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FINAL REPORT
GEOTHERMAL RESOURCES PROJECT-STAGE ONE

PART 9
DEEP BOREHOLE TEST
SOUTH VOLCAN MOMOTOMBO FUMAROLE AREA

Prepared for
GOVERNMENT OF NICARAGUA
Ministry of Economy, Industry and Commerce

By
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TEXAS INSTRUMENTS INCORPORATED
Services Group

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PREFACE

This Final Report on STAGE ONE of the Nicaraguan GEOTHERMAL RESOURCES PROJECT is submitted to the Government of Nicaragua by TEXAS INSTRUMENTS INCORPORATED in Spanish and English versions.

The report is the work of several authors and consists of ten parts, or chapters, each of which is bound separately, as follows:

Part 1 - PROJECT SUMMARY, by D. E. Heilner and L. T. Braun

Part 2 - REGIONAL GEOLOGY: Thermal Manifestations of Western Nicaragua, by John B. Thigpen

Part 3 - SURFACE GEOLOGY: San Jacinto-Tisate-Najo Area, by John B. Thigpen

Part 4 - SURFACE GEOLOGY: South Volcan Momotombo Fumaroles, by John B. Thigpen

Part 5 - GRAVITY AND MAGNETIC SURVEYS, by Mario Mazzolini

Part 6 - ELECTRICAL GEOPHYSICAL SURVEYS in Relation to the Location of Geothermal Power Resources in Northwestern Nicaragua, by George Keller and Norman Harthill

Part 7 - GEOCHEMISTRY of the Nicaraguan Geothermal Project Area, by R. Bennett

Part 8 - TEMPERATURE GRADIENT WELLS at San Jacinto and South Volcan Momotombo, by R. Bennett

Part 9 - DEEP BOREHOLE TEST at the South Volcan Momotombo Fumarole Area, by John B. Thigpen

Part 10 - CONCLUSIONS AND RECOMMENDATIONS, by Texas Instruments Staff and Consultants

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ABSTRACT

During the final part of Stage I of the Nicaragua Geothermal Resources Project it was deemed necessary to supplement the project data by drilling a deep test hole to determine the base temperature of the steam reservoir at the South Volcan Momotombo Area. The Momotombo area was selected instead of the San Jacinto-Tisate area on the basis of geological, geophysical and geochemical data presented as separate parts of this report.

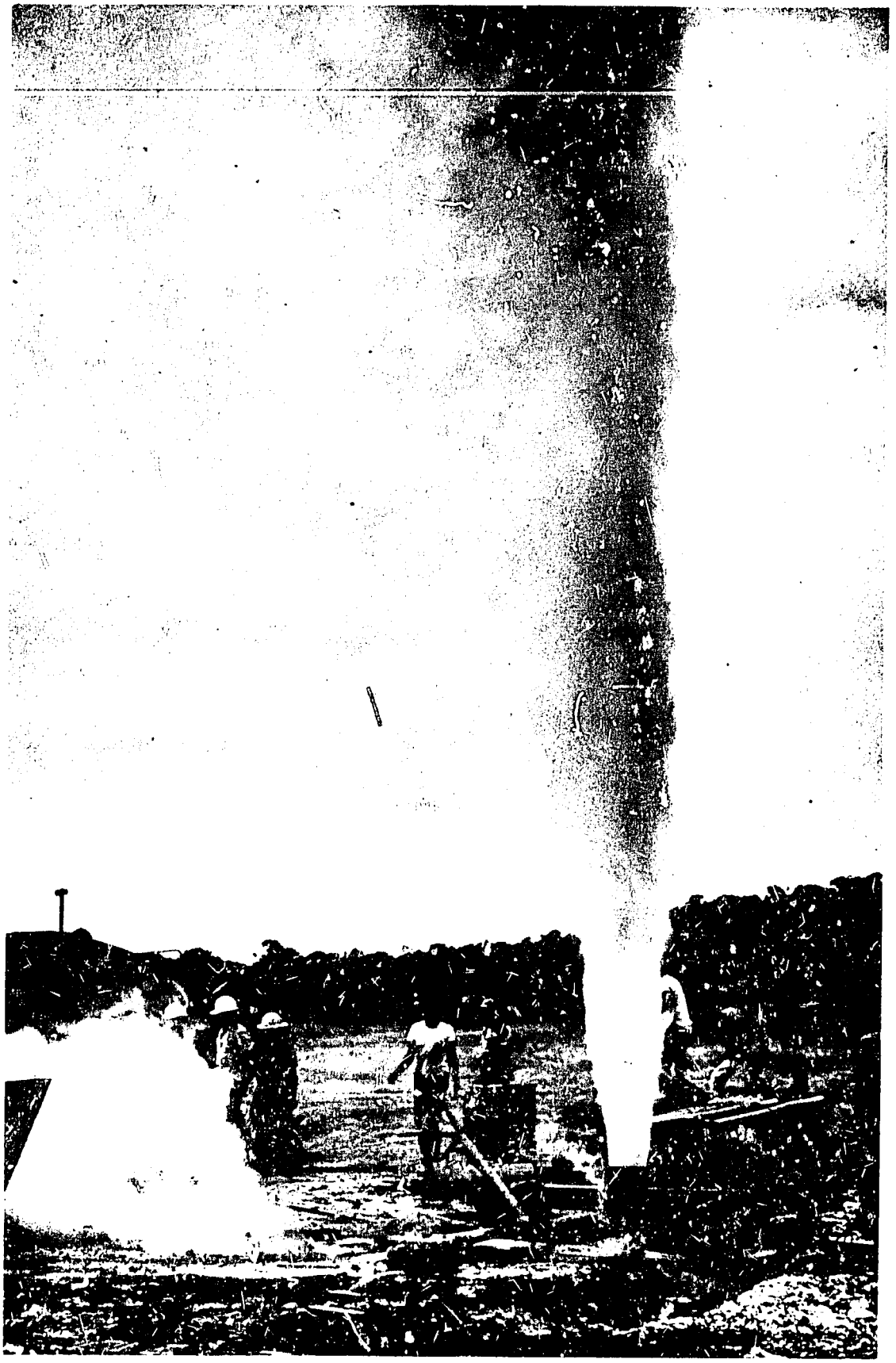
The hole was drilled to a total depth of 1995 feet with the available marginally adequate drilling equipment.

