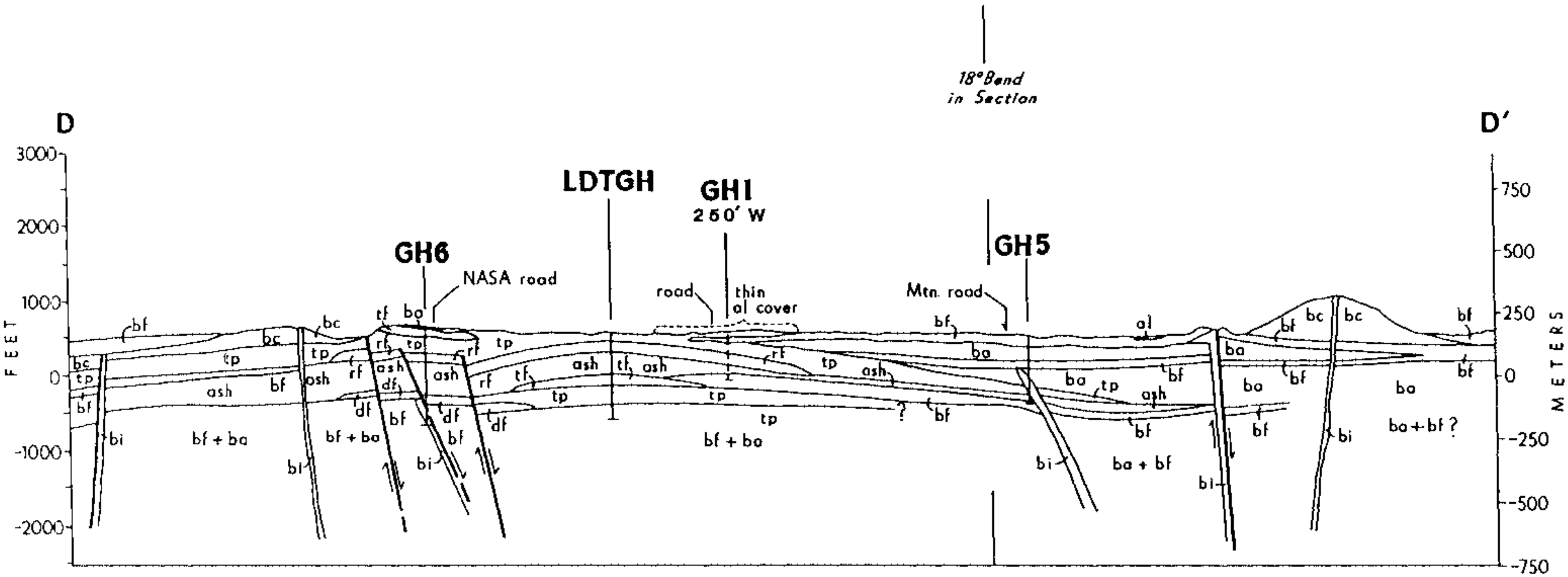
670 - 945	Volcanic Breccia and Pyroclastics, Rhyolitic blocks to lapilli with course to med. ash matrix. CM. size cavities, multi-colored.
945 - 1039	Basalt Flows with vesicular flow breccias and dense flow centers white to light pk. or grn. clay alt. ash (?) fills fractures and flow breccia of basalt down to ~ 970', upward flow structures in ash. Minor basaltic ash between flows 1015-1033'
1039-1057	Ash and Pumice lapilli, rhyolitic, pale grn, yellow, pinks & brn-gray lapilli.
1057-1115 T.D.	Basalt Flow Breccia and Flows, black, non-porph., small ≤mm irregular vesicles, dark brown clay infilling, Densely fractured rock with open spaces.

Figure 9 (continued). Lithologic Log and Alteration of LDTG.

available from these units. All three of these holes bottomed in basaltic rocks. LDTGH and GH-6 encountered the underlying basalt at about the same level, 375 and 391 ft (114 and 119 m) below sea level, respectively. GH-1 entered basaltic rocks at 106 ft (32 m) above sea level, just below the rhyolite flow. The equivalent unit below the rhyolite flow in the two other holes was triconed, however, and GH-1 did not go to the depth of the other holes, so it is not known how the stratigraphy below the rhyolite flow in GH-1 compares to GH-6 and LDTGH.

Correlation of Subsurface-Surface Geology

Three rock units in the upper part of GH-6, LDTGH and GH-1 can be correlated among holes and are exposed to the east on Middleton ridge. The tops of these units consist of about 90 m (300 ft) of trachytic pyroclastic. The pyroclastics (tp) form the top of Middleton ridge where weakly welded tuff-breccia flows and airfall pumice lapilli beds are exposed. At the west foot of the ridge, between LDTGH and GH-6, the pyroclastics consist mostly of pumice lapilli with a fused breccia flow included. In the drill holes, much of the pyroclastic unit was triconed, so data are limited. A basalt flow is present within this unit in GH-1. A rhyolite flow 100 to 135 ft (30 to 41 m) thick underlies the thick pyroclastic unit (Fig. 10). The thinning of the rhyolite flow to the south is uncertain because the upper contacts in GH-6 and LDTGH were drilled with a tricone bit before coring resumed. This rhyolite flow, rf, forms the west base of Middleton ridge. A volcanic breccia, bx, and a trachyte flow, tf, are exposed between the rhyolite lava flow and the overlying pyroclastic unit on Middleton ridge. The breccia and trachyte flow were not found in the subsurface, probably because they pinch out to the west, and the volcanic breccia may have been missed when tricone drilling. The



G E O L O G I C   U N I T S

al — alluvium
bc — basaltic cinder cones
ba — basaltic ash
bf — basalt flows
bi — basalt dike

ash — mixed basaltic and trachyte ash
tp — trachyte pyroclastics, includes welded flows.
tf — trachyte lava flows
rf — rhyolite lava flow
df — dacite lava flow

Figure 10. Cross section D-D' through holes GH5, GH6, and LDTGH, central part of the island.

third unit which can be correlated among holes is a thick ash unit under the rhyolite flow. The ash varies from 360 ft (110 m) thick in GH-6 and LDTGH to 86 ft (26 m) in GH-1. The unit consists of volcanic sandstone, breccia, basaltic ash and cinders in GH-1. At least some trachytic ash is present in the thicker occurrence in GH-6 where pink clay-altered ash came up with the bit. A small exposure of trachyte pyroclastics underlying the rhyolite flow occurs 2000 ft (600 m) northeast of GH-6. The ash unit was tricone drilled without returns in GH-6 and LDTGH.

A tentative correlation was made between a thick dacitic to rhyolitic pyroclastic unit penetrated from 702 to 961 ft (214 to 293 m) in GH-2 (Fig. 4) and a similar pyroclastic unit (tp) exposed 1 mi (1.6 km) northwest of Cricket Valley. Welded pyroclastic flows of dacitic to rhyolitic composition, containing about 3 percent crystals, 60 to 80 percent lapilli to block size pumice and the remainder ash and lithic fragments, are present in the pyroclastic unit in both GH-2 and outcrop. In outcrop, the welded unit (pf) is 10 to 20 ft (3 to 6 m) thick. Non-welded pyroclatics (tp) are present above and below the welded unit. A thick lava flow (df) underlies the dacitic pyroclastics in both outcrop and GH-2. The dacite flow is 321 ft (98 m) thick in GH-2 and over 250 ft (76 m) thick, with base not exposed, in outcrop. Using these correlations, cross section E-E' was drawn (Fig. 11), and offset between outcrop and GH-2 was calculated to be 800 to 1100 ft (250 to 340 m) apparent offset increasing with depth.

The Cricket Valley area is one of the more geologically complex on the island. However, there is a considerable amount of topographic relief, which has enabled some amount of correlation between the units mapped on the surface and those seen in GH-2. The 348 ft (106 m) thick, massive, olivine basalt penetrated in the upper part of GH-2 forms the cliffs on the south side of

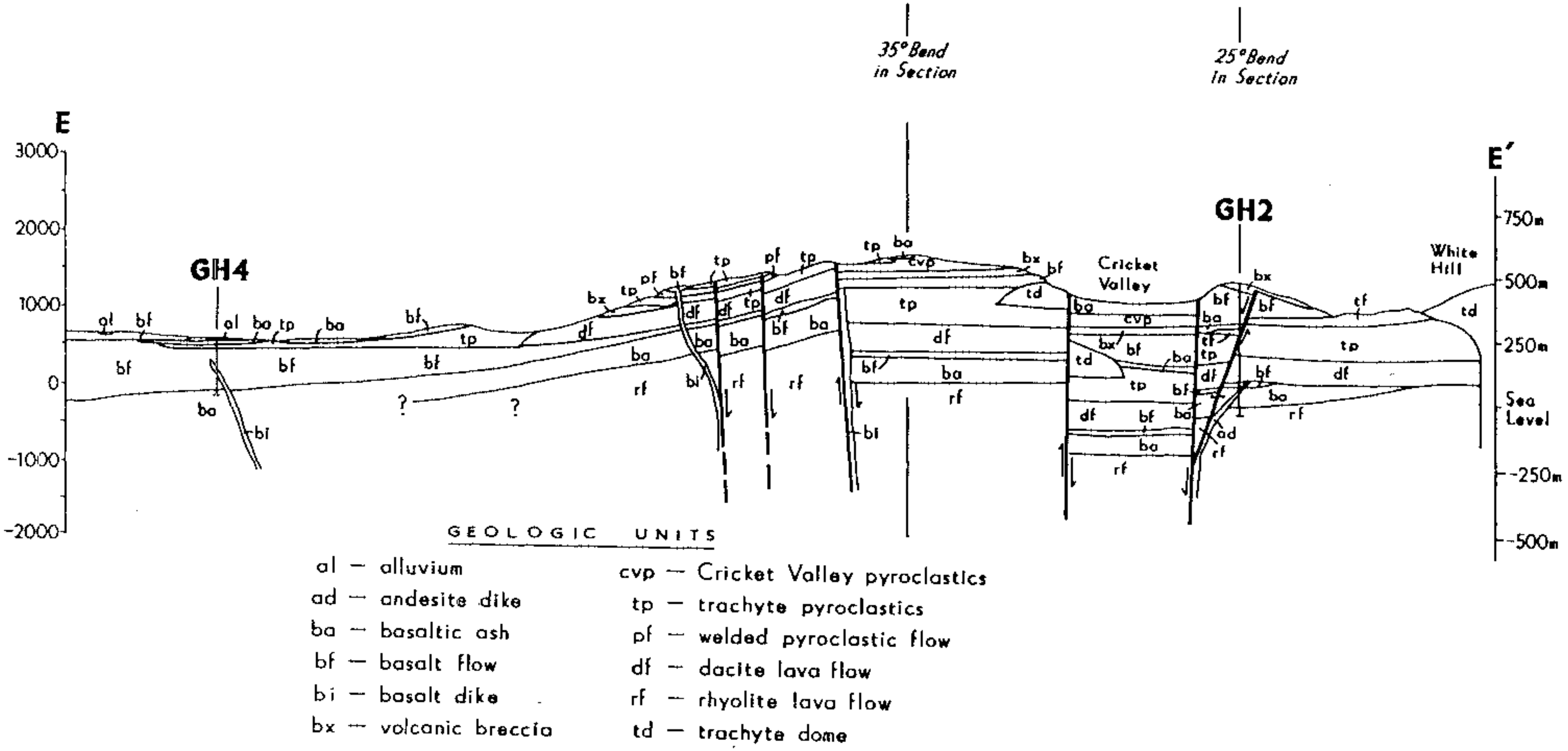


Figure 11. Cross section E-E' through GH2 and GH4, eastern part of the island.