The hole erupted violently 11 hours after completion. This and subsequent eruptions consisted mostly of steam with some admixed water.

Temperatures of up to 209° C were measured at a depth of 725 feet. A cave-in prevented deeper temperature measurements.

The gross lithology penetrated is of interlayered basaltic-andesitic lava flows and pyroclastic deposits to a depth of 215 feet. Below 215 feet occur pyroclastic deposits, often intensely altered, with minor andesitic and basaltic lava flows.

Considerable reinforcement of the hole is required before extensive testing can be done. This testing is very important for further evaluation of the geothermal power prospects of the area.



Initial eruption of deep borehole MT-1 from 9 5/8 inch casing, 4 Dec. 1970, Momotombo geothermal prospect.

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Erupcion inicial del pozo profundo MT-1 desde la encajada de 9 5/8 pulgadas, 4 Dec. 1970, perspectiva geotermal de Momotombo.

DEEP BORE HOLE TEST
SOUTH VOLCAN MOMOTOMBO AREA

INTRODUCTION

Following the completion of the other methods of investigations described in the final report on Stage I of the Nicaragua Geothermal Resources Project, it was deemed important to supplement these investigations by drilling a deep test hole at the South Volcan Momotombo Area. The purpose of this hole was to determine if the base temperature exceeded 200° C - a critical parameter in evaluating the economic potential of a steam reservoir (Bodvarsson, 1970). Although the Mayhew 1500 drill was only marginally adequate for this task, and auxillary equipment such as water and mud pumps, cementing equipment, etc., was not designed for deep holes, it was decided that an attempt should be made to drill a hole to about 2000 feet.

The Momotombo area was selected over the San Jacinto-Tisate area on the basis of geological and geophysical data presented in other parts of this report, which indicated Momotombo to have greater geothermal potential. The deep test location (figure 1) was selected during a conference between the project staff and the consultants. Geological and geophysical data were considered, as well as access and a ready supply of lake water for drilling and cooling the hole.

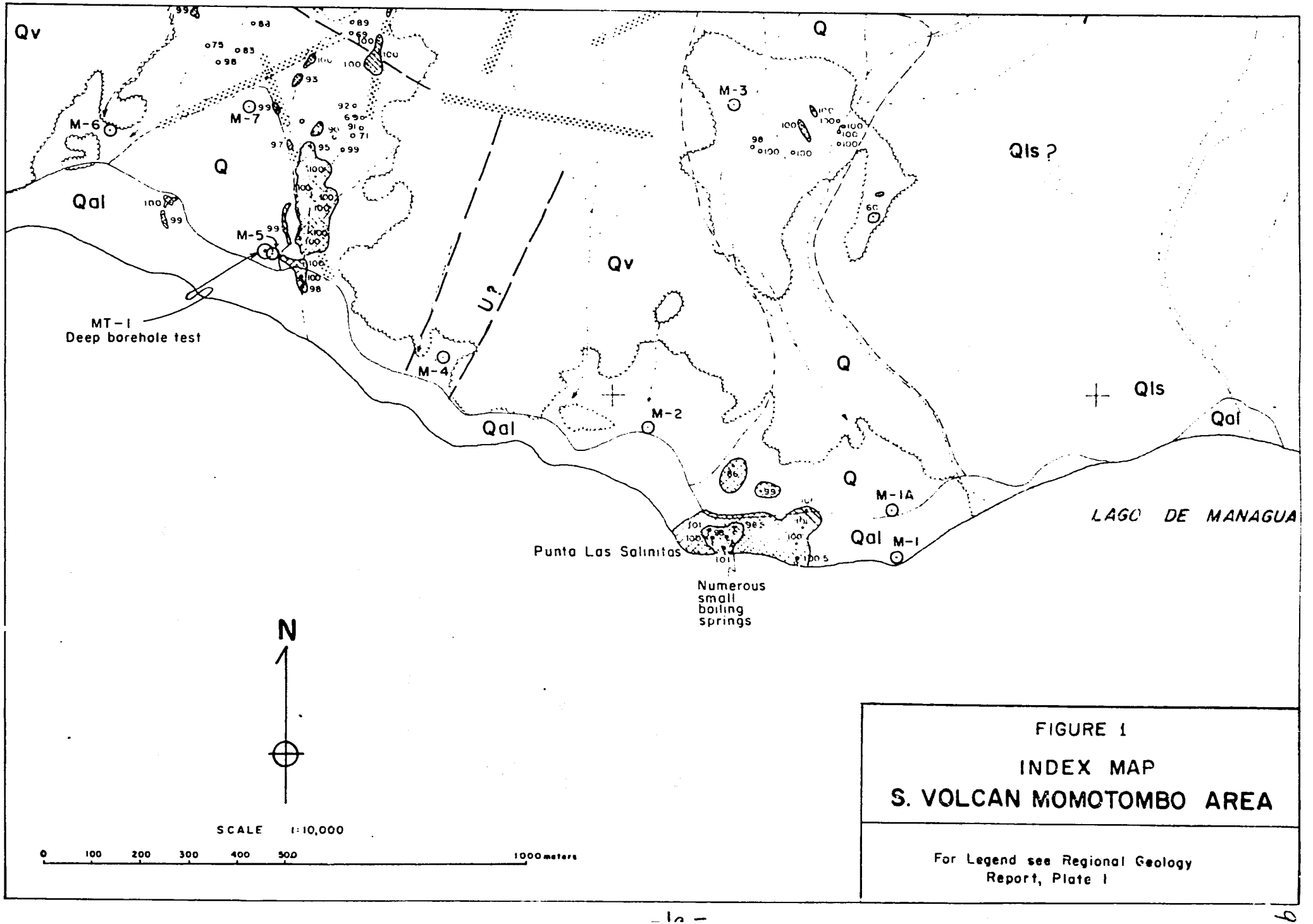


FIGURE 1

INDEX MAP

S. VOLCAN MOMOTOMBO AREA

For Legend see Regional Geology Report, Plate 1

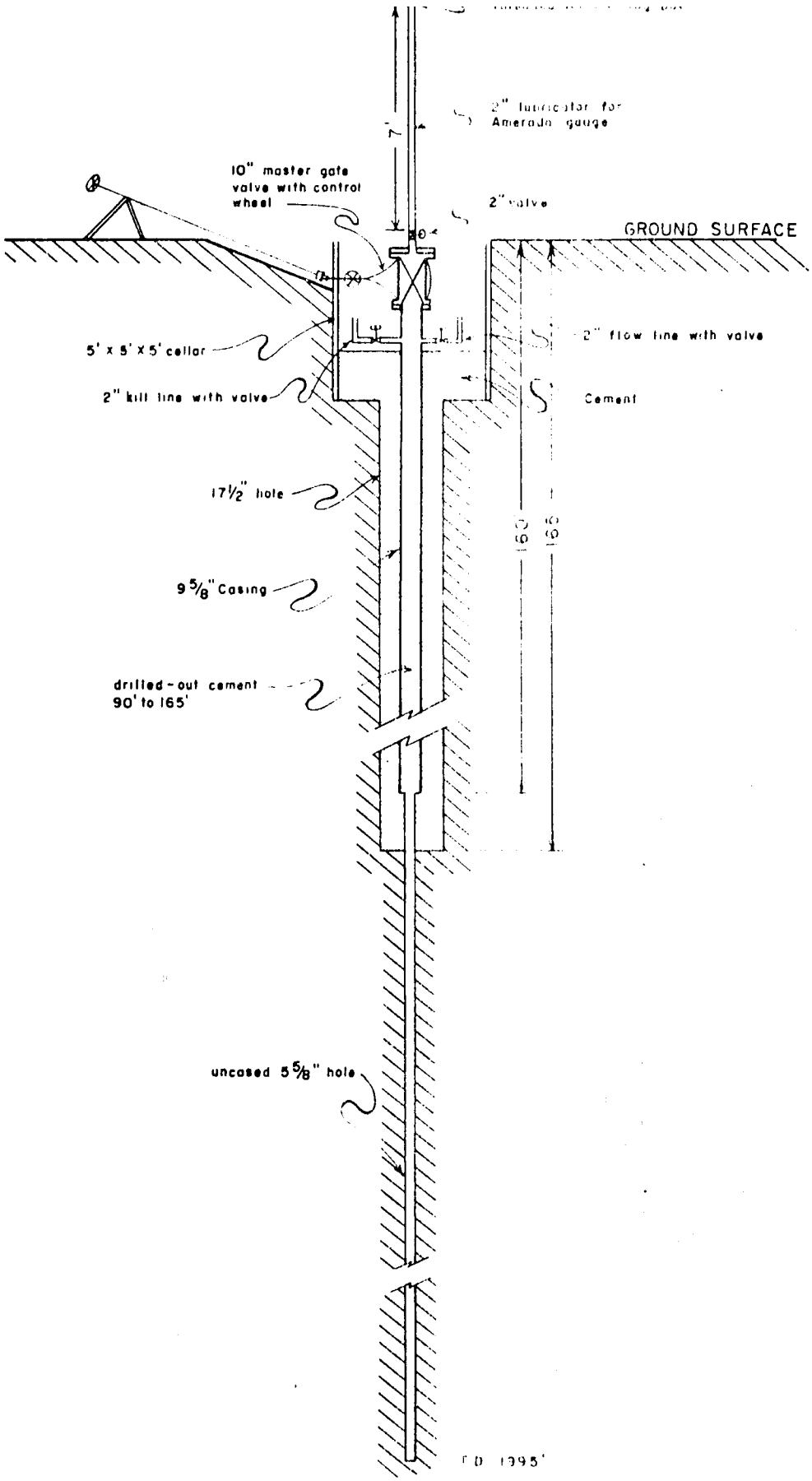
DRILLING

Tentative plans for the hole called for successive strings of 13-3/8 inch, 9-5/8 inch, and 6-7/8 inch casing in 17-1/2 inch, 12-1/4 inch, and 8-1/2 inch holes respectively, with the lower portion of the hole to be uncased and 5-5/8 inch diameter. Execution of this plan depended upon the ability of the Mayhew 1500 rig to drill a large diameter hole in hard rocks. Drilling was started with a 17-1/2 inch hole on 2 November 1970. Penetration with 17-1/2 inch bits was very slow, about 0.5 to 8 ft/hr in interlayered lava flows and pyroclastics. A depth of 165 feet was reached with the 17-1/2 inch hole on 21 November 1970.

An independent drilling engineer consultant, P. J. Moore, with extensive drilling experience, including steam drilling in El Salvador, arrived to assist operations on 25 November. Subsequent operations were guided by his advice.

Very slow drilling rates were obtained with the large diameter hole. Because of limited time and funds as well as penetration of several competent lava flows for anchoring of surface casing, the decision was made to install only the 9-5/8 inch casing and to drill ahead with a 5-5/8 inch bit. This size of hole was adequate for temperature measurements (see figure 2).