Cricket Valley. The flow is exceptionally thick for a basalt and the extent of exposure around Cricket Valley indicates it is not a dike or volcanic neck. The thick basalt seems to be a lava lake ponded inside a closed basin.

Data from geologic mapping and the GH-2 lithologic log (Fig. 4) suggest that the eruption of the thick pyroclastic unit discussed above was followed by subsidence of a small caldera. The caldera, herein named the Weather Post caldera, was the source of a large volume of dacitic to rhyolitic pyroclastics and lava flows and encompasses the area from The Peak and the NASA site to north of Devils Cauldron (Fig. 1). The north rim of the caldera can be traced from Spire Rock to Northeast Cottage. Approximately 1000 ft (300 m) southwest of Spire Rock, the caldera rim is characterized by trachyte flows and domes on the south (interior) side with pyroclastics and basalt flows to the north. Slumping has obscured the rim at this location. North of Devil's Cauldron, north-dipping pyroclastic deposits underlie the trachyte flows. South of the caldera rim, 1500 ft (500 m) north of the Devil's Cauldron, the dip of the pyroclastic deposits is south into the vent area. The same dip reversal is exposed in the canyon west of the Devil's Cauldron. Dikes along the ring fracture are exposed 400 ft (122 m) south of the dip reversal in this canyon. South of the dikes, a flat-lying basalt flow and the nearly horizontal Cricket Valley pyroclastics and a volcanic breccia form the intracaldera deposits. Just north of Northeast Cottage, the ring fracture is exposed where it truncates a rhyolite flow. To the northwest, volcanic breccia, welded tuff-breccia flows and airfall pumice lapilli dip 15° to the north, down the flank of the caldera. To the southeast of Northeast Cottage, basaltic ash of Green Mountain, and the Devil's Ashpit postdate and cover the Weather Post caldera rim.

Cricket Valley is a smaller and much younger subsidence or explosion feature within the Weather Post caldera. The lack of concentric faults or slumping into Cricket Valley suggest that it may be an explosion crater rather than having been formed by subsidence as shown in Figure 11. Although several explosive breccias are exposed around Cricket Valley, it is difficult to correlate the breccias with formation of Cricket Valley.

A younger and larger caldera, which we have called the Boatswain Bird caldera (Fig. 1), may be present on the far eastern side of the island. Subsidence on a large scale has formed the 1000 ft (300 m) high escarpment around Spire Beach. The lava flows and pyroclastic beds exposed along this escarpment have relatively low dips to the north and east, suggesting that this part of the island had more gentle relief and extended farther east when the rocks were emplaced. The trachyte domes and vents of Letterbox, White Hill, Weather Post and Devil's Cauldron suggest an arcuate trend which follows the escarpment and coastline to the northeast. This may mark the western edge of a ring fracture system of a caldera which is largely hidden beneath the sea.

Island Subsidence

The change from subaerial to subaqueous rocks is important because it will be a significant change in rock character affecting both drilling and permeability, plus possibily having a control on the geothermal system. Subaerial rocks extend to the bottom of all holes drilled and subaqueous extrusives were not encountered. GH-6 extended to the lowest elevation, 674 ft (205 m) below sea level. Ascension Island has therefore subsided at least 674 ft (205 m) since emergence as an island. To estimate the depth to the subaerial-subaqueous rock contact, two factors must be considered, plate subsidence due to cooling, and isostatic subsidence due to loading of the Ascension pedestal. Parsons and Schlater (1977) studied ocean plate subsidence with time and cooling as plates move away from spreading centers. Based on uniform plate subsidence (Parsons and Sclater, 1977) the 7 million years old ocean floor under Ascension has subsided 2950 ft (900 m). If the volcanic pile did not reach the surface until 2 m.y. ago, the plate has subsided only 656 ft (200 m) in the past 2 m.y. Isostatic subsidence is a function of height and density of the volcanic pile. However, subsidence since emergence of the island will be related to the elevation of the island and the additional height added to compensate for plate subsidence. The subaerial-subaqueous contact on Sao Miguel, Azores, has subsided 786 m (Muecke et al., 1974). The island is directly on the spreading center so all the subsidence is considered isostatic. Sao Miguel has a maximum elevation of 3116 ft (950 m), so the subsidence to elevation ratio is 0.83. Applying this ratio to Ascension's maximum elevation of 2815 ft (858 m) plus 656 ft (200 m) for plate subsidence gives a calculated isostatic subsidence of 2870 ft (875 m). This is a very rough estimate but it indicates that the subaerial-subaqueous extrusive rocks interface may be about 3000 ft (900 m) below sea level, or much more if the island emerged earlier.

Whole-rock Chemistry

Whole rock chemical analyses on core samples and outcrop samples collected during Phase II are listed in Tables 2, 3, and 4. Comparison of the analyses for core samples and surface samples (see also analyses reported in Phase I technical report, Nielson and Sibbett (1982)) indicates that subsurface rocks have the same chemical range as surface exposures. These analyses have been useful in correlating rock units as well as providing information which can be used in the interpretation of the aeromagnetic survey.

Table 2. Whole rock chemical analyses of basalts and andesite from Ascension Island. Major element analyses are expressed as weight percent and trace elements in parts per million.

	AI-83-1	AI-83-7	AI-83-8	AI-83-11	GH2-276
SiO_2	57.40	46.61	58.20	49.80	50.70
Al_2O_3	16.00	14.96	17.65	15.42	15.19
FeO*	8.78	12.35	6.46	11.24	11.04
MgO	2.14	4.91	0.95	4.82	5.31
CaO	4.82	8.88	3.38	8.00	8.39
Na_2O	5.70	3.75	6.34	3.87	3.57
K_2O	2.01	1.54	2.82	1.17	1.23
MnO	0.26	0.21	0.16	0.19	0.18
TiO_2	1.67	4.14	1.15	3.04	2.65
P_2O_5	0.71	0.97	0.72	0.82	0.43
LOI	0	0.85	0.85	0	
Total	99.49	99.17	98.68	98.37	98.69
Sr	386	522	503	717	368
Ba	620	430	850	470	260
Co	25	35	17	39	56
Ni	<5	15	8	44	56
Cu	6	27	7	38	36
Pb	< 10	<10	10	<10	<10
Zn	135	108	126	117	100
Li	12	7	12	9	8
Be	3.2	2.3	4.1	2.6	2.1
Zr	194	140	280	199	133
La	61	43	77	52	33
Ce	92	66	123	81	49

*Total iron calculated as FeO.
LOI is loss on ignition

1. AI-83-1 Basalt flow exposed west of Spire Beach.
2. AI-83-7 Basalt flow exposed along wash northeast of runway.
3. AI-83-8 High-K andesite flow, southeast flank of Devil's Riding School.
4. AI-83-11 Basalt flow in sandwash, just north of runway.
5. GH2-276' Olivine basalt forming south wall of Cricket Valley.

Table 3. Whole rock chemical analyses of dacites from Ascension Island. Major element analyses are expressed as weight percent and trace elements in parts per million.

	AI-83-9	AI-83-10	GH2-825	GH2-1041	GH6-955	GH6-979
SiO_2	68.20	63.70	67.60	67.50	68.20	67.80
Al_2O_3	14.33	16.08	14.54	13.51	15.71	15.70
FeO*	5.94	5.48	4.30	4.15	4.50	4.35
MgO	0.15	0.81	0.31	0.12	0.25	0.44
CaO	0.78	2.38	0.76	0.63	1.49	1.76
Na_2O	6.73	6.45	5.28	6.70	6.18	5.85
K_2O	2.27	2.75	3.31	4.43	2.41	1.36
MnO	0.28	0.20	0.18	0.16	0.05	0.14
TiO_2	0.48	0.63	0.37	0.37	0.46	0.45
P_2O_5	0.08	0.16	0.05	0.06	0.12	0.13
LOI	0.19	1.00	2.79	0.32	0.60	1.48
Total	99.43	99.64	99.49	97.95	99.97	99.46
Sr	26	223	26	37	185	237
Ba	1060	970	200	890	540	610
Co	25	18	17	9	12	15
Ni	7	12	<5	<5	<5	<5
Cu	6	9	8	6	<5	34
Pb	16	14	<10	<10	<10	<10
Zn	211	146	151	139	122	111
Li	19	19	28	14	10	16
Be	5.8	4.6	6.3	5.3	4.0	3.8
Zr	621	427	660	786	501	432
La	105	71	88	28	53	64
Ce	180	117	136	40	83	100

*Total iron calculated as FeO.
LOI is loss on ignition

1. AI-83-9 Welded tuff breccia flow, pf on southwest side of Green Mountain.
2. AI-83-10 Welded tuff breccia flow, pf north of Northeast Cottage.
3. GH2-825' Non-welded vitric-lithic tuff in Cricket Valley hole.
4. GH2-1041' Dacite flow or dome in Cricket Valley hole.
5. GH6-955' Porphyritic dacite lava flow in Devil's Riding School hole.
6. GH6-979' Dacite lava flow in Devil's Riding School hole.

Table 4. Whole rock chemical analyses of rhyolites from Ascension Island. Major element analyses are expressed as weight percent and trace elements in parts per million.

	AI-83-4	GH2-696	GH2-762	GH2-1633
SiO_2	69.40	70.20	69.40	74.80
Al_2O_3	13.72	14.09	11.80	12.28
FeO*	4.96	4.20	4.20	2.62
MgO	0.06	0.10	0.07	0.06
CaO	0.47	0.53	0.43	0.20
Na_2O	6.59	6.36	6.44	5.00
K_2O	2.42	3.24	4.92	2.97
MnO	0.21	0.20	0.16	0.05
TiO_2	0.31	0.27	0.28	0.18
P_2O_5	0.02	0.02	0.03	0.01
LOI	0.10	0.26		0.40
Total	98.26	99.47	97.73	98.57
Sr	8	7	7	4
Ba	270	100	110	210
Co	13	23	12	49
Ni	<5	<5	7	<5
Cu	7	7	11	6
Pb	<10	<10	11	<10
Zn	191	154	170	181
Li	22	20	21	27
Be	6.7	6.9	6.1	7.0
Zr	666	640	936	531
La	95	89	53	79
Ce	146	141	84	151

*Total iron calculated as FeO.
LOI is loss on ignition

1. AI-83-4 Rhyolite flow north of Dampiers' Spring.
2. GH2-696 High-K rhyolite lava flow in Cricket Valley hole.
3. GH2-762 Welded ash-flow tuff in the Cricket Valley hole.
4. GH2-1633 Rhyolite dome at the bottom of Cricket Valley hole.

Alteration

Alteration minerals and secondary fracturing are indicated on the lithologic logs for the thermal gradient holes (Figs. 3 through 9). In most of the holes no significant alteration was present above a depth of 600 ft (183 m). Clay alteration of pyroclastic material is the most common, with clay alteration in lava flows and dikes generally restricted to fractures. Smectite is the most common clay mineral. Hematite staining along fractures is common in the deeper part of the holes and is typically associated with basalt dikes or highly fractured rocks. Calcium carbonate filling fractures and vesicles is abundant only in the bottom of GH-6 and in GH-4. Well-formed crystals in GH-4 core are the aragonite polymorph. All of this alteration could be produced by normal weathering.

Chlorite is present near the bottom of GH-4 and associated with the basaltic dike in GH-6. The chlorite in GH-6 was probably produced by deuteric alteration of the dike. Psilomelane or manganite cement trachytic breccia in LDTGH at a depth of 678 to 694 ft (207 to 212 m). These manganese minerals are generally supergene in origin, however, manganese minerals are associated with geothermal systems at some locations (Nielson et al., 1978).

SUBSURFACE TEMPERATURES

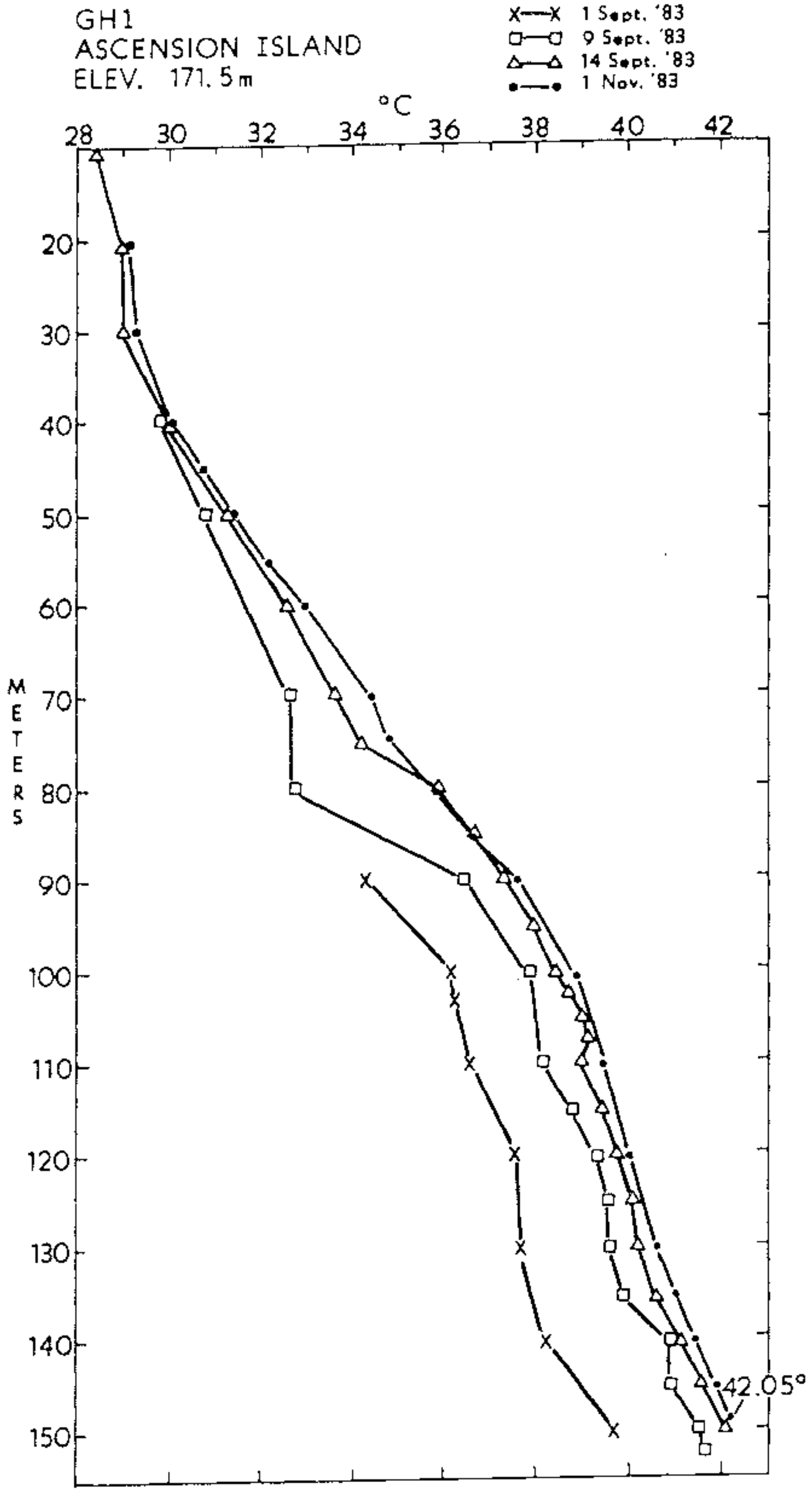
Subsurface temperature measurements are of obvious usefulness in the exploration for geothermal systems. The drilling process itself modifies the temperature in the holes and a series of measurements made at different times following hole completion are useful in not only watching the holes come to thermal equilibrium, but also in explaining some of the hydrologic properties of the rocks penetrated by the drilling process.

GH-1 was the first of the thermal gradient holes drilled. It was located on the basis of detailed electrical resistivity measurements (Ross et al., 1984) which documented a 10 Ω-m resistivity zone at a depth of about 1000 ft below sea level in this location. The temperature profiles for this hole are shown in Figure 12. The highest temperature recorded is 42.06°C (107.7°F), and it was encountered at the bottom of the hole. The gradient at the bottom of the hole is about 67°C/km (3.7° F/100 ft.).

GH-2 was drilled to a depth of 1750 ft near the southern margin of Cricket Valley. The temperature logs for this hole are summarized in Fig. 13. The elevation of the hole is about 1570 ft above sea level. This, in conjuction with the high permeability of the rocks and the constant cloudiness and mist on that side of the island, have resulted in a depressed thermal gradient in the upper portions of the hole. This gradient is characteristic of a zone of recharge with downward percolating meteoric water buffering the temperature of the hole to approximately the average atmospheric temperature.

Below 492 ft (150 m), however, the gradient increases to 58°C/km. The maximum temperature measured in this hole was 45.6°C (114°F) at the bottom, 1,739 ft.

GH-3 was drilled near Booby Hill in the dump to the north of the runway. Booby Hill is a relatively young basaltic vent area, and the hole was



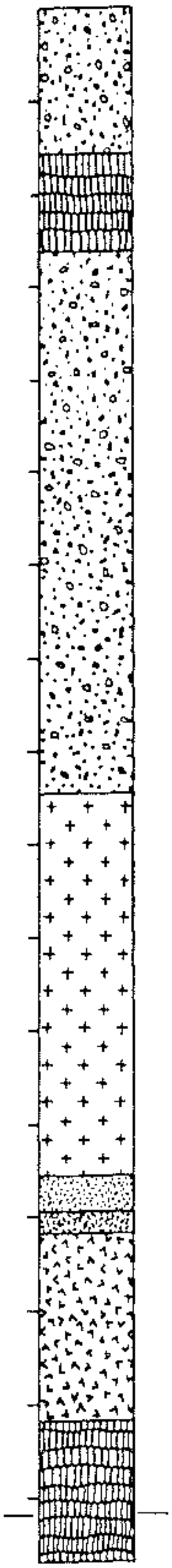


Figure 12. Temperature logs for GH-1. See Figure 3 for explanation of lithology symbols.

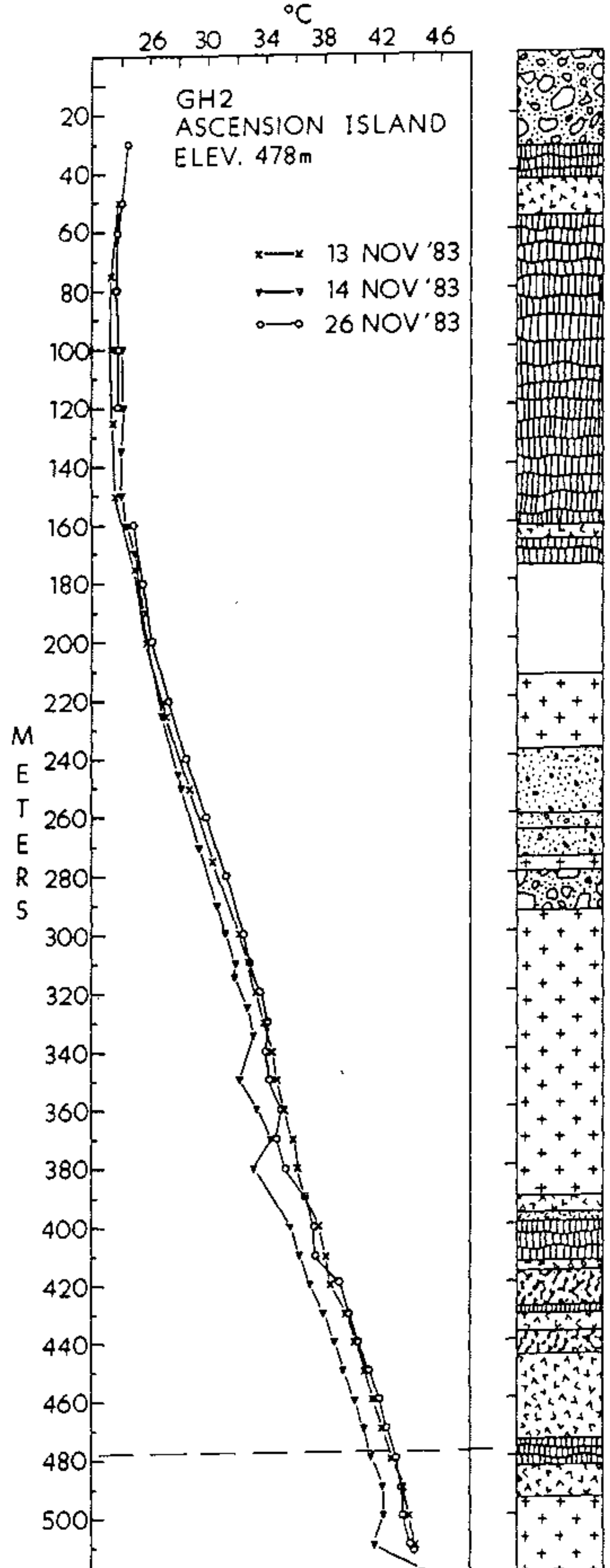


Figure 13. Temperature logs for GH-2. See Figure 4 for explanation of lithology symbols.

drilled to test for any latent heat along this zone. Due to drilling problems described previously, the hole only reached 206 ft. The thermal log from this hole is illustrated in Fig. 14. This log shows that the hole has a negative thermal gradient. That is, it is hotter at the surface than at depth. The higher temperatures near the surface result from heating by the sun. The cooler temperatures at depth suggest that high temperatures will not be found at sea level where water would be expected to be encountered.