The 9-5/8 inch casing was set to 160 feet depth and cemented on 26 November. The cellar and well-head assembly, consisting of a 10 inch gate valve and two 2 inch connections to the casing below the main valve for use as flow and kill lines, was completed on 27-28 November.



DEEP BOREHOLE TEST MT-1
Hole diagram as completed

Figure 2

Drilling with 5-5/8 inch tricone bits started from 165 feet on 28 November, with subsequent highly variable drilling rates of about 7 to 100 ft/hr, averaging about 15 to 25 ft/hr (see figure 3), in variably altered tuff and minor lava flows.

Mud return temperatures were maintained in the 44 to 80° C range, averaging 55-65° C, by injection of cold water when necessary.

An important lost circulation zone was encountered at 540-650 feet, with other minor lost circulation zones. Overall circulation losses during drilling probably averaged about 20 percent.

The hole was completed at a depth of 1995 feet, 5 feet short of the planned total depth, at 0200 hours 4 December 1970. At this depth three twenty-foot drill collars and the bit wobbled off and were abandoned in the hole.

RESULTS

Thermal Activity

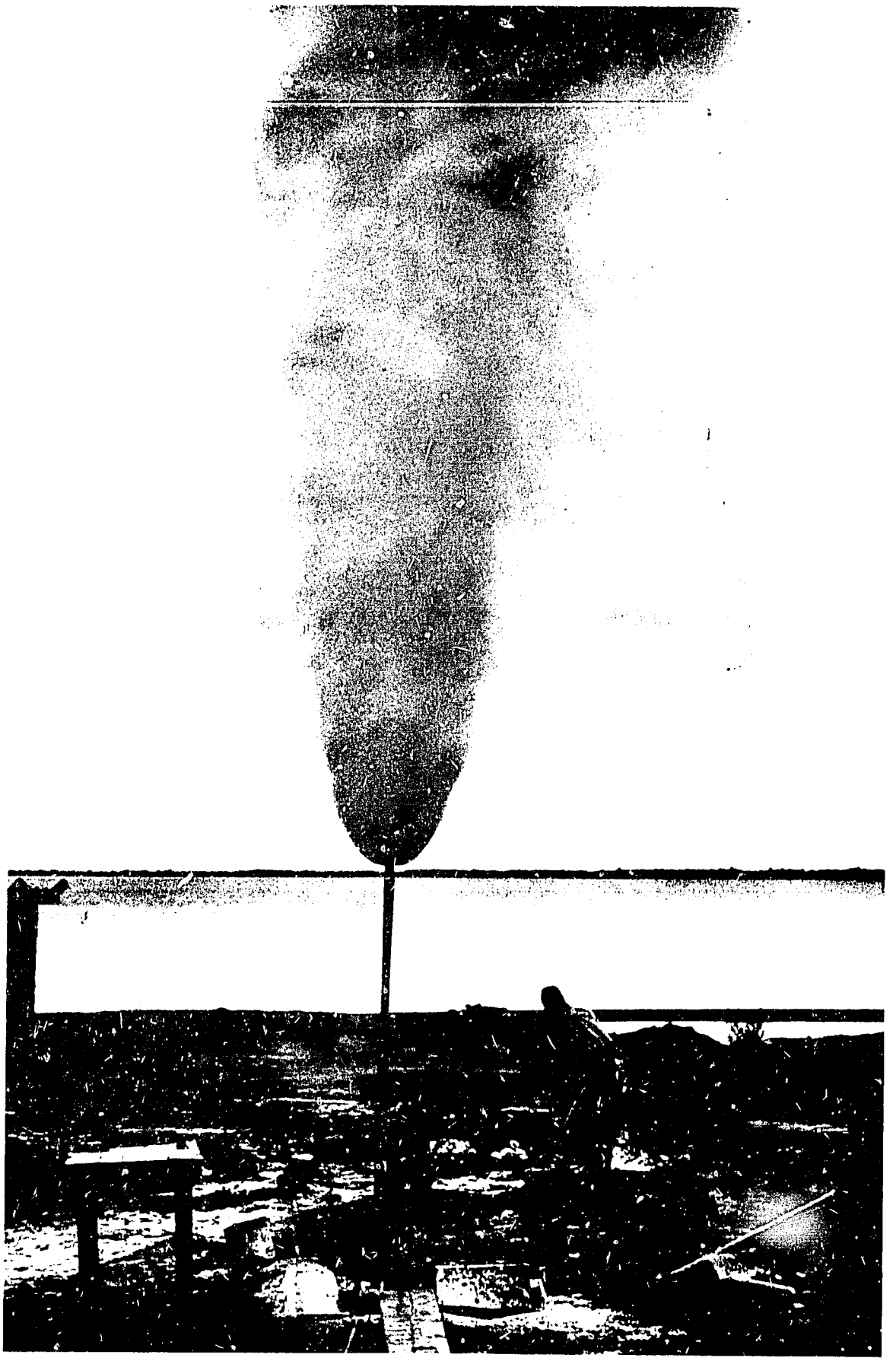
The hole was left open until it erupted violently through the 9-5/8 inch casing at 1255 hours 4 December 1970, 11 hours after completion of the hole. The eruption of water, steam, and mud plus small blocks of altered rock continued for 20 minutes until the master valve was closed. Initially, the eruption column was muddy but it had practically cleaned-up by the time the valve was closed.

The hole was allowed to erupt through a two inch pipe for a few minutes at about 1000 hours 5 December. At 1630 hours 5 December the hole was again allowed to erupt through a horizontal two inch pipe for 10 minutes. When the valve was opened, first compressed air, then steam and water, and then within seconds, steam with minor water, visible as a dense, white plume of condensed water vapor, with no water run-off, blew out of the pipe under high pressure.