Hole GH-4 was drilled near Bear's Back largely to test the geothermal potential of an aeromagnetic trend detected in this area (Ross et al., 1984). The temperature logs of this hole are shown in Fig. 15. The maximum temperature recorded is 40.27°C (104.5°F) at the bottom of the hole. The thermal gradient recorded above the water table is 54.7°C/km. The earlier logs (Fig. 15) show zones between 394 and 427 ft (120-130 m) and at 525-558 ft (160-170 m) which, through time, equilibrated to form a linear gradient. These areas probably represent permeable zones which accumulated large amounts of cooler drilling fluid during drilling and required some amount of time to recover from the cooling effects. The change in slope of the gradient curves at sea level suggests that that is where water is first encountered in the hole.

GH-5 was drilled along the Old Mountain Road to the south of Sisters Peak. The logs for this hole are shown on Fig. 16. The equilibrium temperature on this hole shows a slightly positive gradient from 197 ft (60 m) down to sea level, and then a negative gradient to the total depth of the hole. This suggests that there is a zone of slightly warmer water present at sea level. This zone is probably either fresh water or a mixture of fresh and salt water. Below this, the water is briney and colder. The gradient above sea level is 14.4°C/km. This low gradient suggests that the portion of this

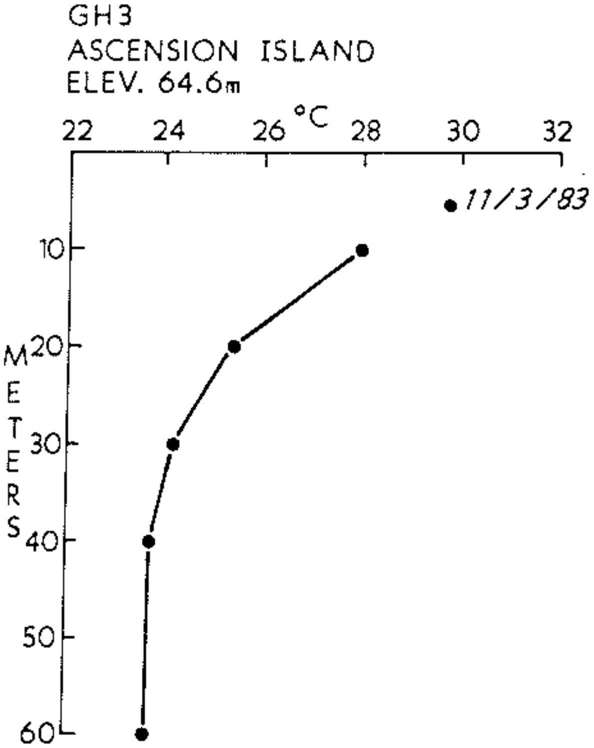


Figure 14. Temperature log for GH-3.

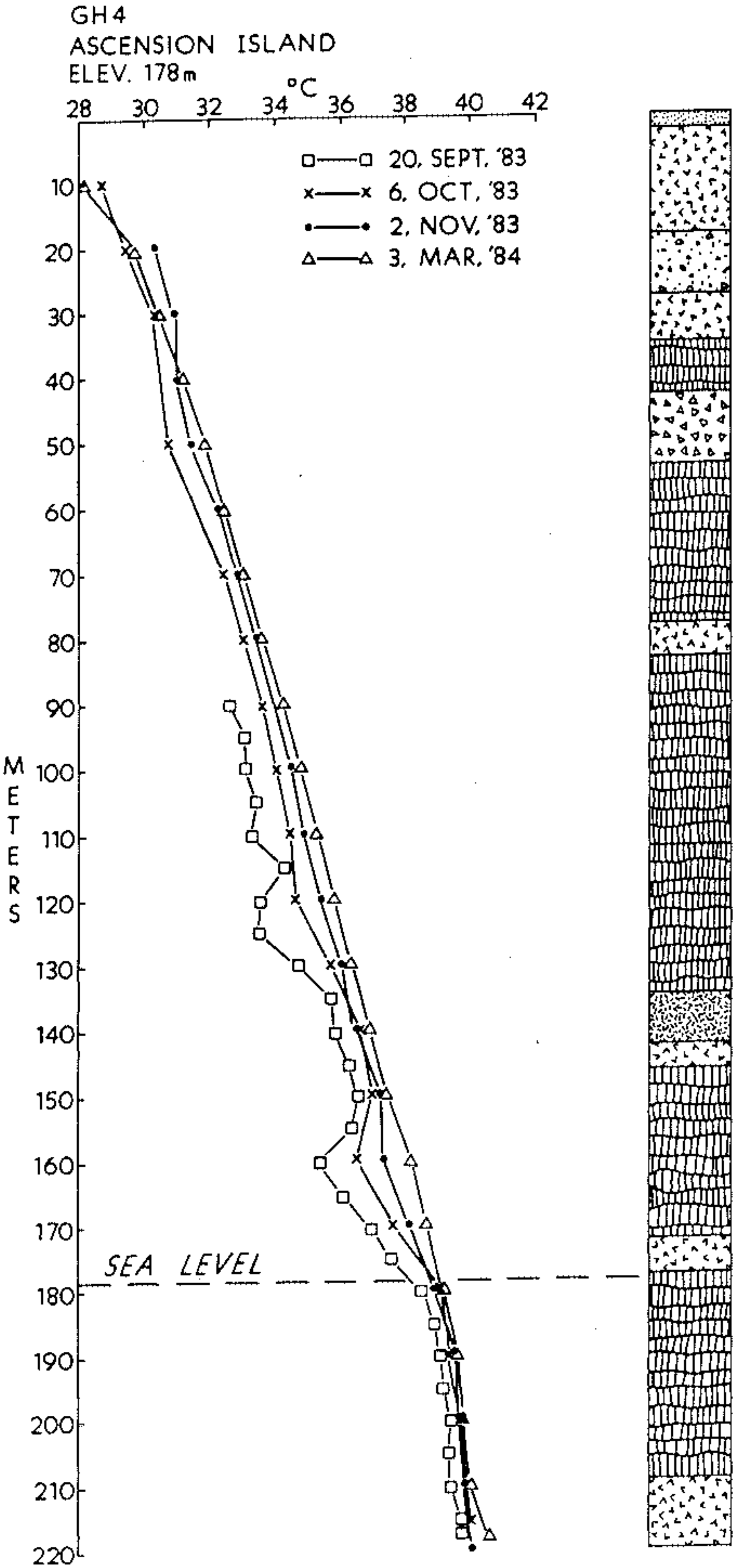


Figure 15. Temperature logs for GH-4. See Figure 6 for explanation of lithology symbols.

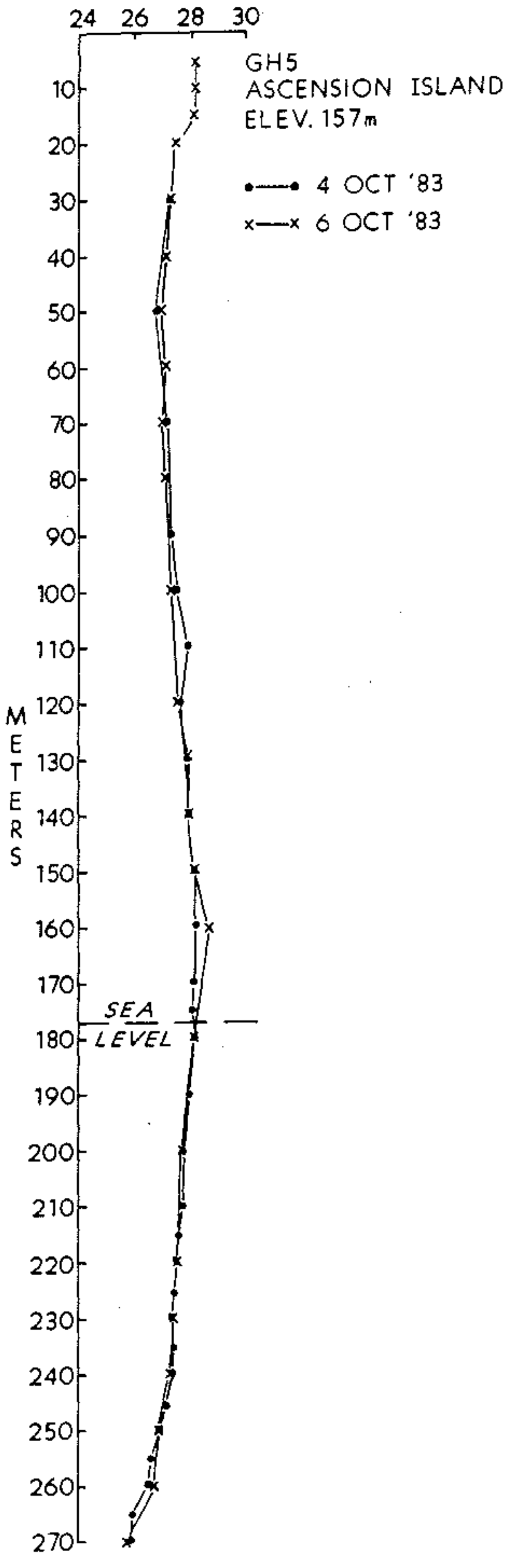


Figure 16. Temperature logs for GH-5.

hole which is located above the water table is an area whose temperature is controlled by downward percolation of meteoric water or lateral flow below sea level which sweeps away most heat coming from depth.

Hole GH-6 was drilled on the east flank of Devil's Riding School along the NASA road. This hole reached a maximum of 54.4°C (130°F) at the total depth of the hole. Fig. 17 shows the temperature logs of this hole. The gradient above the water table is 65.5°C/km. Zones at 787 ft (240 m) and 951-984 ft (290-300 m) were cooled considerably by drilling fluid and had not quite re-equilibrated at the last logging. The straight profile below sea level suggests conductive rather than convective heat transport. The gradient at the bottom of this hole is 71.9°C/km (3.9° F/100 ft.), and the conductive nature suggests that the rocks are anisotropic with little vertical permeability.

LDTGH was drilled approximately halfway between GH-1 and GH-6 to test for a fresh water resource. The temperature logs of this hole are shown in Fig. 18. The highest temperature measured in this hole was 48.32°C (119°F) on 4 December 1983. The last log (3/9/84) shows that the lower portion of the hole has become isothermal with a temperature which is approximately average that found during the 12/4/83 logging. This is probably due to water flow within the drill hole itself and does not represent a "static" geothermal phenomena.

Composite Logs

Figures 19 and 20 are composite logs of the equilibrium temperatures of all the holes drilled. Figure 19 shows temperatures plotted against depth below the surface while Figure 20 shows temperature plotted with respect to elevation. We have plotted these logs against elevation because evidence suggests that the water table is essentially sea level throughout the island. Plotting in this manner eliminates the bias of temperature

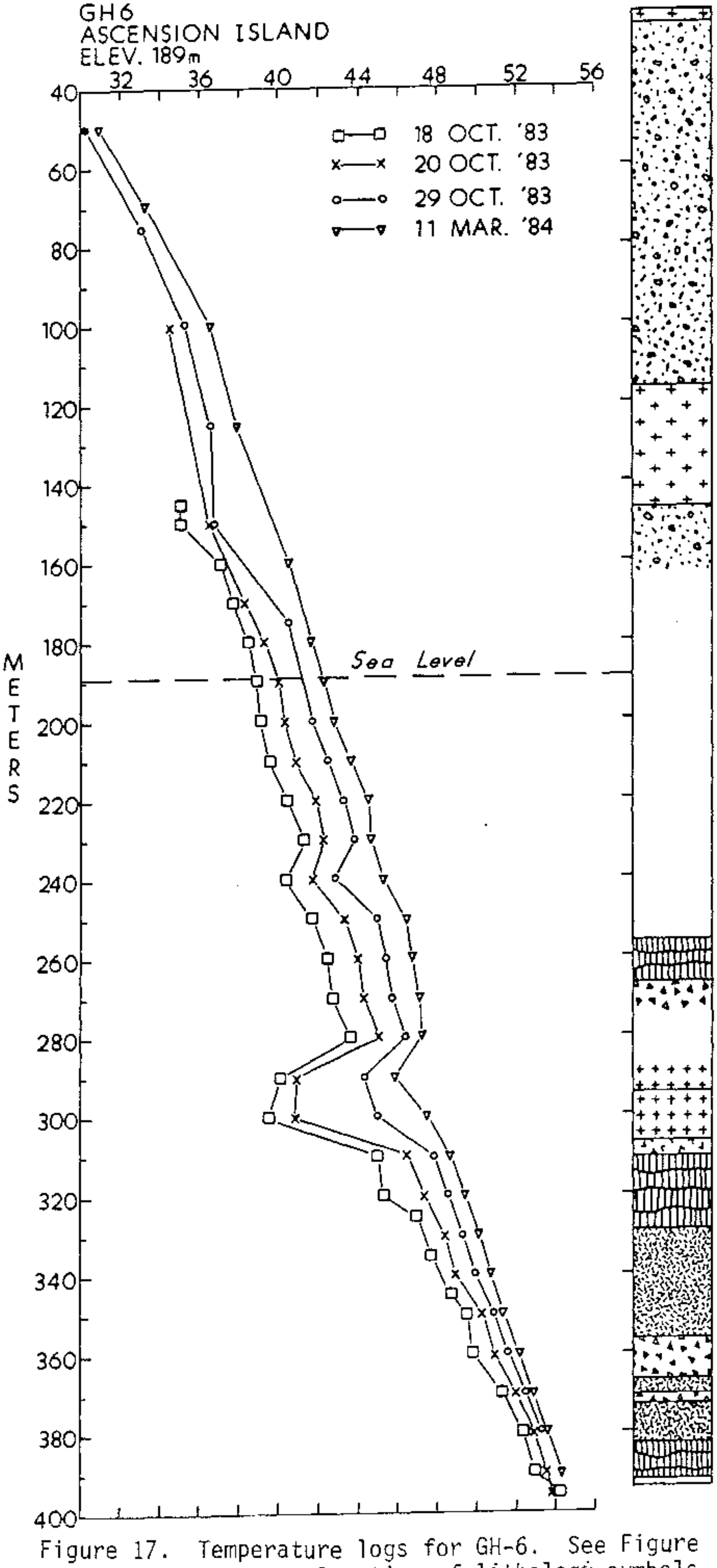


Figure 17. Temperature logs for GH-6. See Figure 8 for explanation of lithology symbols.

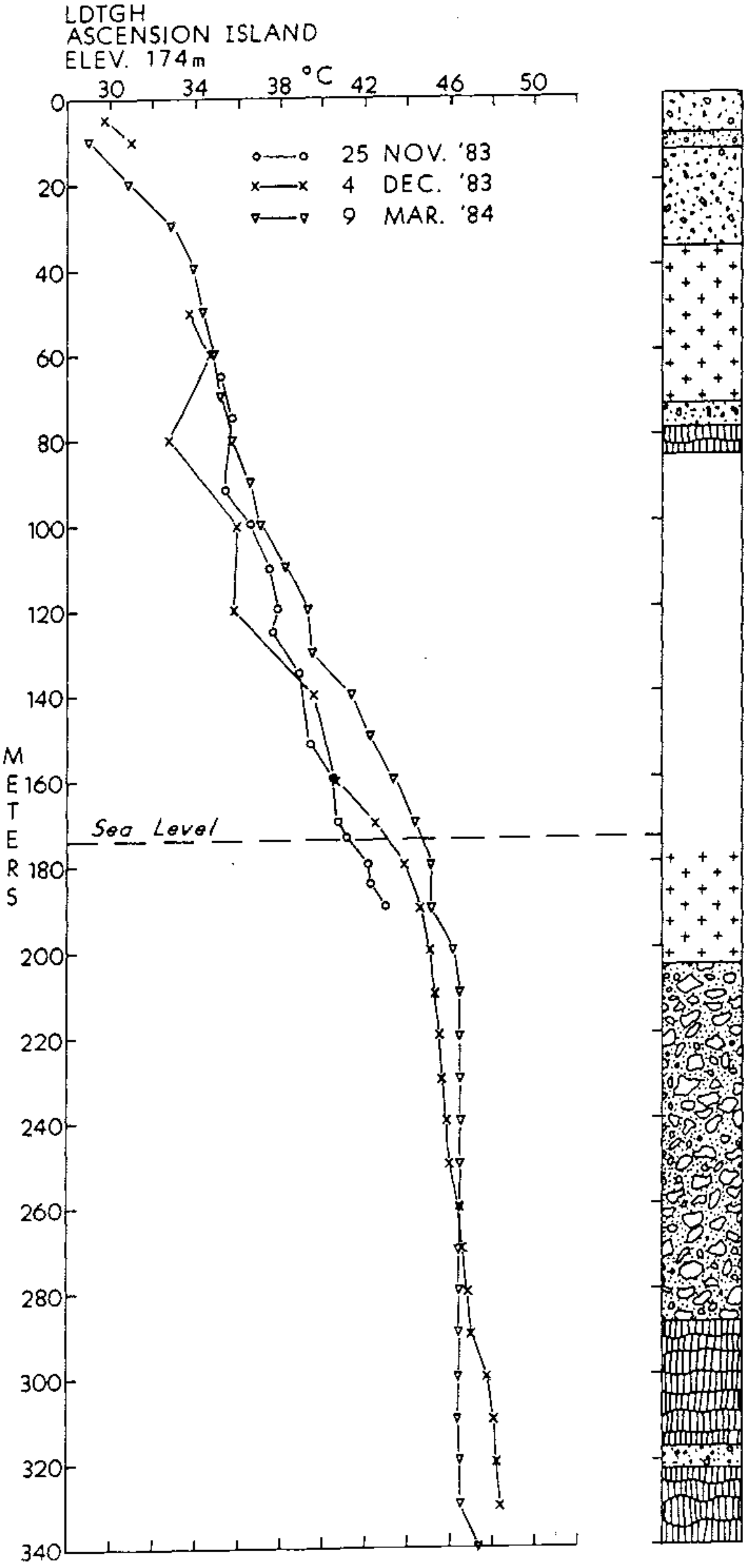


Figure 18. Temperature logs for LDTGH. See Figure 9 for explanation of lithology symbols.

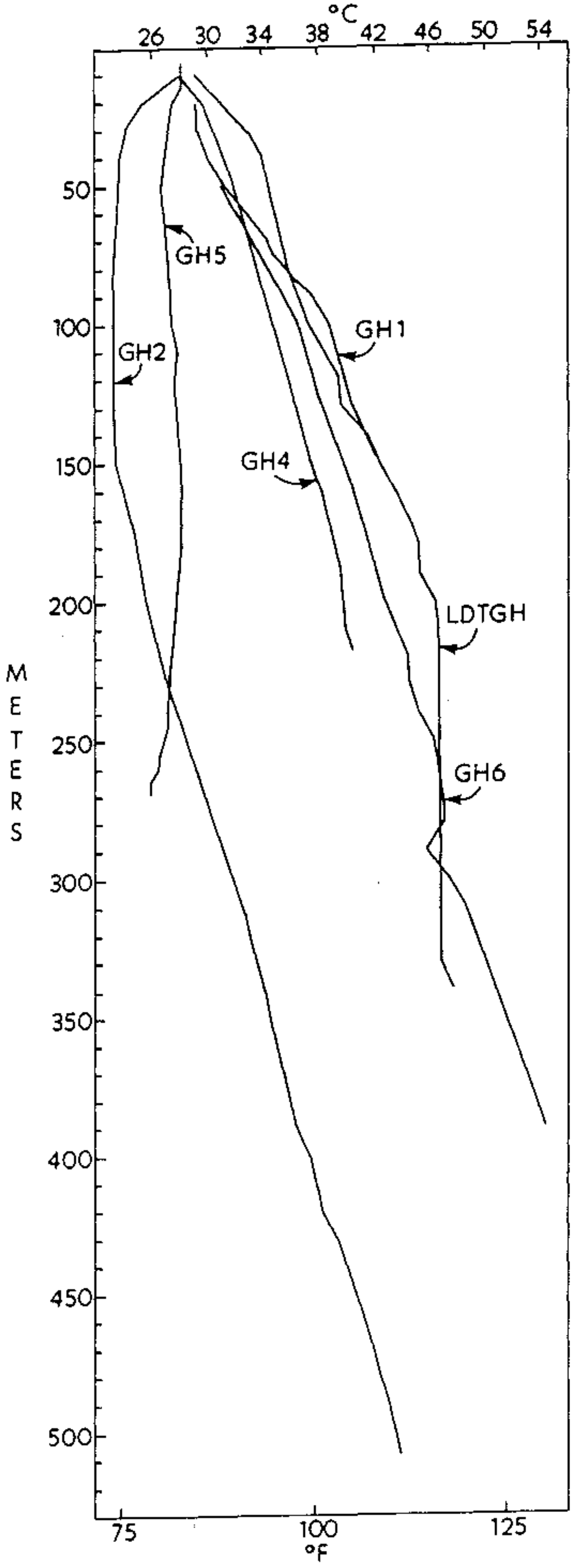


Figure 19. Composite temperature log for all holes.