During these eruptions through the two inch pipe, some problems were encountered with groundwater boiling around the outside of the casing, due to heating caused by the high heat transfer in the hole during an eruption. The additional heat from the flowing well heated the surrounding groundwater, which was already very near the boiling point in its natural condition, and caused a minor eruption of boiling water and steam in the cellar around the outside of the casing. This activity gradually ceased each time the hole was shut-in. Partially filling the cellar with cement stopped most of this activity and made the well more accessible during an eruption.

The boiling groundwater problem at this hole indicates that the sites of future deep holes must be stabilized by extensive grouting in the vicinity of the hole. The solution of the problem at this particular hole is further discussed in the testing section of this report.

The hole was again allowed to erupt through a vertical two inch pipe for 11 minutes at 1230 hours 13 December 1970 in an attempt to dislodge a cave-in zone at 725 feet depth. This eruption also consisted of mostly steam, visible as a dense, white



Deep borehole MT-1 erupting from 2 inch pipe 13 Dec. 1970.

.....

Erupcion del pozo profundo MT-1 desde tubo de 2 pulgadas 13 Dec. 1970.

plume of condensed water vapor, with no water runoff, after a few seconds of blowing compressed air and a steam-water mixture. An interesting phenomenon observed during this eruption was a "belling" effect of the erupted steam-water mixture immediately above the two inch orifice. The "belling" effect was an abrupt increase in diameter from two inches to about 1-1/2 feet. According to D. E. White (oral communication), this phenomenon indicates admixed water which flashes to steam when pressure is released at the surface. About one to two inches of vertical casing expansion, due to heating during the eruption, was observed. After the well was shut-in, the casing gradually contracted indicating a good cement bond in the lower part of the hole.

Temperature Measurements

An attempt was made to install a 2000 foot thermister cable into the well before the first eruption. Only 950 feet of cable could be installed due to entanglement of the lower end. The tangles observed when the cable was removed indicate the cable had at least 100 feet of slack in the lower end, and probably did not reach a depth of more than 750 or 800 feet. A maximum temperature of 189° C was measured at a depth of about 600-650 feet. All of these measurements, indicated on figure 3, were made at 1120 hours on 4 December 1970, about 1-1/2 hours before the first eruption.

After a lubricator set-up was installed on the well-head, the Amerada temperature gauge was run on 12 and 13 December 1970, both times encountering a cave-in at 725 feet depth. The measured temperatures gradually increased from about 179° C at 100 feet to 205° -209° C at 725 feet depth, as shown on figure 3.

Lithology

The rock sequence penetrated by the hole is shown on figure 3. The rocks consist of basaltic lava flows and interlayered moderately to intensely altered tuffs from Volcan Momotombo to a depth of 215 feet. Below 215 feet the rocks are primarily tuff with variable, often intense alteration, with a few minor basaltic-andesitic lava flows. These deposits below 215 feet are apparently of pre-Volcan Momotombo origin.

All of the lithologic descriptions are from binocular microscope examination of cutting samples. No cores were taken due to safety problems, since, with available equipment, circulation could not be stopped and the hole allowed to heat up to any large extent during coring trips.

Water Samples

A limited number of water samples were obtained from the well. No drilling

mud return samples were taken due to problems encountered with chemical analysis of similar samples from the gradient wells.

Analyses of the two most significant water samples are in the appendix of this report. No water samples could be obtained from the hole after the first eruption without special equipment, since the hole erupts violently, without free water, as soon as the valve is opened. Samples of the water and steam for chemical analyses, and deeper temperature measurements, are very important for further evaluation of the geothermal power prospects of the area, but additional samples and measurements must await further work on the well as discussed below.

TESTING

Before extensive production tests can be undertaken at MT-1, certain strengthening measures must be taken to overcome the groundwater boiling problem and to insure safety. This work may not be economically feasible, since it may be less expensive to drill a new production-type well. MT-1 has served its purpose of determining deep temperatures and it may be desirable to abandon this hole. If the decision is made to rework MT-1, this work should probably be done as the first part of Stage II :

- Kill the well, with a drill rig and sufficient pump capacity.
- Plug the lower part of the casing.

- Perforate the casing above the plug and perform several squeeze jobs, forcing cement laterally into the formation.
- Some surface grouting may be required.
- Clean the hole out and possibly install a liner, probably with continuous perforations.

The necessity for performing this work prior to testing cannot be over-stressed, since large safety problems are involved. It the decision is made to rework MT-1, it is recommended that MT-1 be tested and sampled for about three to six months before other deep drilling.

CONCLUSIONS

The deep test hole was a success since high temperatures were measured, and a steam well, even if small diameter, was obtained with the first effort.

Temperatures of up to 209° C were measured to a depth of 725 feet. The inability to reach greater depth for temperature measurements was partially compensated by the fact that the hole does erupt steam under high pressure.

The hole must be strengthened somewhat before extensive production tests can be undertaken. This is a consequence of drilling the hole only as a temperature measurement hole with available marginal drilling equipment. These production tests and samples are very important for further evaluation of the geothermal power possibilities of the area.

REFERENCE

Bodvarsson, Gunnar, 1970, Evaluation of geothermal prospects and the objectives of geothermal exploration: Geoexploration, Vol. 8, pp. 7-17.