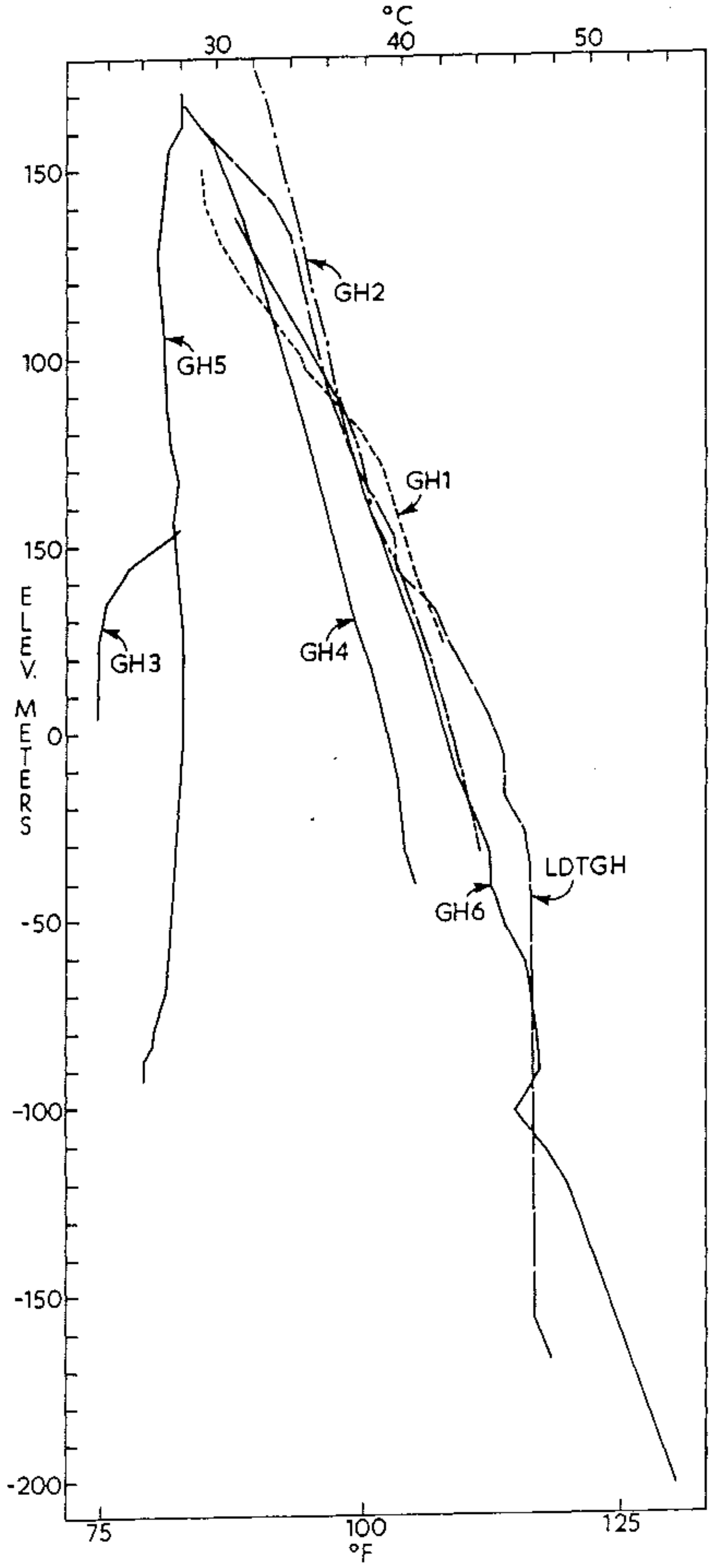


Figure 20. Composite temperature logs as a function of elevation for all holes.

measurements in zones of recharge above the water table.

Figure 20 shows that the wells may be grouped into three distinct categories. Wells GH-3 and GH-5 are clearly cold and must be controlled by the flux of cold water at depth. GH-1, 2, 6 and LDTGH are warm and show very similar temperature signatures. GH-4 is intermediate between the other two groups. The signatures of these wells suggest the presence of active geothermal processes both in the area of Middleton ridge (GH-1, 6 and LDTGH) and Cricket Valley (GH-2). Since drilling depths are greater around Cricket Valley, and the site is farther from the U.S. Base, it is clear that future exploration should concentrate on the area around Middleton ridge.

FLUID CHEMISTRY

Samples of the subsurface fluids from Ascension Island were collected from drill hole LDTGH. As reported previously (Nielson and Sibbett, 1982) no hot springs, seeps or fumaroles were found during geologic mapping of the island. Following the completion of LDTGH, the well was airlifted to clean drilling fluid from the well bore. During March, 1984 the fluids in the well were sampled using a downhole sampling system which allowed us to take samples at various depths in the well. These samples are also shown in Table 5.

Introduction

Although there is no evidence at the surface of the presence of geothermal activity on Ascension Island, geothermal fluids were encountered in thermal gradient well LDTGH. Six water samples were collected from four different depths to help determine the subsurface reservoir temperatures and the origin of the thermal fluids. The samples were taken from depths of 573, 578, 599, and 625 ft (175, 176, 183 and 190 m) using a downhole sampler after the well had been allowed to stand undisturbed for approximately four months. The water level in the well is at a depth of 570 ft (174 m).

Analytical Results and Discussion

The concentrations of 37 major and minor cations, fluoride, chloride, sulfate and bicarbonate were determined on each of the six water samples. In addition, the total dissolved solids (TDS) content and the pH were determined on each of the samples. The cation concentrations were determined by inductively coupled argon plasma spectrometry. The precision and accuracy of this method and the sample preparation techniques have been described by Christensen et al. (1980). Fluoride and chloride were determined by specific ion electrode, sulfate by silver nitrite titration and TDS by gravimetry. All

Table 5. Chemical Composition of Ascension Island Samples, Seawater and Seawater-Derived Geothermal Brine from Reykjanes, Iceland.

Sample #	573'	578'	599'	625'	625'#1	625'#2	Reykjanes[2]	Seawater[3]
Date of Collection	3/12/84	3/12/84	3/12/84	3/12/84	3/13/84	3/13/84	nr	nr
Temperature (°C)	45	45	45	45	45	45	269°C	nr
Na	4,273	4,283	4,272	9,282	9,587	9,710	10,135	10,500
K	167	166	165	318	327	331	1,480	380
Ca	419	433	435	608	538	544	1,628	400
Mg	584	586	578	1,169	1,202	1,222	1.0	1,350
Sr	3.24	3.24	3.24	6.76	6.94	7.03	nr	8
Fe	324	311	334	92	74	78	nr	.01
SiO_2	25	25	24	94	99.0	101	600	6.4
Li	.13	.14	.13	.22	.22	.22	nr	.17
B	1.84	1.84	1.79	2.71	2.72	2.76	nr	4.6
HCO_3	15	<10	13	86	119	225	nr	142
SO_4	1,006	1,018	1,003	2,320	2,402	2,446	22.2	2,700
Cl	8,760	8,690	8,640	17,100	17,800	17,800	19,727	19,000
F	2.40	2.00	2.10	2.40	2.70	2.70	.1	1.3
Br	29	na	na	na	na	63	nr	65
TDS	15,430	15,420	15,340	30,770	32,460	32,500	nr	nr
pH	6.1	6.1	6.1	6.1	6.2	6.3	nr	nr

[1] na = not analyzed for, nr = not reported

[2] analysis from Arnorsson (1978)

[3] analysis from Hem (1970)

[4] concentrations in mg/kg

of the samples were analyzed within one month of their collection. The chemical analyses are given in Table 5 and presented graphically in Figures 21 and 22.

The data in Table 5 indicate that the water samples fall into two distinct groups. Waters sampled between 573 and 599 ft are compositionally similar. These waters are relatively dilute with TDS contents of approximately 15,000 ppm. Samples from 625 ft are more saline with a TDS content of near 32,000 ppm. Despite these compositional differences, Figure 21 shows that both groups have close affinities to seawater. The data suggest that several of the elements have behaved in a conservative manner. This relationship is clearly indicated by the overall similarities in the elemental ratios (Table 6) of sodium (Na), potassium (K), magnesium (Mg), strontium (Sr), sulfate (SO_4), bromide (Br), and chloride (Cl) between the water samples collected at 573 and 625 ft. Because of the very different chemical behavior of these elements during hydrothermal alteration, these similarities imply that the two water types have been controlled by similar water-rock interactions.

The relationship between the chemistry of the two water types to seawater is illustrated in greater detail on the mixing diagram shown in Figure 22. For simplicity only one analysis of each water type was plotted on this diagram. The data were plotted against chloride because it is probably the least reactive of the elements present in the samples and therefore its concentration is most likely to reflect the nonreactive history of the waters (Ellis, 1979).

Figure 22 shows that the concentrations of Mg, SO_4, Na and K decrease systematically from seawater to the sample from 625 ft to the sample from 573 ft, suggesting that an apparently simple mixing relationship may exist between

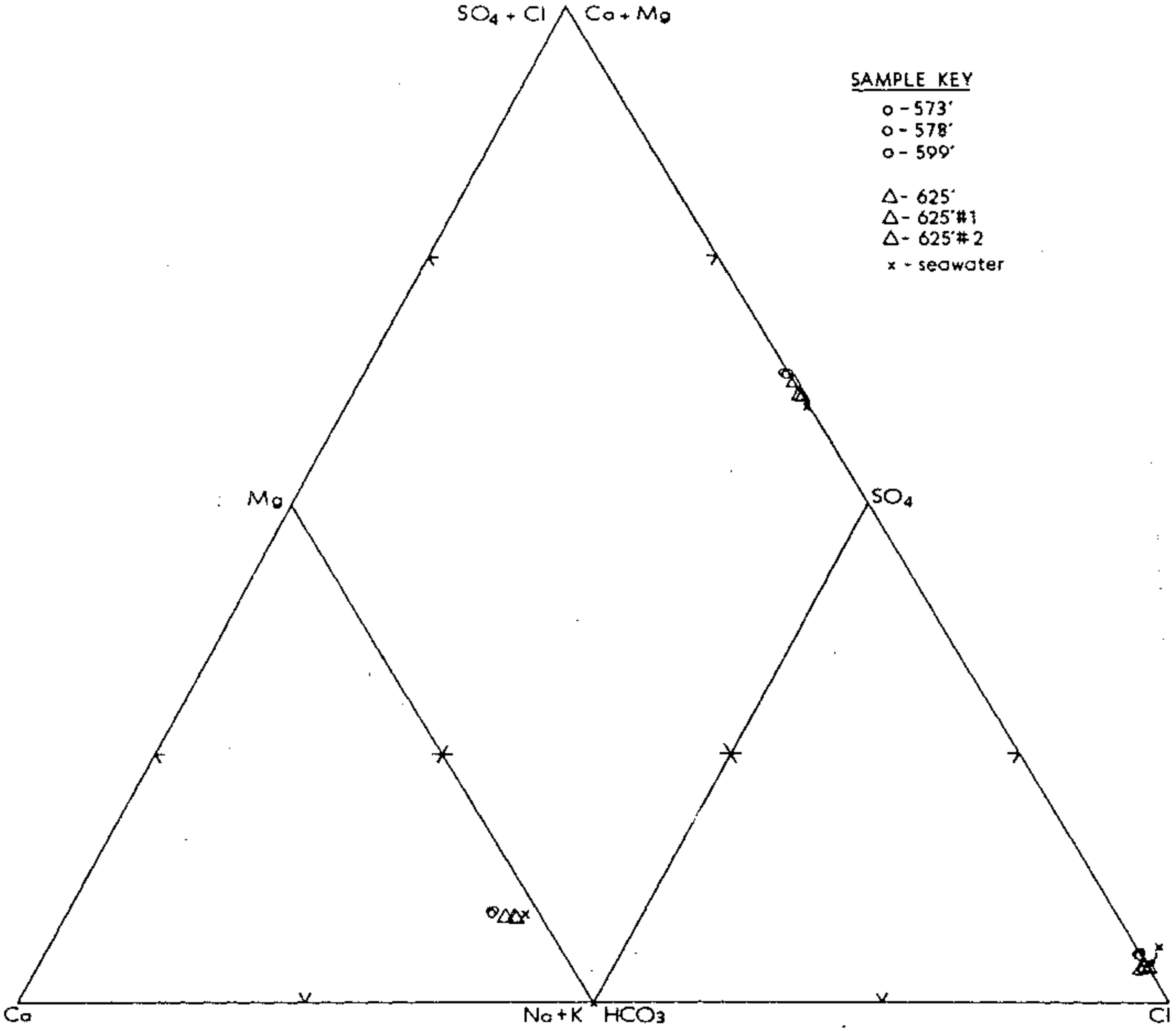


Figure 21. Trilinear diagram showing chemical character of Ascension Island water samples and sea waters.

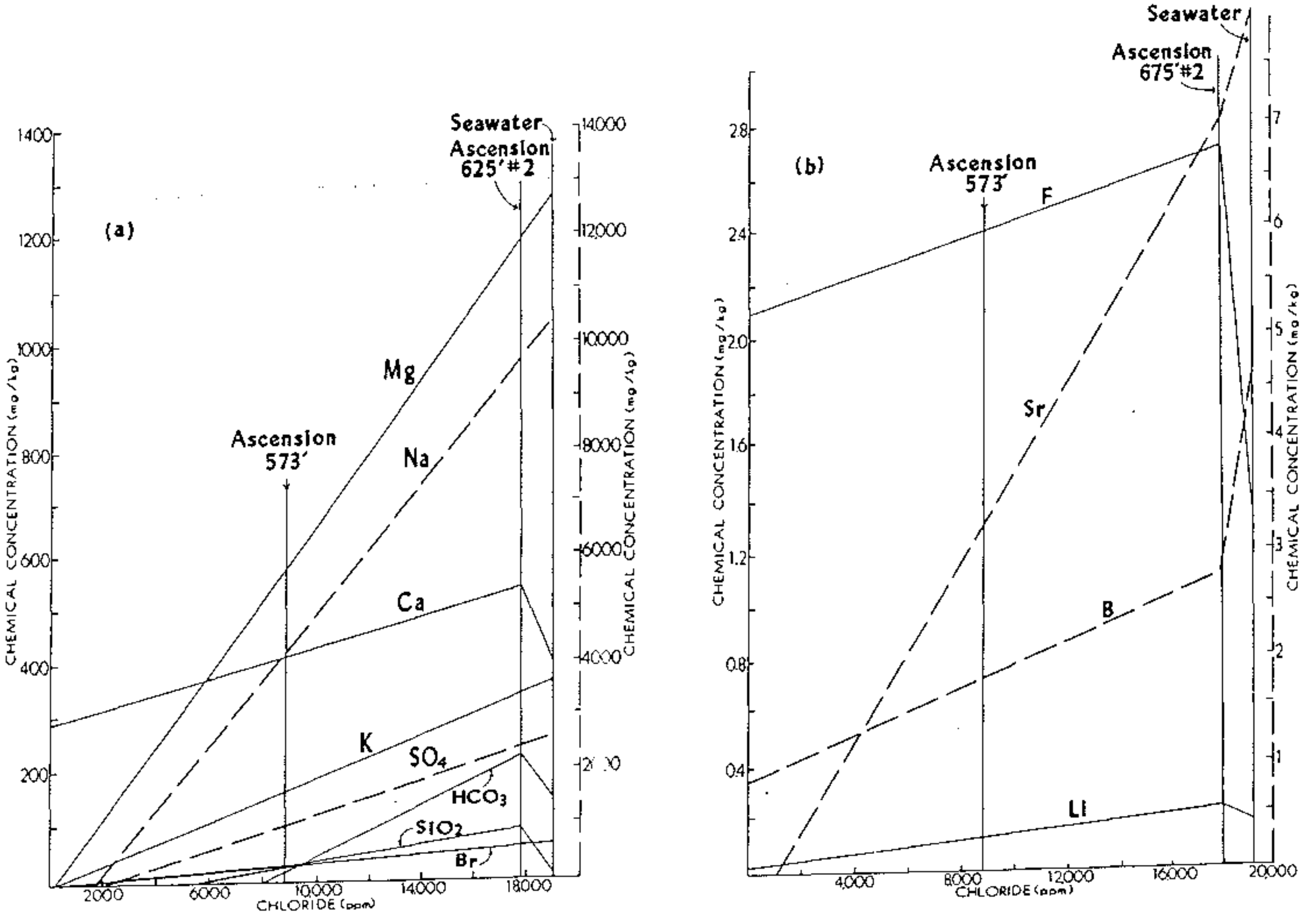


Figure 22. Major and minor element concentrations vs. chloride in Ascension Island water samples and sea water.

the three waters. In contrast, the concentrations of calcium, bicarbonate, silica, boron, and fluoride deviate significantly from a simple mixing model. Calcium, bicarbonate, and silica are enriched relative to seawater, whereas boron is relatively depleted. As discussed more fully below, the behavior of these elements, the major cations and sulfate, in general, typify seawater which has not been heated to temperatures above a range of 300 to 392°F (150 to 200°C).

The low pH of the samples, between 5.9 and 6.3, provides one possible explanation for the enrichments in calcium and bicarbonate. Under these conditions dissolution of calcite leading to increases in calcium and bicarbonate in the waters can occur. Bischoff and Seyfried (1978) have shown that low pH may be produced by the formation of magnesium hydroxide as seawater is heated. However, the similar ratios of Na to Mg in seawater and in the Ascension samples indicate that little Mg has been precipitated.

Both silica and fluoride are highly mobile in geothermal waters (Ellis, 1978), and it has been shown that fluoride is readily leached by thermal fluids even before appreciable hydrothermal alteration has occurred. The concentration of aqueous silica, in contrast, is temperature dependent and can thus be used as a geothermometer (Fournier, 1981). Estimates of the reservoir temperatures based on the silica geothermometers are discussed below.

Boron, in contrast, is depleted by up to 45% in the Ascension waters compared to seawater. Although boron is typically conserved in geothermal fluids because of the absence of boron minerals (Browne, 1978), Brockamp (1973) has shown that boron can be adsorbed onto clay minerals, and that adsorption increases as the concentration of magnesium in the fluid increases. Clays are present in the weakly altered volcanics on Ascension Island and thus may be important in controlling the abundance of boron in these Mg-rich waters.

Estimation of Reservoir Temperatures

Reservoir temperatures of active geothermal systems can frequently be estimated from the cation concentrations of the thermal fluid sampled from wells and springs. Although many different chemical geothermometers have been developed during the last fifteen years (see, for example, Fournier, 1981), only the silica geothermometers have proven reliable when applied to waters containing extremely high concentrations of magnesium. The solubility of silica may, however, be controlled by one of several different silica polymorphs. In Iceland, where geothermal host rocks are similar to those of Ascension Island, Arnorsson (1975) has demonstrated a correspondence between chalcedony-derived temperatures and measured temperatures of fluid from deep (300-2200 m) drill holes. The measured temperature of these fluids ranged from 112 to 230°F (50° to 110°C). At temperatures of 230-356°F (110° to 180°C), quartz or chalcedony equilibrium controlled the solubility of aqueous silica, and at higher temperatures quartz appears to control the solubility of aqueous silica. Temperature estimates based on the silica geothermometers are given in Table 6.

Qualitative estimates of the reservoir temperatures can also be made by comparing the elemental concentrations of the Ascension waters to those found in fluids from similar geologic environments or determined from experimental data. The Reykjanes geothermal system of Iceland is perhaps the best documented of the thermal systems where the geothermal fluids are derived from seawater. Here, heating of seawater results in an increase in potassium, calcium and silica and a dramatic decrease in magnesium and sulfate (Arnorsson, 1978). Sodium and chloride are conserved during heating. These changes were experimentally verified by Bischoff and Seyfried (1978), by

Table 6. Chemical Geothermometer Temperatures and Element Ratios for Ascension Island Water Types.

	Ascension Samples			
	625'#2	573'	Seawater	Reykjanes[1]
Measured Temp (°C)	45	45	<20	269
Geothermometers				
Na-K-Ca[2]	322°F (161°C)	331°F (166°C)	343°F (173°C)	469°F (243°C)
SiO_2[3]	232°F (111°C)[5]	104°F (40°C)[5]	17.6°F (-8°C)[5]	516°F (269°C)[4]

Ratios of Ascension Island Water Types (573'/625#2) For Major and Minor Elements

Na	.44
K	.50
Ca	.77
Mg	.48
Sr	.46
Ln	.59
B	.67
SiO_2	.25
SO_4	.41
Cl	.49
F	.89
Br	.46
TDS	.47

[1] Analyses from Arnorsson (1978)

[2] Method of Fournier and Truesdell (1973)

[3] Method of Fournier (1973)

[4] Quartz polymorph

[5] Chalcedony polymorph

heating seawater with basalt at 122°F (50°C) temperature increments up to 622°F (350°C). Their analyses indicate that calcium and sulfate concentrations do not change until temperatures reach the range of 300 to 392°F (150-200°C). These relationships suggest that the Ascension waters have not been heated to temperatures above this range.

The relationship between a deep high-temperature geothermal reservoir and the fluids sampled LDTGH may, however, be more complex. We believe that the fluids sampled represent the mixing of thermal fluids with other subsurface fluids prior to the time they were sampled. However, since we do not know the composition of the mixing fluids, there are several possible scenarios. Figure 23 illustrates several different mixing models which could explain the characteristics of the high-salinity samples. We have not considered mixing models for the low-salinity waters here because the predicted chalcedony temperatures fall slightly below the measured temperatures and thus give no indication of mixing after heating.

In Figure 23a we have assumed that the postulated reservoir fluid has mixed with cold seawater with a typical oceanic silica concentration of 6.4 ppm. This model predicts a temperature of 536°F (280°C) for the reservoir fluid and that the fluid sampled in LDTGH was a mixed fluid consisting of 87% seawater. Chemical concentrations of the hypothetical 536°F (280°C) fluid calculated using the predicted seawater fraction indicate that the postulated reservoir water would be strongly deficient in potassium and enriched in magnesium, sulfate and fluorine compared to waters from Reykjanes. Thus this model is not likely. However, the reservoir fluid could have mixed with cool seawater that has an elevated silica content. Although cool water has not been sampled at Ascension Island, this is a reasonable assumption because the aqueous concentration of silica in the ocean is biologically controlled (Hem,

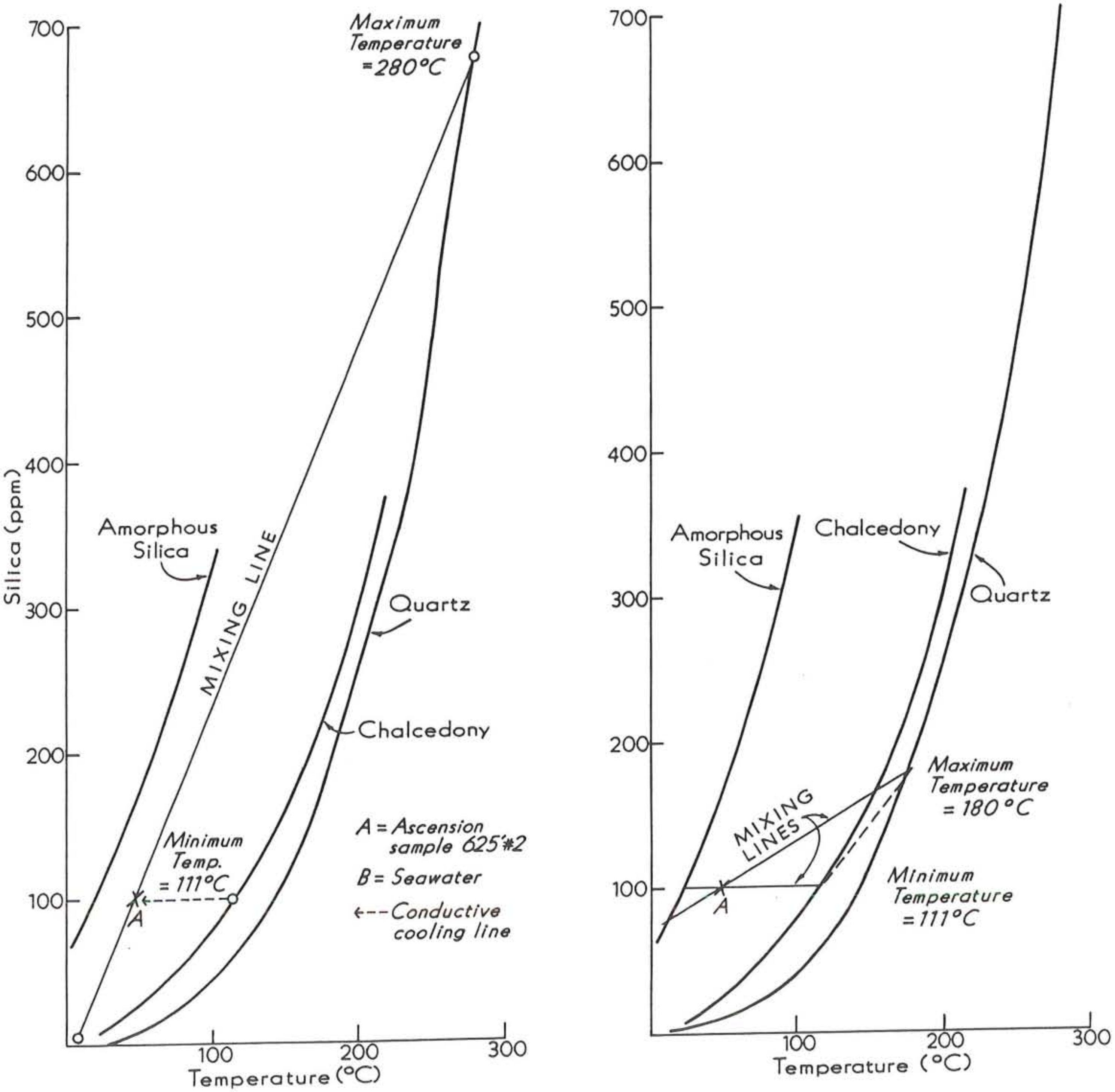


Figure 23. Silica-enthalpy (temperature) mixing diagrams. For explanation see text.

1970). This control would be removed once seawater migrated into an island aquifer. At that point, silica concentration would be controlled by the dissolution rate of amorphous silica, and could have reached saturation with respect to amorphous silica. A model based on mixing chalcedony- or quartz-saturated fluid with amorphous silica saturated fluid is shown in Fig. 23b, and predicts a temperature of 232 to 356°F (111° to 180°C) for the reservoir fluid.

The worst case estimate of reservoir temperature would be the mixing of seawater with a dilute fluid, prior to heating. In this case, the silica geothermometers in Table 6 provide the best estimate of the reservoir temperature of 232°F (111°C).

Conclusions

Chemical analyses of water samples from well LDTGH indicate that the portions of the geothermal system penetrated by the well are strongly stratified. Fluids from the upper portions of the well, to depths of at least 599 ft, are relatively dilute and characterized by total dissolved solid contents of about 15,000 ppm. Waters at a depth of 625 ft are more saline, up to 32,000 ppm, and may have been derived from a geothermal reservoir whose temperatures were up to 111°C and may have been as high as 302° to 392°F (150° to 200°C). Both fluid types display chemical characteristics which suggest that they have been derived from seawater.

SUMMARY AND RECOMMENDATIONS

The Phase II geothermal exploration of Ascension Island has indicated the existence of a geothermal system which may be of sufficient quality to produce electrical power. We know that the fluid temperature at LDTGH is 104°F (40°C) and have interpreted the temperature logs as demonstrating some amount of lateral transport of the fluid. There does not seem to be evidence for thermal upwelling in the vicinity of LDTGH as would be expected if the hole were directly over a convecting hydrothermal system. We also know that the fluid sampled at LDTGH has seen temperatures of at least 232°F (111°C), and possibly as high as 392°F (200°C). The principal problem in arriving at an accurate maximum temperature is that the chemistry of any fluids which mixed with the thermal fluid is unknown.

From all the data collected, we have arrived at two possible conceptual models of the geothermal system beneath Ascension Island. These models are shown in Figure 24. In Figure 24a, a high-temperature geothermal system with temperatures up to 392°F (200°C) rises to sea level and then moves laterally. As the fluids move, they cool both by conduction to the surrounding rock and by mixing with meteoric fluids and unheated sea water. A second possibility is shown in Figure 24b. This shows a high-temperature geothermal convection system which heats the overlying fluid zone by conduction. This fluid is heated to temperatures of at least 232°F (111°C). It also moves laterally away from the zone of greatest heating and is mixed with both meteoric waters and sea water. The highest temperatures in the central portion of this system could reach 500°F (260°C) or more.

In order to test the deeper portions of this geothermal system we recommend an additional electrical resistivity survey in the area of Middleton ridge. This survey will allow us to target a deep temperature gradient hole

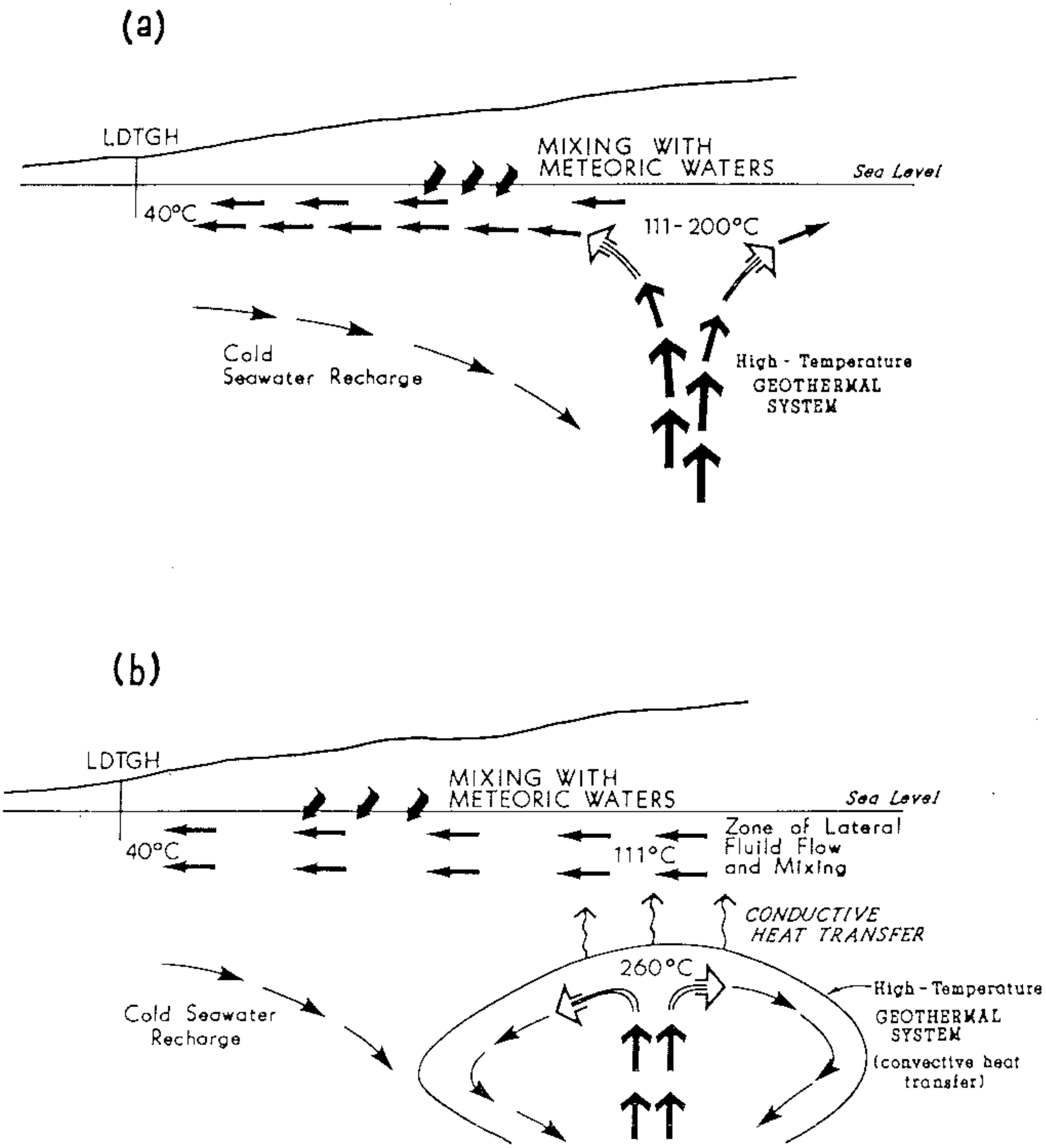


Figure 24. Alternative conceptual models of the geothermal system beneath Ascension Island.

which will be drilled to a depth of 3000 to 5000 ft (914 to 1524 m) to test the temperature and fluid flow characteristics of the deeper portion of the geothermal system. The results of this hole would allow a decision to be made concerning the drilling of production wells and the development of a power plant and electrical distribution system.

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