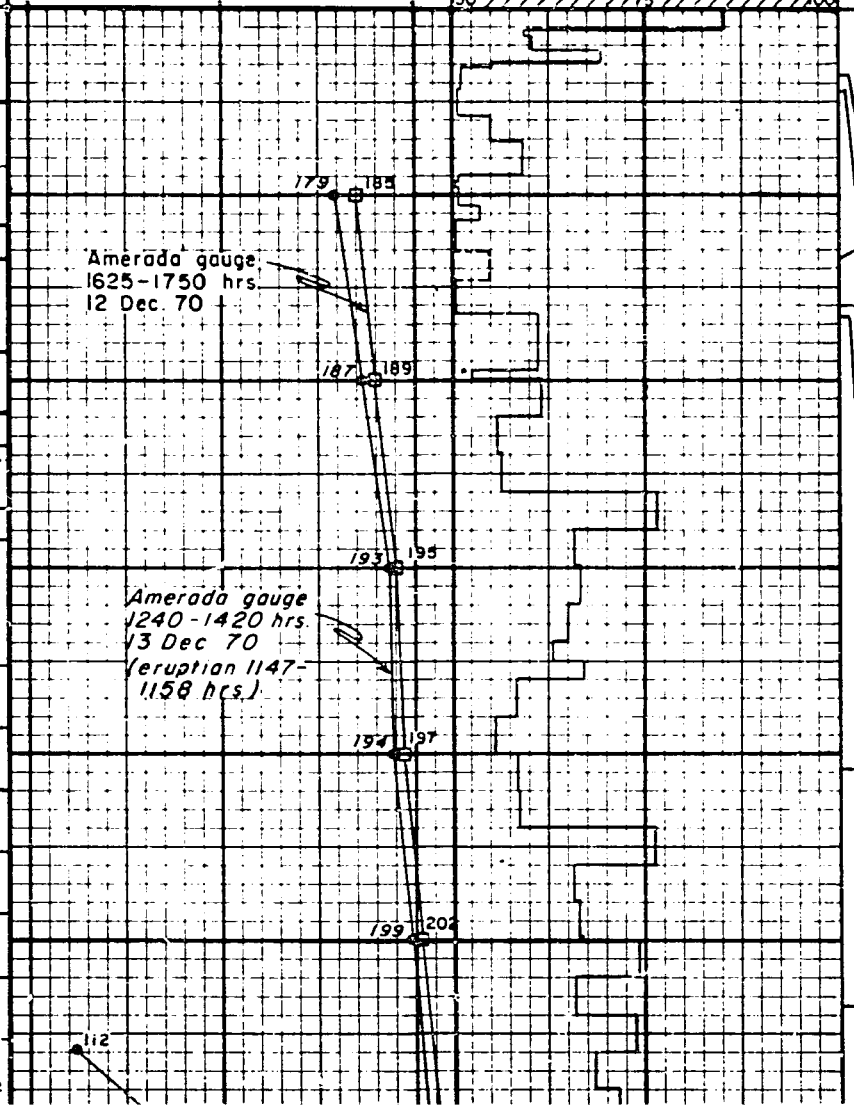
A P E N D I C E

A P P E N D I X

DEEP BOREHOLE TEST MT-I

SOUTH VOLCAN MOMOTOMBO FUMAROLE AREA

DEPTH (feet)	LITHOLOGY DESCRIPTION	COMMENTS
	PYROCLASTICS: mainly cinders, brown to red-brown, mod. - intense alt., some clay, poorly consolidated.	Spudded w/17-1/2" step-bit 2 Nov. 70, Mayhew 1500 drill rig.
	TUFF: green, mod. - intense alt., soft to mod. hard.	Bit 2, 17-1/2 step-bit 36'
100	lt. gray, - intense - very intense alt considerable argil., minor zeolites.	Bit 3, 17-1/2 HI tri-cone at 44'
	BASALT: dk. green-gray, slight alter.	No circulation 135-150
	TUFF: lt. med. gray w/red-brown, very intense alt., considerable argil., minor pyrite and heulandite-analcite.	9-5/8 casing in 17-1/2" hole
200	BASALT: dk. gray w/red-brown, fresh - mod. altered, hard.	Uncased 5-5/8" hole to TD Bit 4, 5-5/8" OWC at 165
	TUFF: med. gray, sli. - mod. alt.	
	mod. gray to blue-gray w/yellow, mod.-intense alt., minor heulandite.	
	green to red-gray, sli. alt., cse.	
300	lt. gray with green-gray and red-brown, intense-very intense alt., numerous zeolites (heulandite?), some silic. and argil., minor pyrite.	
	med. gray to green-gray w/red-gray, slight alt., minor heulandite.	
400	lt. gray and blue-gray, mod. - inten. alt., minor zeolites and pyrite.	
	lt. - med. gray, mod. alt., slight - inten. silic.	Mud return temperature increased to 80°C, circulated cold water to decrease temp.
	lt. - med. gray, mod. - intense alt., minor silic. and argil.	
500	med. gray, sli. - mod. alt., mod. - inten. silic., minor pyrite.	
	lt. - med. gray w/yellow-gray, mod. - intense alt., mod. argil.	
	lt. gray, intense - very intense alt., intense argil., sparse zeolites-pyrite	No circulation 535-660



600

ANDESITE: dk. gray to green-gray, sli. alt., hard.

700

TUFF: med. gray, sli. - mod. alt., cse.

lt. gray w/green-gray and red-brown, mod. - very intense alt., intense argil., mod. silic., sparse to locally abundant pyrite, variable zeolites -- mostly heulandite, sparse carbonates, chlorite, and gypsum (?).

800

lt.- med. gray w/red-brown, mod. - intense alt., mod. silic., abundant qtz. and pyrite, mincr zeolites and carbonate.

900

1000

red-brown to maroon-gray, mod.-intense alt., mod. argil., minor silic., sparse dissem. hematite and carbonate.

med. gray to green-gray w/red-brown, mod. -intense alt., minor silic., minor pyrite, analcite, and carbonate.

1100

BASALT-ANDESITE: dk. gray, sli. alt.

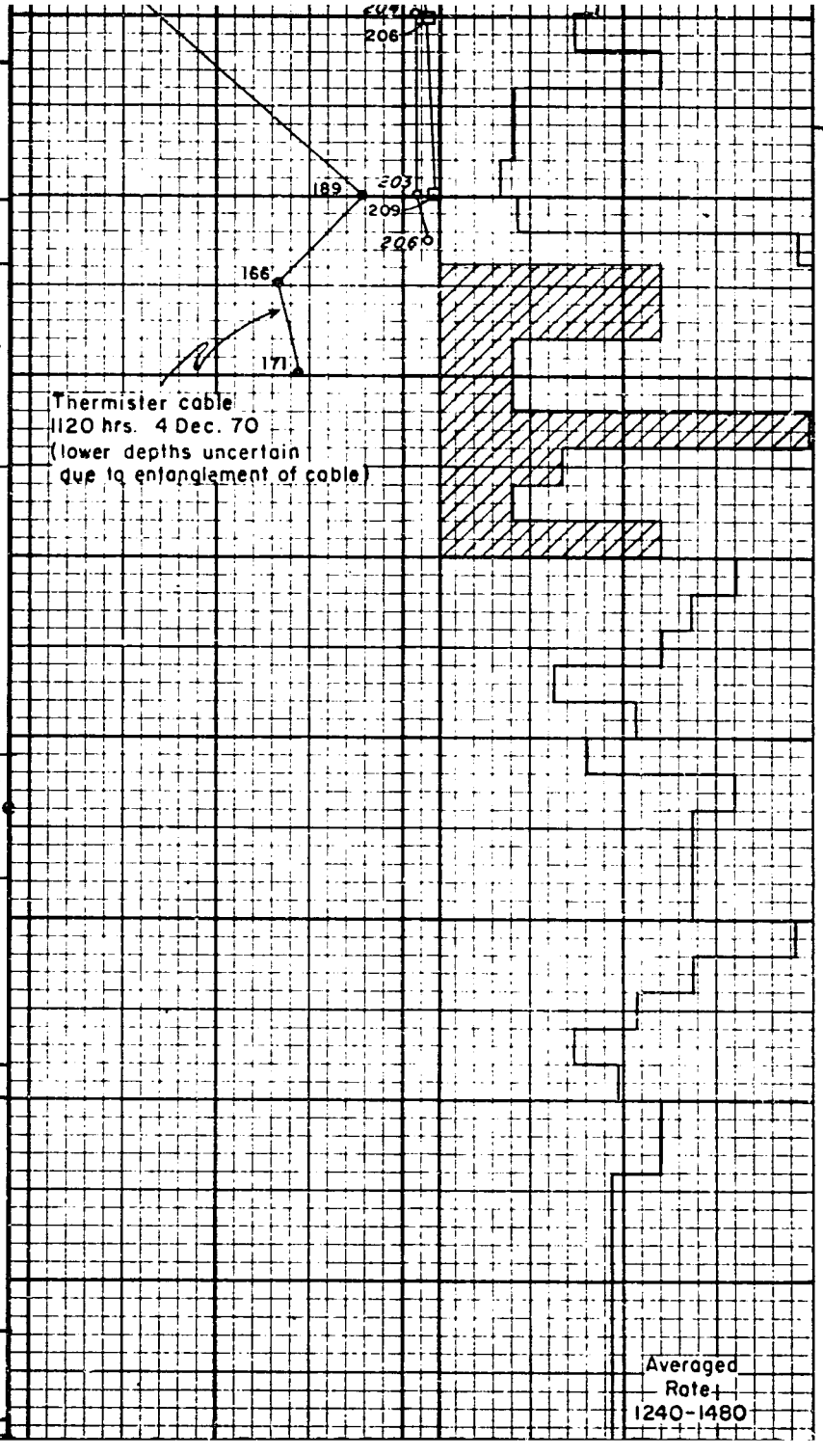
1200

TUFF: lt. gray, red-gray w/green-gray, mod. -intense alt., intense argil., minor silic., minor qtz., chlorite, analcite, and carbonate.

1300

BASALT: dk. green-gray, sli. alt., w/ poss. alt. tuff layers.

TUFF: green-gray, sli. -mod. alt., minor



Bit 5, 5-5/8" OWC at 660

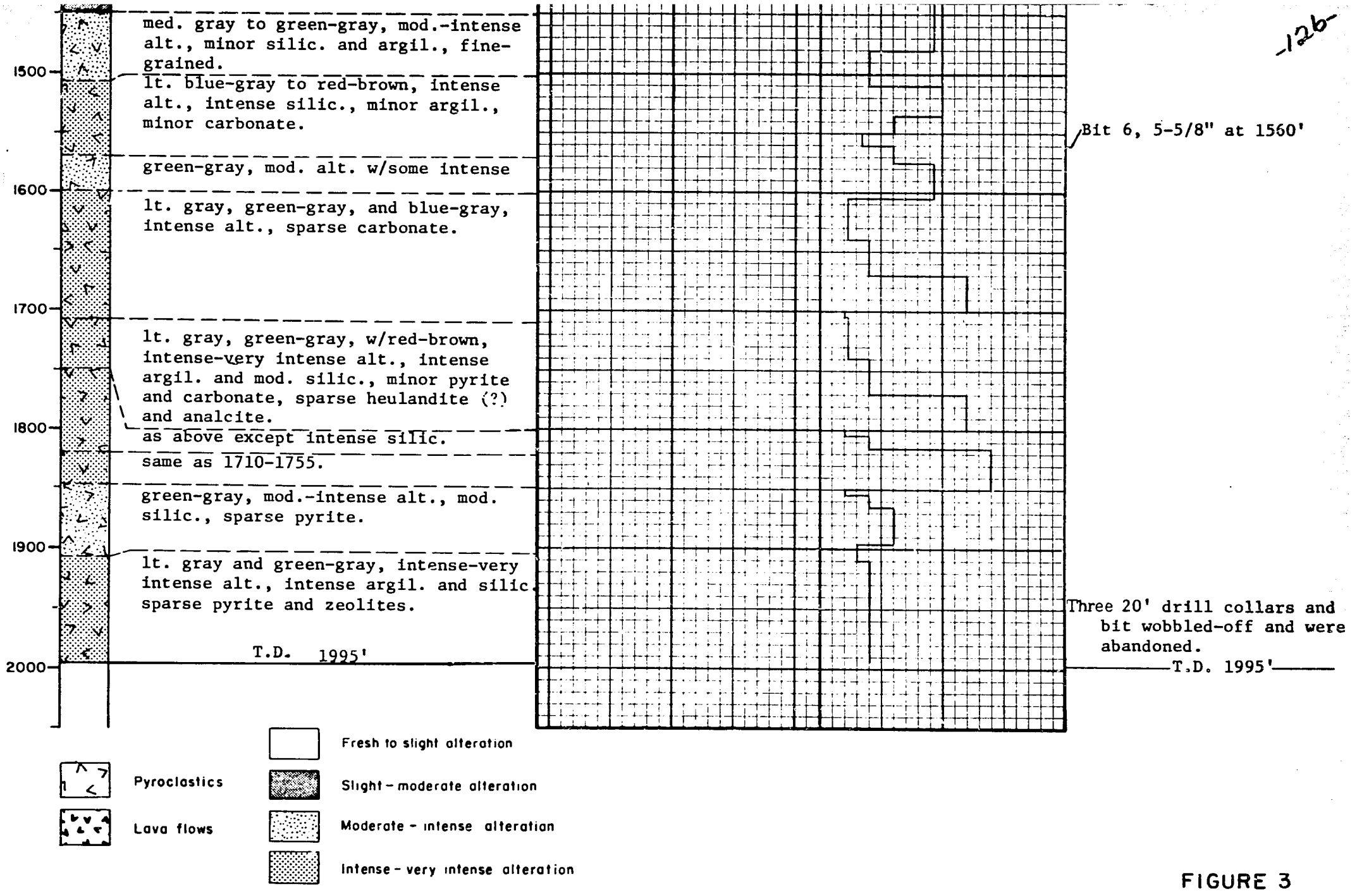

1500
1600
1700
1800
1900
2000
med. gray to green-gray, mod.-intense alt., minor silic. and argil., fine-grained.
lt. blue-gray to red-brown, intense alt., intense silic., minor argil., minor carbonate.
green-gray, mod. alt. w/some intense
lt. gray, green-gray, and blue-gray, intense alt., sparse carbonate.
lt. gray, green-gray, w/red-brown, intense-very intense alt., intense argil. and mod. silic., minor pyrite and carbonate, sparse heulandite (?) and analcite.
as above except intense silic.
same as 1710-1755.
green-gray, mod.-intense alt., mod. silic., sparse pyrite.
lt. gray and green-gray, intense-very intense alt., intense argil. and silic. sparse pyrite and zeolites.
T.D. 1995'
Bit 6, 5-5/8" at 1560'
Three 20' drill collars and bit wobbled-off and were abandoned.
T.D. 1995'
Pyroclastics
Lava flows
Fresh to slight alteration
Slight - moderate alteration
Moderate - intense alteration
Intense - very intense alteration

FIGURE 3

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REPORT OF ANALYSIS

Job No.
January 27

P.O. No.

Geophoto Services, Inc.
P.O. Box 22293
Denver, Colorado 80222

1 Drilling Fluid Sample

:m	Sample No.	Na (mg/l)	K (mg/l)	Cl (mg/l)	SiO_2 (mg/l)	Ca (mg/l)	Mg (mg/l)	CO_3 (mg/l)	HCO_3 (mg/l)
	MT-1--1550	990	160	1,700	210	110	11	<10	540

:m	Sample No.	SO_4 (mg/l)	B (mg/l)	As (mg/l)	Li (mg/l)	PO_4 (mg/l)	TDS (mg/l)	pH
	MT-1--1550	6	12	.4	4.4	3	3,460	7.0

for Edwin V. Post
Charles E. Thompson
Chief Chemist

BEST AVAILABLE DOCUMENT

Sample collected from drilling fluid return with hole at 1550 feet depth.

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REPORT OF ANALYSIS

Job No. 80003
February 10, 1971

Geophoto Services, Inc.
P.O. Box 22293
Denver, Colorado 80222

Part II

1 Drilling Fluid Samples

Item	Sample No.	Colorimetric SiO_2 (mg/l)
1.	MT-1-1550	130

Charles E. Thompson

Analysis of water sample from MT-1, collected from cellar immediately after first eruption 4 Dec. 70.

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Procedencia GEOTERMICA Muestra No. MT-1 No. de Archivo PG-1

Ubicación Pozo profundo Lugar Momotombo Propietario

Profundidad N.E.A. Diámetro Uso

Fecha de toma 4 Dec. 1970 Fecha de análisis 15-1-71

	PPM	m.e.l.	METODO
Temperatura ca 80°C			
Ph 8.2			
Sólidos Disueltos (SD)	2168		
Boro (B)	.20		
Silicio (SiO2)	76		
Dureza Total (DT)			
LITIO (Li)	4.5	.64	
Calcio (Ca)	46	2.30	
Magnesio (Mg)	5	.40	
Sodio (Na)	700	30.43	
Potasio (K)	75	1.92	
		35.69	
Carbonatos (CO3)	6	.20	
Bicarbonatos (CO3H)	92	1.50	
Sulfatos (SO4)	58	1.20	
Cloruros (Cl)	1245	35.06	
Fosfatos (PO4)	.25	T	
Nitratos (NO3)	1.30	.02	
Floruros (F)			
		37.98	
Conduct., micromhmos a 25º	4300		
Relac. Absor. Sodio (SAR)			
Porciento de Sodio % (Na + K)			
Turbidez Agitada			
Turbidez Decantada			
Carácter			
Clasificación			

OBSERVACIONES:

ANALIZADO POR: INFORME ENTREGADO A: