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GEOLOGICAL AND GEOPHYSICAL ANALYSIS OF COSO GEOTHERMAL EXPLORATION HOLE NO. 1 (CGEH-1), COSO HOT SPRINGS KGRA, CALIFORNIA

MASTER

Robert M. Galbraith

May 1978

Work performed under Contract No. EG-78-C-07-1701

EARTH SCIENCE LABORATORY
University of Utah Research Institute
Salt Lake City, Utah

Prepared for
U.S. Department of Energy
Division of Geothermal Energy

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ILLUSTRATIONS

ABSTRACT

The Coso Geothermal Exploration Hole number one (CGEH-1) was drilled in the Coso Hot Springs KGRA, California from September 2 to December 2, 1977. Chip samples were collected at ten foot intervals and extensive geophysical logging surveys were conducted to document the geologic character of the geothermal system as penetrated by CGEH-1. The major rock units encountered include a mafic metamorphic sequence and a leucogranite which intruded the metamorphic rocks. Only weak hydrothermal alteration was noted in these rocks. Drillhole surveys and drilling rate data indicate that the geothermal system is structurally controlled and that the drillhole itself was strongly influenced by structural zones. Water chemistry indicates that this geothermal resource is a hot-water rather than a vapor-dominated system.

Several geophysical logs were employed to characterize the drillhole geology. The natural gamma and neutron porosity logs indicate gross rock type and the accoustic logs indicate fractured rock and potentially permeable zones. A series of temperature logs run as a function of time during and after the completion of drilling were most useful in delineating the zones of maximum heat flux. Convective heat flow and temperatures greater than 350° F appear to occur only along an open fracture system encountered between depths of 1850 and 2775 feet. Temperature logs indicate a negative thermal gradient below 3000 feet.

INTRODUCTION

The Coso Hot Springs KGRA is located on the northwest portion of the China Lake Naval Weapons Center in Inyo County, California (Fig. 1). Coso Geothermal Exploration Hole number one (CGEH-1) was drilled to a total depth of 4824 feet in the Coso Hot Springs KGRA by CER Inc. for the Department of Energy, Division of Geothermal Energy, between September 2 and December 2, 1977. The drilling was undertaken to test the area for recoverable steam or hot water. This report describes the geologic features encountered by the drill hole and geophysical measurements made both during and after drilling.

The drill site is located in the NW 1/4 sec. 6, T. 22S, R. 39E. (Mt. Diablo base line and meridian) on the southwest flank of the Coso Range. Coso Hot Springs, two miles east, and Devil's Kitchen, one mile south of the drill site, are the two most active fumerolic areas in the KGRA. The drill site is roughly centered within a 10 heat flow unit contour (Fig. 2).

GEOLOGIC INTERPRETATION

Geology

The oldest rocks in the Coso area are intermediate to mafic metamorphic rocks occurring as roof pendants and xenoliths in Cretaceous (?) granitic rocks. The basement rocks are partially covered by Pleistocene rhyolite domes, ash fall tuffs, and basalt cinder cones and flows (Duffield and Bacon, 1977; Hulen, 1978). The drill site (Fig. 3) was prepared on unconsolidated ash fall tuff in a topographically closed basin adjacent to outcrops of the metamorphic sequence. The Cretaceous(?) leucogranite outcrops roughly 2000 feet north, and again 4000 feet east and southeast of the drill site. A cluster of rhyolite domes lie 2000 feet west of the drill site and extend to the south and east.

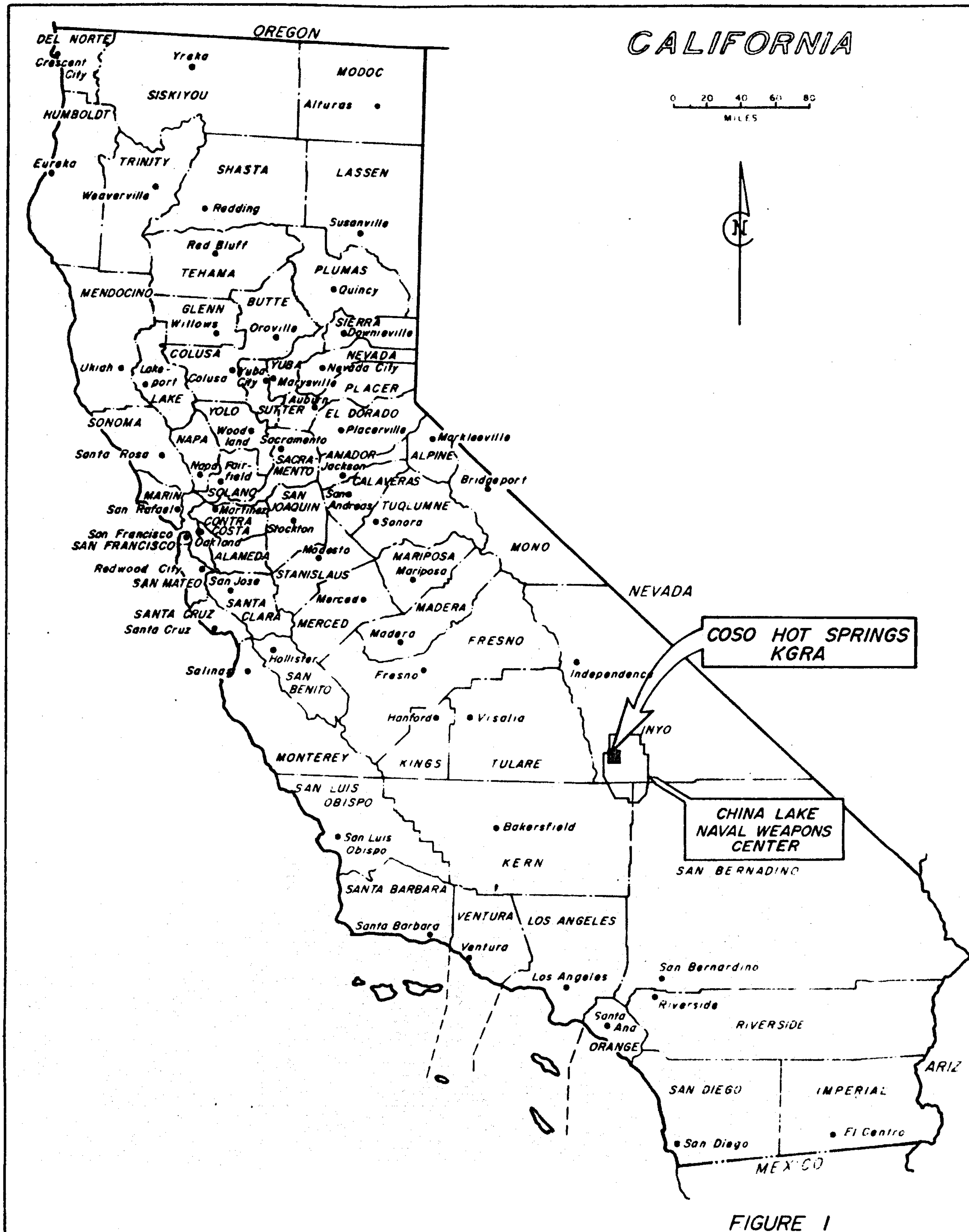
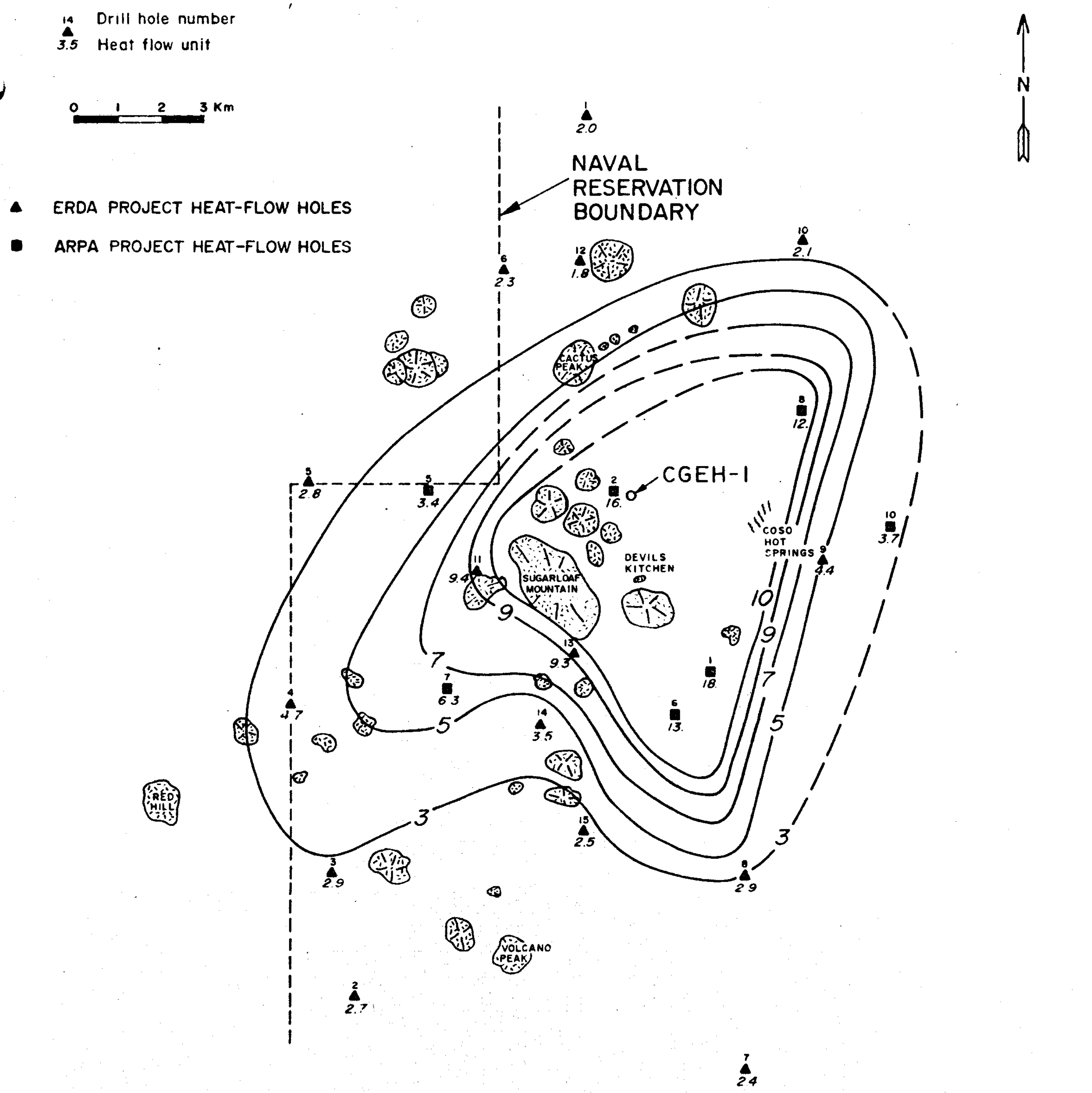


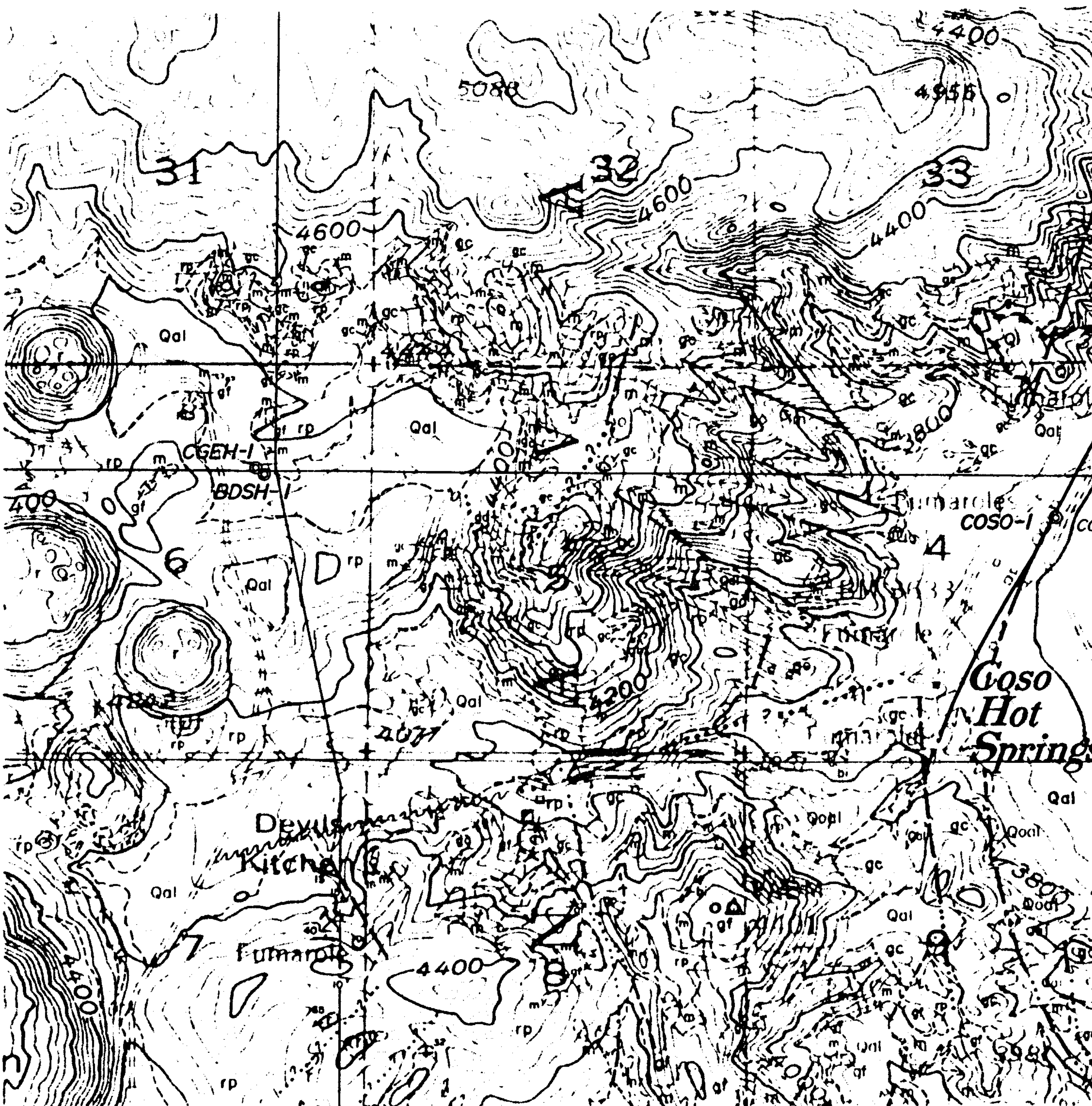
FIGURE I

LOCATION MAP



HEAT FLOW MEASUREMENTS
FROM: OPERATIONS PLAN COSO GEOTHERMAL
EXPLORATORY HOLE Nº 1 (CGEH-1)

Figure 2



after Hulen 1978

Symbol	Explanation
Qal	alluvium
Ql	landslide debris
Qoal	older alluvium
r	rhyolitic volcanic rocks
rp	rhyolitic pyroclastic debris
bi	intrusive basalt
gbx	biotite granite intrusion breccia
gf	fine to med. crystalline granite and quartz monzonite, undifferentiated
gc	coarse crystalline leucocratic biotite granite
m	metamorphic rocks undifferentiated

- contact
- graditional contact
- fault; dashed where approx.
- fault; inferred, concealed
- concealed fault - resistivity
- drill hole
- strike and dip of beds
- strike and dip of flow foliation

N

0 2000 4000 6000 Feet

GEOLOGIC MAP IN THE VICINITY OF DRILL HOLE CGEH-1

Figure 3

Sampling Procedure

Samples were collected from the shaker table by placing a plastic tray below the lip of the shaker screen for roughly 5 minutes. This procedure caught enough material to fill a 12 by 7 inch sample bag. The chips were washed, dried, and split into two 5.5 by 10.5 and one 5 by 7 inch bag. One of the larger bags was delivered to the Navy's Geothermal Resources Division at the China Lake Naval Weapons Center, the other two bags are stored in the Geothermal Sample Library operated by the Earth Science Laboratory on the University of Utah campus. A few tablespoons of material were used for on-site logging and mounting on chip boards. The chip boards are also stored at the Geothermal Sample Library.

An attempt was made to take continuous samples representative of the ten foot interval while drilling the first 600 feet. This proved to be futile and subsequent samples were collected at the ten foot mark. This still resulted in samples containing more than one rock type due to chips mixing in the hole and due to the complexities of these igneous and metamorphic rocks.

Cores were taken four times: from 1680* to 1685, 2197 to 2207, 2973 to 2983 and 4036 to 4039. The short runs were primarily due to the hard fractured rock jamming in the core barrel. Thin sections from the core are indicated on Plate I with the symbol **.

---

* All depth references in this report are to ground level.

Appendix A contains the geologic field log referenced to the kelly bushing which was 21.6 feet above ground level. All other depth references in this report are with respect to ground level. The sample depths shown in the field log are used in this report as sample identification numbers only.

Geologic Log

The rocks of the Coso geothermal area are divided into four groups by Hulen (1978).

1. An older, pre-Late Cretaceous, intermediate to mafic metamorphic sequence.
2. Post-metamorphic quartz latite porphyry and felsite.
3. Late Cretaceous granite complex.
4. Late Cenozoic volcanic rocks, which include the flows and associated pyroclastic deposits of the Coso rhyolite dome field.

Figure 3 is a geologic map of the drill site which illustrates the complexity of the geologic setting. The drill site is on rhyolite pyroclastic debris covering the granite complex which contains numerous large xenoliths of the metamorphic complex. Bedrock under the rhyolite pyroclastics and in outcrop adjacent to the drill site is either a xenolith or a roof pendant. CGEH-1 penetrated units from all four rock groups including a rhyolite dike probably emplaced comtemporaneously with the rhyolite domes 2000 feet east although no such dikes can be mapped on the surface.

The graphic log on Plate I shows the distribution of rock types in CGEH-1, except for the latites which were less than 50% of any sample. Table I gives representative compositions (based on visual estimates) of the metamorphic sequence, latite, leucogranite and rhyolite.

Table I

Representative Compositions of Rock Types

Sample Number	Rock Type	Quartz	Potassium Feldspar	Plogioclase	Honblende	Biotite	Chloite	Sericite	Epidote	Sphene	Apatite	Calcite	Magnetite	Hematite	Pyrite
1480	Latite	17	15	50		15		1					2		
1706 core	Metadiorite			60	30	4	1	3	3	4	4	2	4		Tr
1870	Metadiorite	15	2	60			10	10			2		1		
2227 core	Leucogranite	30	37	30		2							Tr		
2750	Rhyolite	20	70					10							
2997 core	Leucogranite	30	35	30		5							Tr		
4059 core	Metadiorite	15	55	Tr	10	1		3	3		10	Tr		Tr	2

From the surface to 2065 feet CGEH-1 penetrated rocks of the metamorphic sequence cut by several alaskite dikes and minor latites. From 2065 to 4674 feet the lithology is dominantly Cretaceous leucogranite with numerous xenoliths of the metamorphic sequence, while the bottom 150 feet is in metamorphic rock. Alaskites and latites cut the metamorphic intervals but do not appear to cut the leucogranite although surface exposures do indicate that some alaskites are post leucogranite.

Alteration

Only weak hydrothermal alteration was observed in the cuttings from CGEH-1. In the metamorphic sequence hydrothermal alteration occurs in the cores of zoned plagioclase. Typically ten percent or less of the plagioclase grains are altered to sericite + epidote + carbonate. Between samples 820 and 1170, only seven samples with weak to moderate clay alteration were noted in the field log. This interval is the zone of strongest hydrothermal alteration in the hole and appears to be related to a fault. Weak development of chlorite after biotite and chlorite + carbonate + epidote after hornblende is also found throughout the metamorphic rocks. This development is probably due to regional metamorphism and is probably unrelated to the geothermal system.

Hydrothermal alteration in the leucogranite occurs only in the cores of zoned plagioclase grains. Typically less than five percent of any plagioclase grain is altered to sericite + epidote + carbonate.

Chloritization is locally strong in shear zones in the metamorphic sequence and is particularly evident in samples 1540-1560. One inch pebbles were blown out of the hole with several cubic yards of gouge in this interval. These rocks are 80% chlorite and exhibit very strong sheared textures. Similar chips occur in samples 1760-1770, 1810 to 1850, 2090-2100, and 2540.

Carbonate veining is indicated in almost every sample, usually as hair line veins that can only be seen in thin section. Occasionally chips of carbonate material are present from veins greater than one quarter inch across. A carbonate vein appears in the core sample 4059 as an aggregate of carbonate-clay veins where the clay is adjacent to the main mass of carbonate and replaces plagioclase more than orthoclase. Core sample 4060 contains a carbonate vein developed in a shear zone with hematite envelopes developed outside the vein.

Pyrite and hematite occur intermittently throughout CGEH-1. Pyrite, less than one percent, occurs as occasional disseminated fine grains in the metamorphic sequence and appears to be a primary component of the metamorphics. Oxidation of pyrite to limonite by ground water was observed to a depth of about 1000 feet. Hematite occurs along carbonate veins in the metamorphic rocks and is deposited in fractures within quartz grains in the leucogranite. Hematite is most abundant from 2830 to 3190 and 4600 to 4660 feet but never exceeds two or three percent of the rock.

STRUCTURAL INTERPRETATION

Figure 3 indicates that CGEH-1 was sited in an area that has undergone considerable faulting. Faults have been mapped to the east and south, and rhyolite domes have been emplaced to the west and south. The drill site overlies the border zone between two major rock groups. Duffield (1975) described a regional fault system including Pliocene ring fractures, a north-

northeast tensional fault system and a west-northwest trending, possibly left-lateral dip-slip, fault system. Weaver and Walter (in preparation), on the basis of current seismicity, infer a north-northeast fault system which defines a zone of crustal spreading in the Coso KGRA area.

Structural Control of Hole Deviation and Drilling Rate. Figure 4 is a plan view of CGEH-1, essentially a vertical hole influenced by fault and fracture zones so that the bottom of the hole is 351 feet west and 130 feet south of the collar. Stippled intervals on Figure 4 indicate intervals where drilling rates exceeded fifteen feet per hour per eight hour shift. Intervals with cross lines indicate the major lost circulation zones. Both high penetration rates and lost circulation zones indicate that the rock is faulted or fractured in these intervals.

Figure 5 shows drilling rates for each eight hour shift. Figure 6 shows drilling rates from 3500 feet to 4824 feet computed from the Totco recorder (such records are not available above 3500 feet). The data in Figure 5 represent an average rate over a larger interval than shown in Figure 6, but they do indicate an average drilling rate of about ten feet per hour. All coring was accomplished at less than two feet per hour and only short runs of three to ten feet were possible due to the fractured nature of the rock. Kakirite chips made up a trace to ten percent of almost every sample indicating that fractures with some movement are intersected throughout the entire hole.

Figure 7 is a conceptual schematic of the interpreted structural control in CGEH-1. The horizontal scale is about ten times the vertical which produces an apparent 60 degree dip on the near vertical west-northwest structural zones.

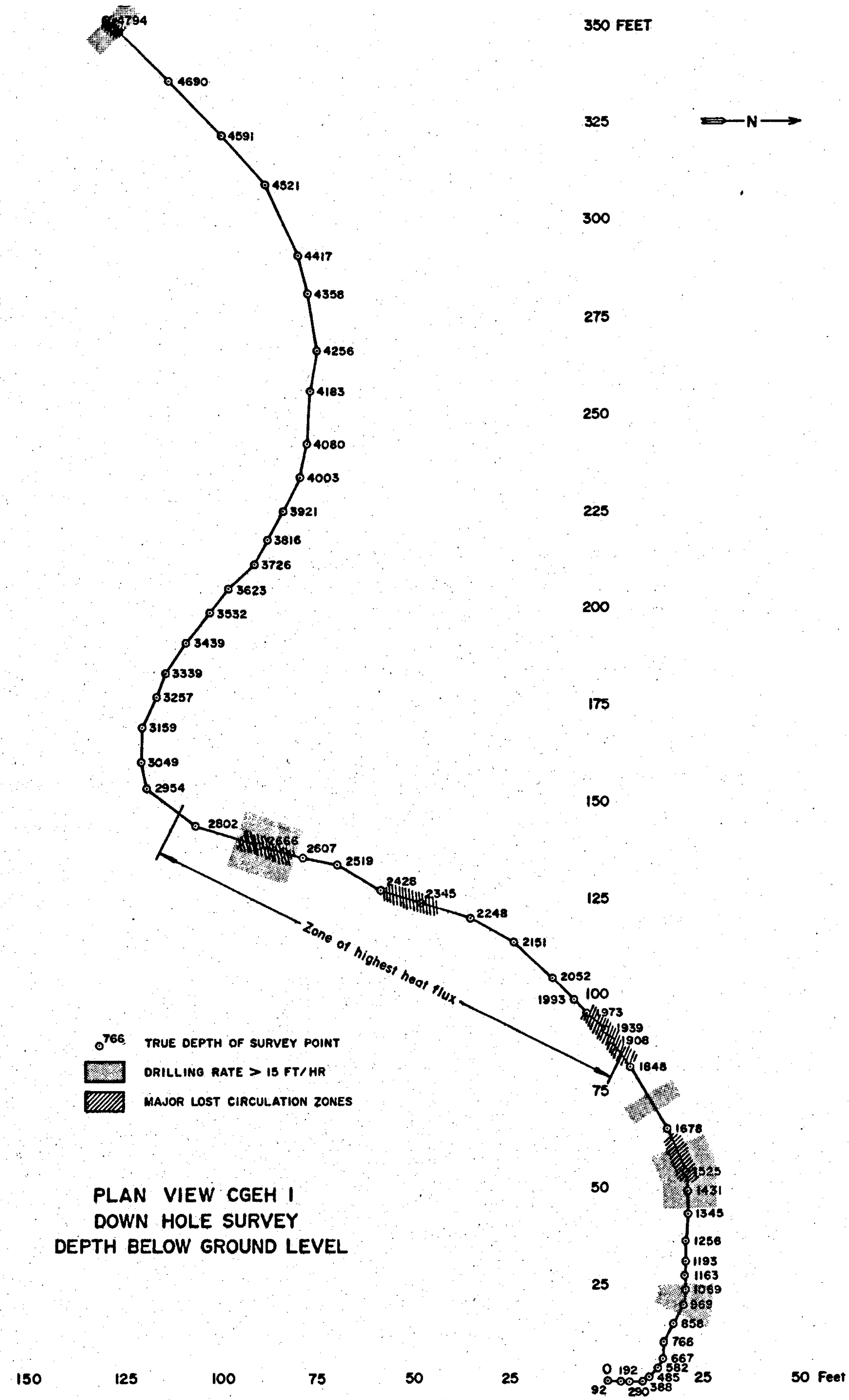
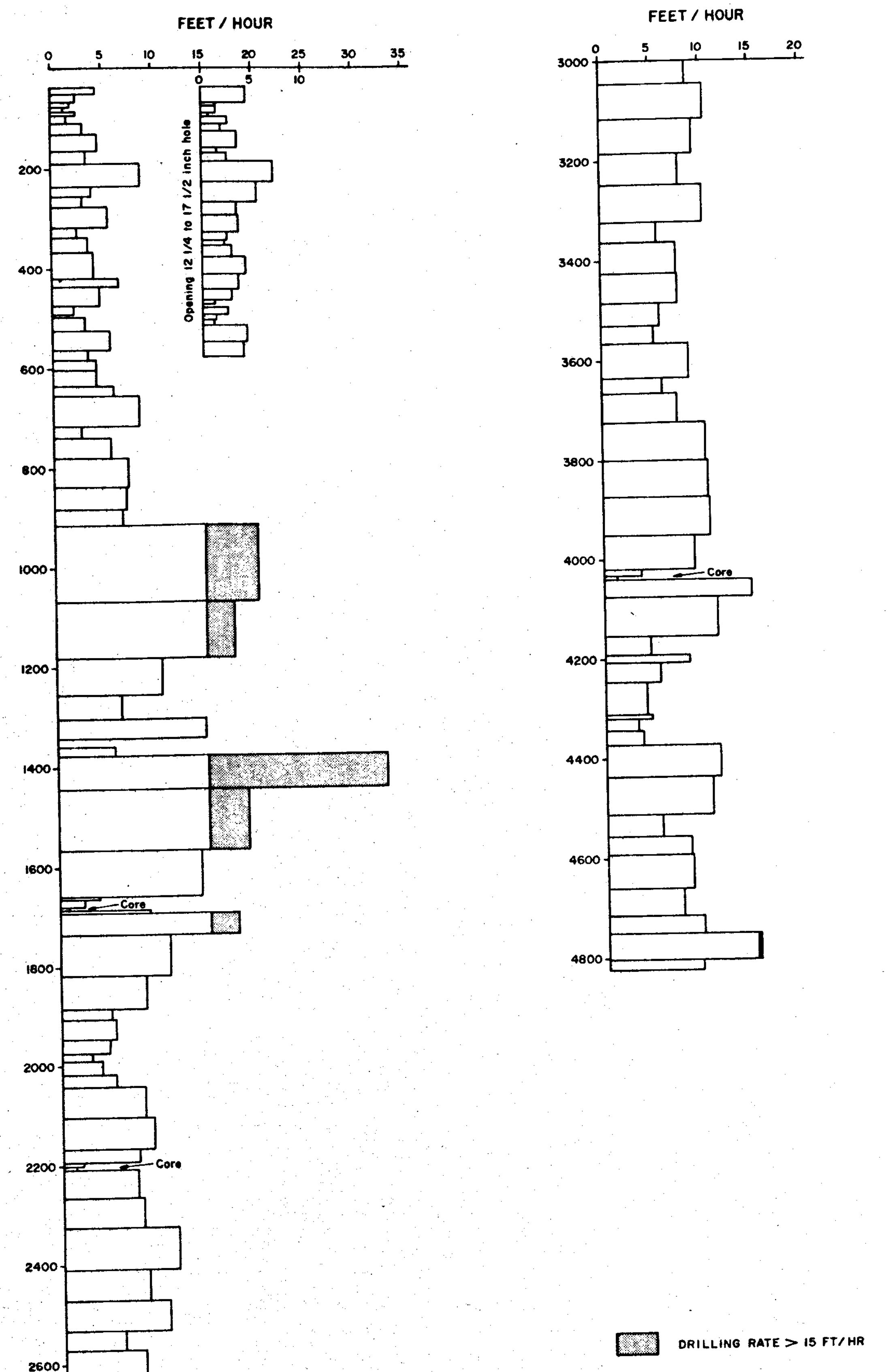
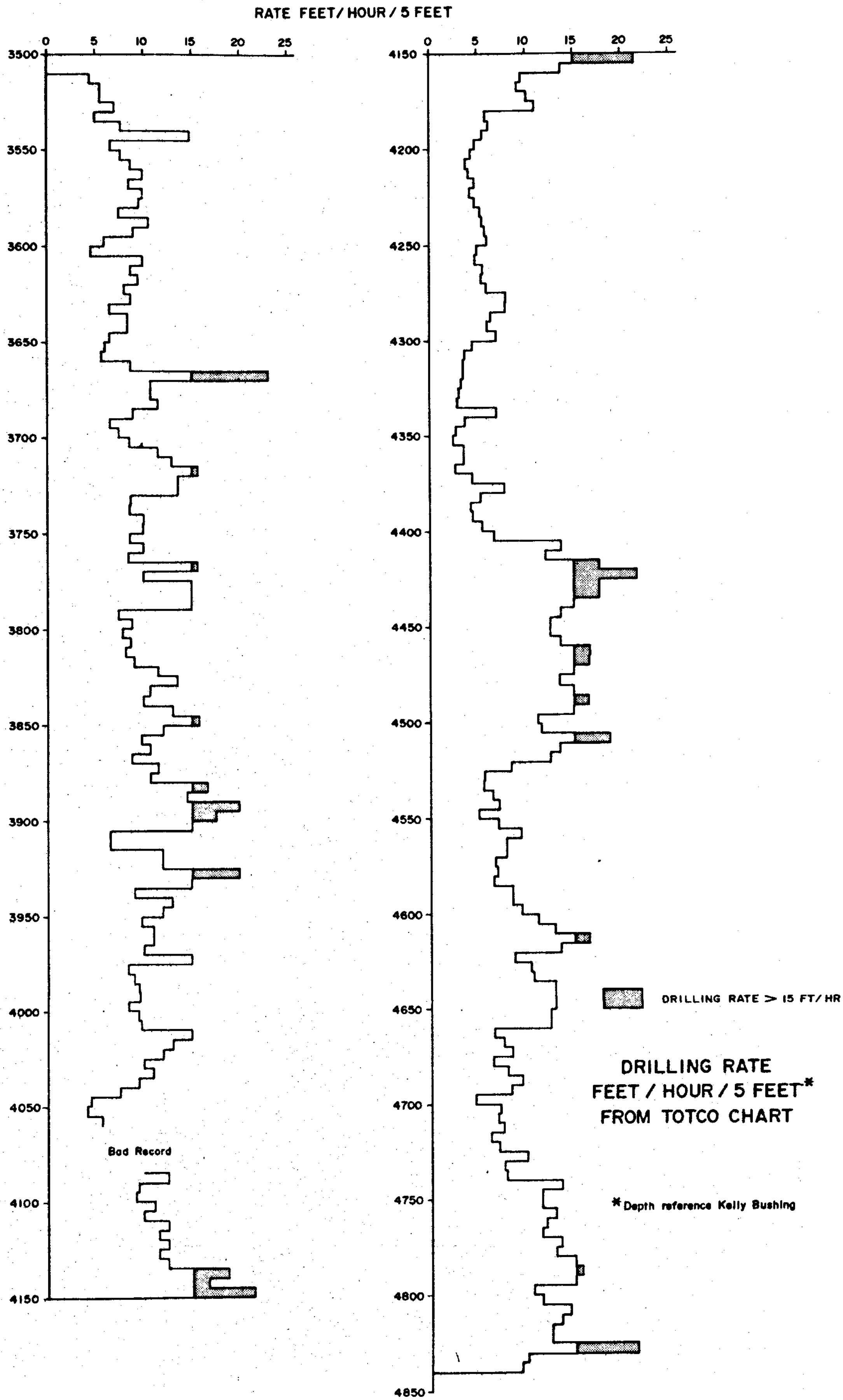

350 FEET
325
300
275
250
225
200
175
150
125
100
75
50
25
N
4794
4690
4591
4521
4417
4356
4256
4183
4080
4003
3921
3816
3726
3623
3532
3439
3339
3257
3159
3049
2954
2802
2666
2607
2519
2428
2345
2248
2151
2052
1993
1973
1939
1908
1848
1678
1525
1431
1345
1256
1193
1163
1069
969
858
766
667
582
485
388
290
192
92
0
150
125
100
75
50
25
25
50 Feet
Zone of highest heat flux
766 TRUE DEPTH OF SURVEY POINT
DRILLING RATE > 15 FT/HR
MAJOR LOST CIRCULATION ZONES
PLAN VIEW CGEH I
DOWN HOLE SURVEY
DEPTH BELOW GROUND LEVEL

Figure 4



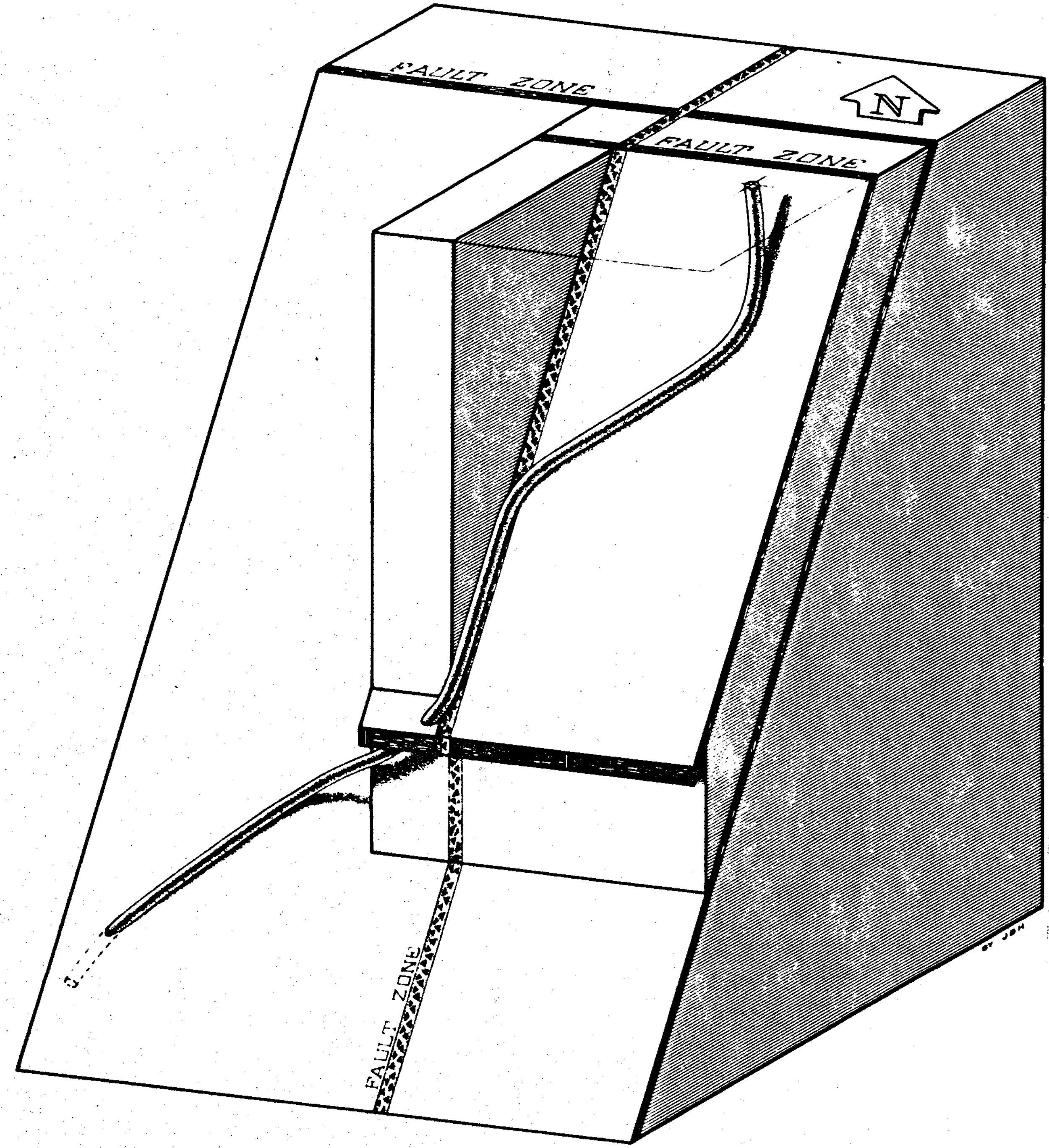
DRILLING RATE
FEET / HOUR / SHIFT
FROM TOWER SHEETS
DEPTH BELOW GROUND LEVEL

Figure 5



RATE FEET/HOUR/5 FEET
0
5
10
15
20
25
3500
3550
3600
3650
3700
3750
3800
3850
3900
3950
4000
4050
Bad Record
4100
4150
4200
4250
4300
4350
4400
4450
4500
4550
4600
4650
4700
4750
4800
4850
DRILLING RATE > 15 FT/HR
DRILLING RATE
FEET / HOUR / 5 FEET*
FROM TOTCO CHART
*Depth reference Kelly Bushing

Figure 6



Conceptual Schematic of the Structural Control of CGEH-1

Open Fracture or Fault System

Tight Fracture or Shear Zone

Vertical scale is approximately 10 times horizontal scale

Figure 7

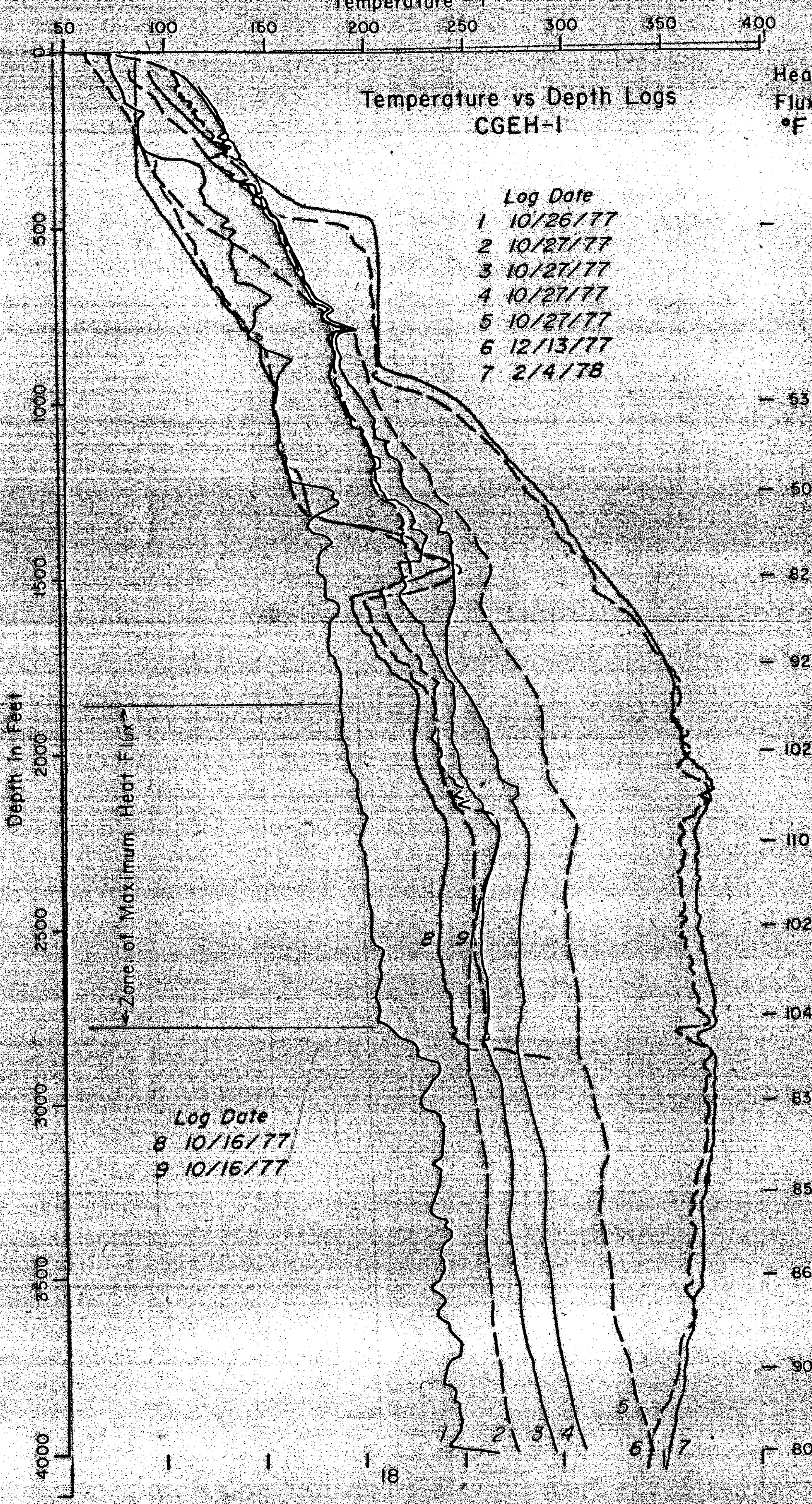
Figures 4 and 7 show that the hole was influenced by the west-northwest striking structural zone at about 500 feet and was deflected along it at about 900 feet. Between 1520 and 2800 feet the drill followed the intersection of the west-northwest trend and a north-northeast open fracture system. From 2800 to 2975 feet the drill bit passed northward through the west-northwest zone and westward through the east-northeast zone. At about 4380 feet the hole was again directed by a component of the west-northwest zone and passed into this zone at 4770 feet. The lost circulation problems which stopped drilling are probably the result of having penetrated this zone. The almost continuous partial loss of fluids from 2800 feet to total depth was most likely due to fracturing of the rock between the two parallel west-northwest zones.

Influence of Structure on drilling and cementing. The faults and fractured rock not only controlled the hole direction but limited the type of drilling procedures that could be used. From 900 to 1547 feet the drill followed the west-northwest structural trend system. Gouge (rock ground to clay size particles) was encountered and recorded in the field log for this interval. The interval from 1515 to 1550 produced several cubic yards of clay gouge with sheared rock fragments up to one inch in diameter. The volume of sloughing material and its high viscosity due to the clay gouge severely inhibited circulation and precluded continued drilling with air. The 1515 to 1550 foot interval was cemented off and air drilling was resumed. Additional gouge was encountered from 1905 to 1935 feet which stopped air drilling a second time. Below 2800 feet the hole was less tightly controlled by fault zones but still encountered many broken rock zones with enough permeability to cause lost circulation problems.

The intensity of fracturing caused several problems and delays in the drilling operation itself. Bit weight was limited and the use of button bits was not practical because of the vibration generated by the intense fracturing encountered in the first 600 feet. More cement was required than the calculated volume when casing was set. Thirteen days were required to set eighteen cement plugs to seal off lost circulation zones before the seven inch casing could be cemented from 3500 feet back to the surface. The actual cement volume used to set the casing exceeded the calculated volume needed by 84%.

The GO International caliper log, Plate II, was run at the start of this 13 day operation. The log indicates minor washouts except from 1515 to 1535 where the hole diameter was greater than thirty-two inches (the limit of the caliper tool). The excess cement used to set the casing went into fractures not filled by the eighteen 100 foot plugs set in an attempt to close off these fractures.

Structural control of the thermal system. Structures also appear to control the convective heat flow system. Figure 8 shows the five temperature logs run at various time intervals in the 50 hours after the hole reached 4000 feet. These logs indicate a 925 foot interval of high thermal flux beginning at 1875 feet. This is the interval where CGEH-1 followed the north-northeast structural trend. A north-northeast trending conductive zone was delineated by the dipole-dipole resistivity survey (Fox, 1978) north of the drill site which may be the same structural zone. This structural system seems to control the convective plumbing system bringing heat up into CGEH-1.



Temperature °F
50
100
150
200
250
300
350
400
Temperature vs Depth Logs
CGEH-1
Heat
Flux
°F
Log Date
1 10/26/77
2 10/27/77
3 10/27/77
4 10/27/77
5 10/27/77
6 12/13/77
7 2/4/78
Depth In Feet
0
500
1000
1500
2000
2500
3000
3500
4000
53
50
82
92
102
110
102
104
83
85
86
90
80
Zone of Maximum Heat Flux
8
9
Log Date
8 10/16/77
9 10/16/77
1
2
3
4
5
6
7

Figure 8

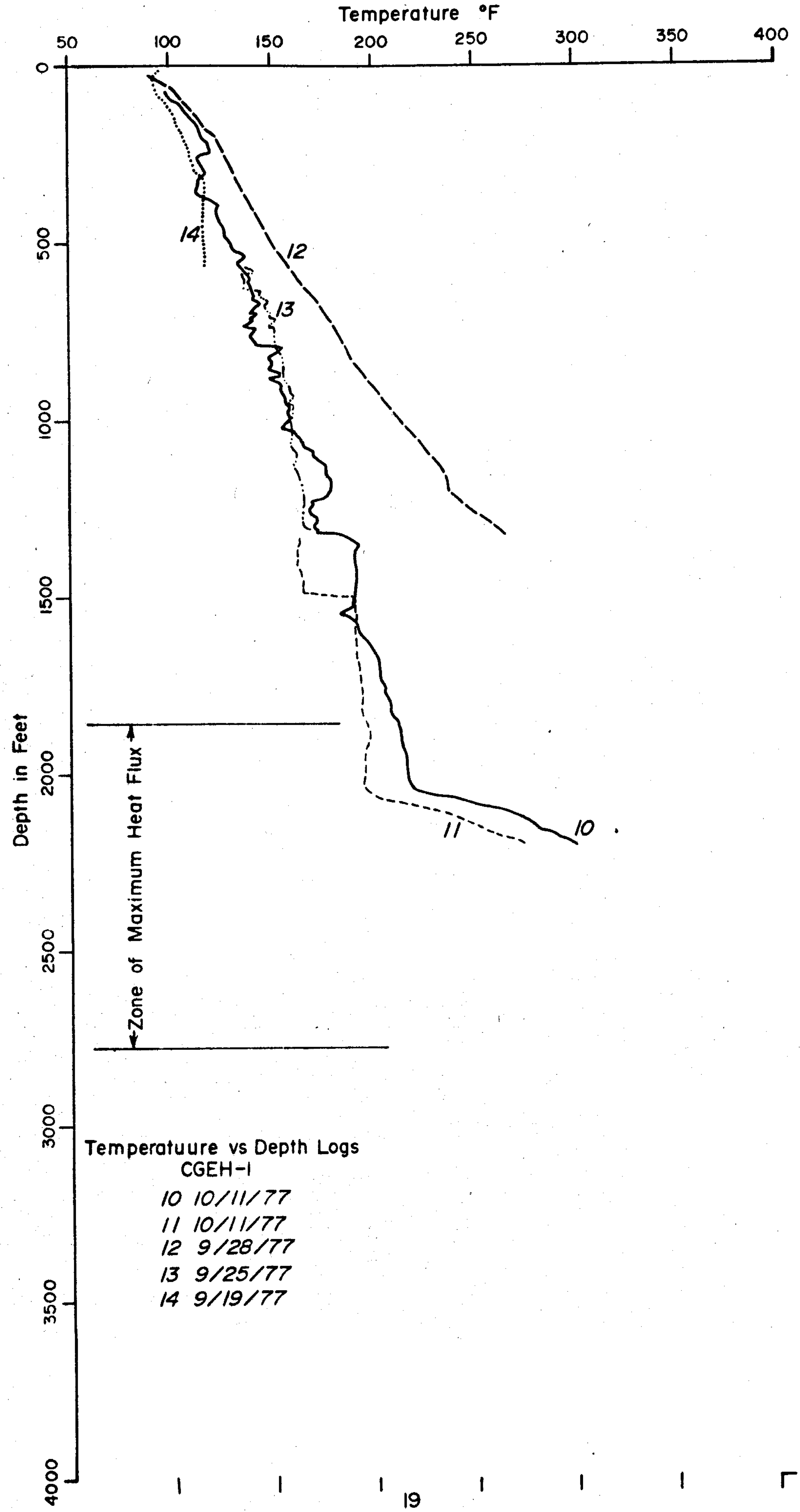

Temperature °F
50
100
150
200
250
300
350
400
0
500
1000
1500
2000
2500
3000
3500
4000
Depth in Feet
14
12
13
10
11
Zone of Maximum Heat Flux
Temperatuure vs Depth Logs
CGEH-1
10 10/11/77
11 10/11/77
12 9/28/77
13 9/25/77
14 9/19/77

Figure 8 b

Temperature logs run since drilling stopped have a negative slope below 2800 feet. This reversal is most pronounced on the log run on December 13, 1977 (Fig. 8a, 7; Pl. I). The open hole below 3488 feet is tapping a relatively cooler regional ground water flow system warmed only by conductive heat flow through the rock. The 60 foot relatively cool interval at 2775 feet adjacent to a small high temperature interval at 2700 feet illustrates the complexity of the fluid and heat flow system penetrated by CGEH-1. The slope of the log run on February 4, 1978 is the same as the December log indicating the hole had recovered in December from any cooling effects due to drilling, thus these logs represent stable conditions in the hole.

These west-northwest and north-northeast structural trends are very important to any future drilling in the Coso KGRA. They have a strong influence on hole direction and penetration rate, and limit the type of drilling methods that may be employed. They also appear to control the locus of high heat flux which would determine future drilling targets. Due to the pyroclastic and alluvial cover in the drill site area, no faults can be mapped on the surface. The subsurface information indicates that the west-northwest structural zone is a strike slip type system as suggested by both Duffield (1975) and Weaver and Walter (1978). The north-northeast system which appears to control the high heat flux convective system is probably part of the tensional system described by both Duffield (1975) and Weaver and Walter (1978).

Fluid System

The top of the local water table and the piezometric head associated with the bottom of the hole can be interpreted from the temperature logs run in December 1977 and February 1978 (Fig. 8a). Figure 9 shows the 50 to 1100 foot

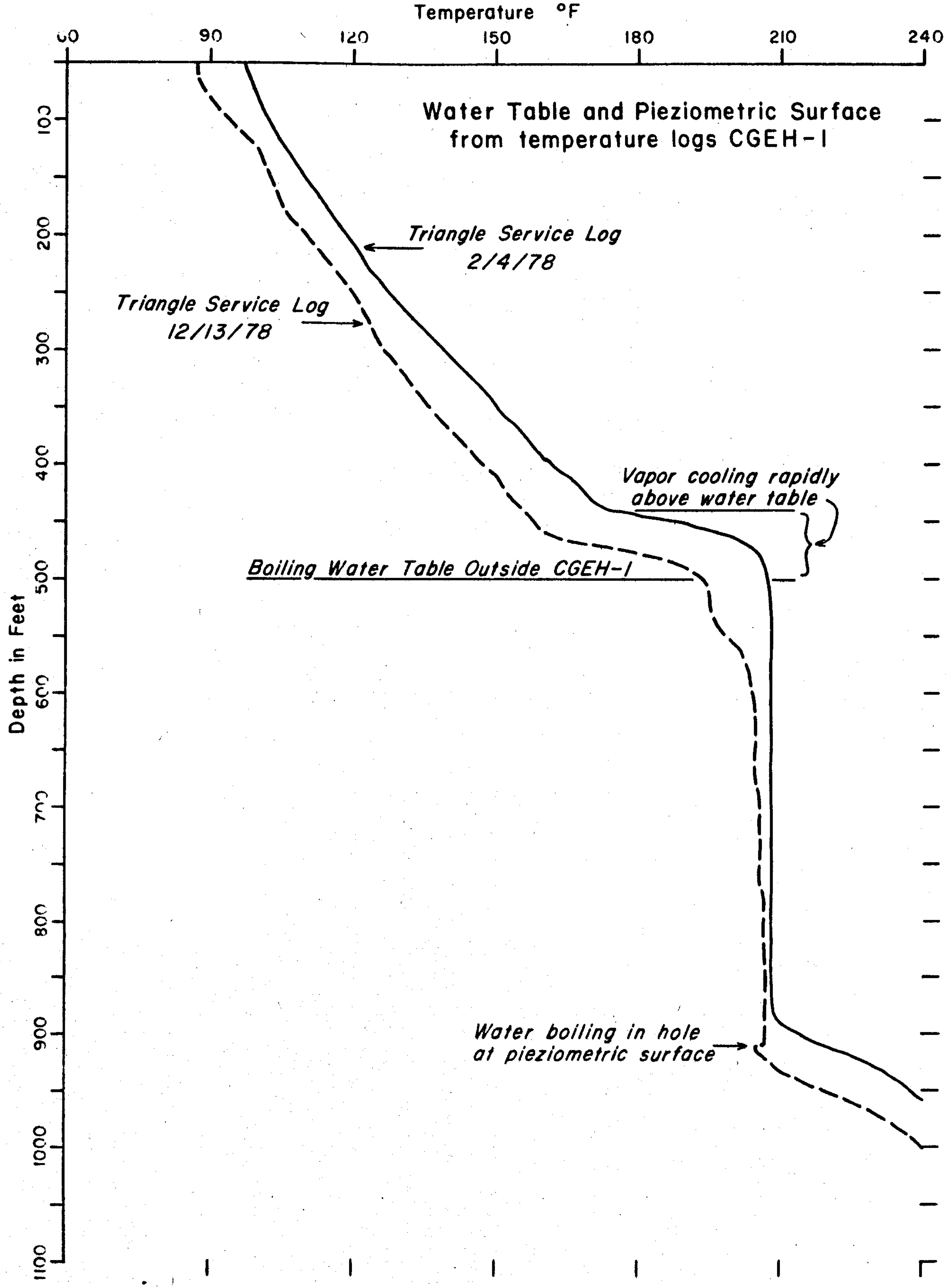

Temperature °F
60
90
120
150
180
210
240
Water Table and Piezometric Surface
from temperature logs CGEH-1
Triangle Service Log
2/4/78
Triangle Service Log
12/13/78
Vapor cooling rapidly
above water table
Boiling Water Table Outside CGEH-1
Water boiling in hole
at piezometric surface
Depth in Feet
100
200
300
400
500
600
700
800
900
1000
1100

Figure 9

interval of these logs. Sharp breaks in slope appear at 500 ±5 feet and at 910 feet. The 910 foot break is clearly the fluid level in the hole which is cased to 3488 feet and open to 4824 feet. The December log (Fig. 8a, 7) has a cooling notch at the water surface where the 205°F temperature is close to the boiling temperature of pure water at that elevation. The break in slope of the temperature curve at 500 feet is interpreted as the top of the water table outside the casing. The constant temperature between 500 and 910 feet indicates the water table surface is boiling, but the rapid temperature decline above this point means the upward heat flux is low. Condensation appears to take place quickly and above 450 feet the rock may be totally dry.

Table II is water chemistry data for samples collected from the 3488 to 4824 foot interval on December 1, 1977 of CGEH-1 as the well was being flow tested, and data published for the 375 foot well drilled at Coso Hot Springs, Coso #1 (Austin and Pringle, 1970). These analyses clearly show that the area is saturated with chloride rich (Cl>50 ppm) water and the geothermal system is water dominated (White, 1973). This is consistent with the resistivity data and the interpretation presented by Fox (1978) which indicate a large area of low near-surface resistivity must, in part, be due to the mineralized water in the area of greatest geothermal activity.

This water-saturated system is boiling at the water table as is seen in CGEH-1, but the rate of heat flux is not high enough or the water table is too deep to cause steaming ground everywhere in the KGRA. Areas like Devil's Kitchen and Coso Hot Springs must be over local channels, such as open fracture systems with high permeability which allow enough heat to reach the surface to develop steam and acid springs. Water samples from these two areas (Table III;

Table II - Water Chemistry CGEH-1 vs COSO-1

	Make up Water	CGEH[3] Sample Interval 3488-4824 Feet, Collected 12/1/77					Coso #1[4]		
		10:45AM	11:00AM	11:15AM	11:30AM	11:45AM			
SiO_2	63.0	710.0[1]	710.0[1]	710.0[1]	710.0[1]	710.0[1]	50.0	27.0	154.0
Ca	100.0	110.0	98.0	99.0	93.0	98.0	72.8	359.0	74.4
Mg	29.8	3.0	2.5	2.3	2.7	2.5	0.5	0.6	1.0
Na	100.0	1600.0	1600.0	1580.0	1590.0	1590.0	1764.0	2808.0	1632.0
K	0.5	122.0	123.0	125.0	126.0	126.0	154.0	172.0	244.0
Li	1.0	9.6	9.7	10.0	10.3	10.0			
Rb	<0.02	0.103	0.105	0.106	0.112	0.118			
Cs	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01			
CO_3[2]								50.4?	77.4?
HCO_3	307.0	150.0	286.0	273.0	297.0	279.0	134.2	0.0	0.0
OH[2]								76.2?	1.7?
SO_4	234.0	314.0	268.0	266.0	257.0	245.0	38.0	216.0	52.8
Cl	81.0	2330.0	2360.0	2420.0	2460.0	2480.0	2790.0	3681.0	3042.0
F	0.1	3.8	3.8	3.8	3.8	4.2	3.7	1.6	2.2
B	0.92	54.0	53.0	54.0	56.0	58.0	48.0	57.4	71.6
PH	7.67	8.14	7.74	8.15	8.14	8.22	8.9	9.8	8.5
TDS	918.0	5410.0	5518.0	5547.0	5610.0	5606.0	5744.0	6894.0	5228.0

1. Silica values include possible colloidal clay dispersed in water.
3. Data source: Fournier, Thompson and Austin, 1978.
4. Data source: Austin and Pringle, 1970.

2. Impossible combination. Transcription error (?) by Lab or by Austin and Pringle.

Table III

Surface Water Analyses

Analysis	Devil's Kitchen Spring 22S/39E 07HS1	Coso Hot Spring Well 60" diam. 3.5' deep 22S/39E 04K2
SiO_2	300.0	200.0
AL	44.0	1.4
Fe	2.8	0.09
Ca	18.0	98.0
My	81	25.0
Na	14.0	81.0
K	28.0	23.0
SO_4	1400.0	530.0
Cl	0.0	6.5
F	0.9	0.8
NO_3	3.0	8.1
B	0.6	0.0
TDS	2260.0	1030.0
Conductivity mmhos/cm	6640.0	1150.0
PH	2.2	4.0
Temp ^{o}C	96.7	25.6

All analyses and sampling by USGS (From Moyle 1977)

Moyle, 1963) appear to indicate a steam dominated resource. As explained by White (1973) such low chloride waters can be derived from high chloride ground water in a geothermal system where boiling occurs at the water table. The Coso KGRA is probably best characterized as a hot water system.

GENERAL GEOPHYSICAL LOG ANALYSIS

Many logs are useful in holes in igneous rocks, but the approach to interpretation is generally quite different than when the logs are run in sedimentary sequences. Bore hole geophysical logs are widely and successfully used in the petroleum and water well industries where development of a successful well is dependent on the porosity, permeability, and saturation of the rocks penetrated by the bore hole. As a result, interpretive methods have logically evolved expressly for sedimentary rocks. Many logs are calibrated against limestone or sandstones and provide reliable estimates of porosity and density for these rock types. Corrections can be applied to these logs to determine porosities or matrix properties of other units in the hole.

Sedimentary rocks are mechanically deposited particulates such as sandstones, shales and some limestone or chemical precipitates like chert, limestone or salt deposits which tend to have little or no porosity or permeability. The rocks at Coso are igneous "precipitates," and recrystallized metamorphic rocks. The metamorphic process of compression and recrystallization has effectively reduced the primary permeability and porosity to zero. Thus the rocks at Coso are analogous to dense chemical precipitate limestones and cherts, and many logs calibrated against a limestone matrix will give the closest approximation of true rock properties. Certain compositional properties of igneous rocks such as orthoclase feldspar and mafic mineral content are measurable by gamma ray and neutron logs to provide lithologic interpretations. Acoustic logs locate fracture zones where secondary porosity and permeability may develop. Induction and SP logs help with lithologic interpretations but will usually be secondary to the radioactive logs.

The common near-vertical orientation of geologic contacts in an igneous or metamorphic sequence further complicates log interpretation. In sedimentary basins contacts are usually near-horizontal unless faulted or folded. At Coso large blocks of metamorphic rock occur within a granite matrix, the complex is highly faulted, and the contacts are often very steep or near-vertical. Thus rock types near the bore hole but not actually cut by it may be "seen" by deep penetrating logs.

The Utility of Various Logs Run in CGEH-1

Gamma Ray The gamma ray tool is passive in that it counts natural radiation without providing any stimulation. Potassium 40 is the main source of gamma ray radiation in common igneous rocks and is found predominantly in potassium feldspar (orthoclase) and potassium mica (sericite/muscovite). Because the two main rock groups at Coso have very pronounced differences in orthoclase content, the gamma ray log is the most useful lithologic tool. The older metamorphic rocks are generally high in mafic minerals and low (<15%) in orthoclase while leucocratic granite has almost no mafics (<5%) and 30-40% orthoclose. Alaskite dikes cut both rocks and have log signatures similar to the leucogranite. The rhyolite is 70% orthoclase and probably has a relatively high uranium and thorium content (Bacon, personal comm.) which results in a much higher gamma ray count than the leucogranite.

Neutron Porosity The neutron log is a measure of hydrogen ion concentration in the rock. High hydrogen ion concentration in porous rocks is interpreted to indicate water or petroleum. Non-porous igneous rocks have water trapped within crystals as well as water along fractures (Nelson and Glenn, 1975). The mafic minerals, biotite and hornblende, contain enough water to affect the neutron log. Thus the metamorphic rocks at Coso show relatively high neutron porosity because of their high mafic content not because of actual porosity. These rocks probably have true porosities of less than one percent.

Acoustic Log Acoustic data can be presented as a full wave picture or as a travel time, Δt, curve where either the time from signal generation to the first P wave arrival is recorded or the time between the first arraivls at two separate receivers is recorded. In fractured igneous rock where signal attenuation is great and the first P wave arrival can not be detected, the full wave sonic log may produce useful qualitative information. In either case strong signal attenuation indicates fractured zones which are possible fluid flow zones.

Caliper Log The caliper log is essential for the correct interpretation of most other logs. Borehole size, particularly washouts or caving, strongly affects the response of most logging tools. For example, note in Plate I the effects washouts have on the SP, neutron and resistivity logs at 1550 and 1950 feet. In these areas of hole enlargement the logging tool responses are dominated by the physical and chemical properties of the drilling mud or borehole fluids.

Induction Log The conductivity (induction resistivity) log often yields the best measure of true rock resistivity where fluid resistivity is not too low and formations are uniform. In an igneous environment resistivity contrasts due to lithologic variations are rare or small. However rock fabric, structure, and variations in metallic mineral content can produce significant apparent resistivity changes. Near-vertical rather than horizontal contacts between rock units further complicates the interpretation. Deeply penetrating induction logs may respond to highly conductive rocks or fluid-filled zones not actually intersected by the bore hole. Several features unrelated to primary rock type may be recorded by the induction log including: fault zones with thick clay gouge, areas where plagioclase feldspars have been hydrothermally altered to clays, and variations in mafic mineral content due to hydrothermal alteration which increases biotite content.

Spontaneous Potential (SP) Spontaneous potentials are usually produced by semipermeable boundaries at shale-sandstone contacts. Cations migrate across the boundary more readily than anions which produces an electrical potential across the boundary. This mechanism is not easily developed in igneous rocks. Units with high chlorite + mica mineral content act somewhat like shales and low chlorite + mica rocks may behave more like limestones. Short intervals of gouge or zones of hydrothermal alteration with high clay content also may behave as shale zones.

The SP, induction, and short normal resistivity logs have a more limited value for lithologic control than the gamma ray and neutron logs in an igneous environment.

Temperature Log The temperature log gives the only direct measurement of the geothermal resource. Interpretation of this log can be the most difficult because the temperature in the hole is influenced by many factors such as the time since the hole was flowing or since circulation has stopped. Temperature logs are most useful when run in a sequence to detect temperature changes in the hole with time. Generally, a hole will be cooled during drilling by the circulation of the drilling fluid. A log run soon after circulation stops will indicate cool zones where the cooling effect is the greatest if the circulating fluid is cooler than the formation water. Subsequent logs run at appropriate time intervals will indicate where heat flux is greatest as the hole recovers from the cooling effect of the drilling process.

Log Interpretation

Plate I is a composite of logs run in CGEH-1. Table IV lists the logging companies and the logs used to make the composite.

The gamma ray and neutron porosity logs have been superimposed in the same field. Generally high neutron porosity coupled with low gamma ray counts indicates mafic rich rocks. Such envelopes have been shaded on the composite and indicate the dark metamorphic complex. Patches of this material are indicated throughout the drill hole; however, metamorphic rocks are dominant above 2065 feet. Zones of low neutron porosity and high natural gamma are silicic igneous rocks. These zones generally delineate the granite pluton below 2065 feet. Above 2065 feet these zones are alaskite dikes. Additional alaskites intersect the leucogranite between 4450 and 4530 feet.

An anomalous high potassium, high neutron porosity zone occurs between 2692 and 2760 feet. The acoustic log (Plate II) indicates this is a zone of intense fracturing and a zone of significant hole caving as indicated in the caliper log. This zone has a gamma ray count in excess of 200 API units which is indicative of a potassium rich rock, or possibly minor uranium and thorium. The

Table IV

Geophysical Logs used to compile Plate I

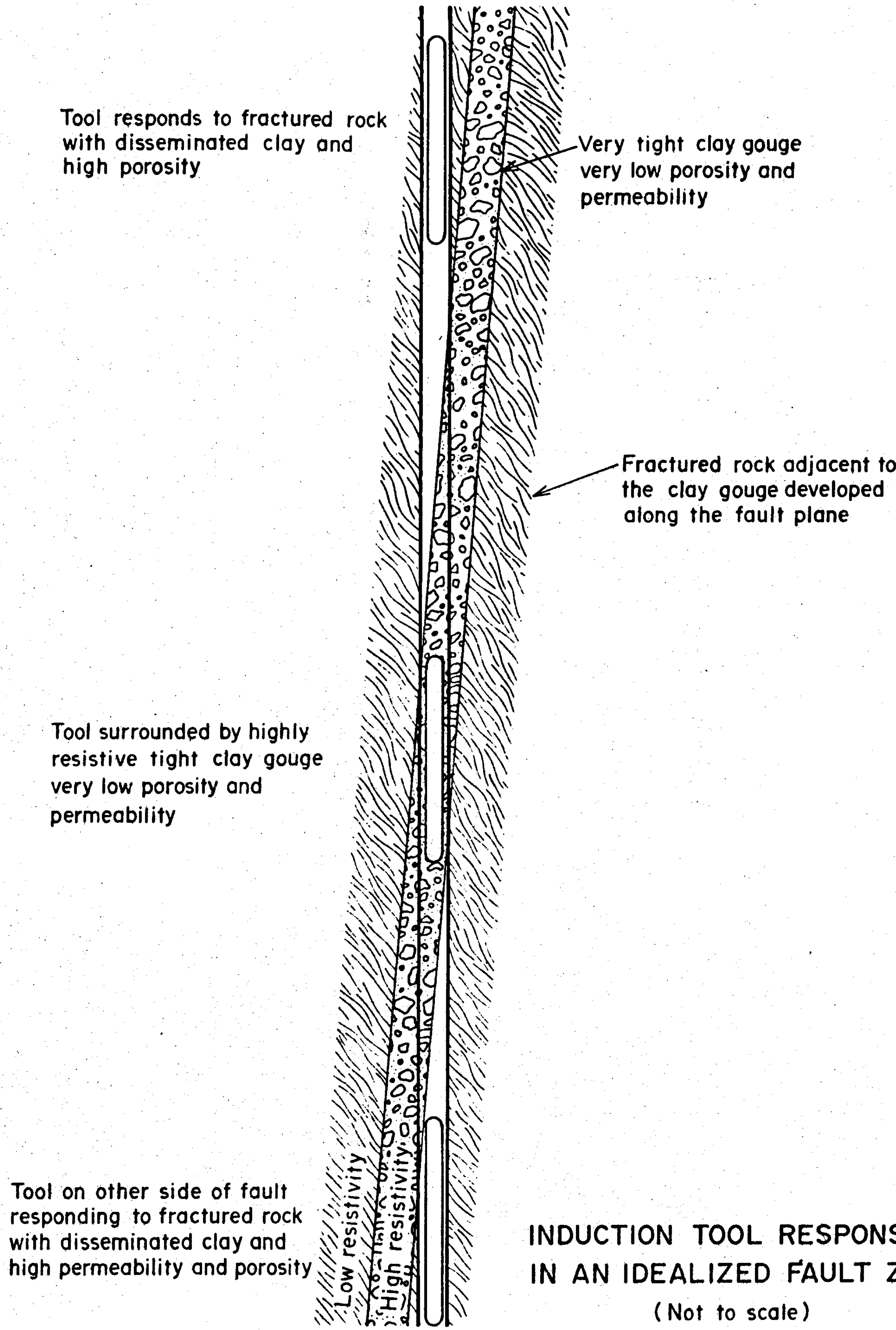
Composite Logs	Logging Companies	Interval	Date run
Gamma Ray	GO International	20-1341	09/25/77
	Dresser Atlas	1348-3900	10/27/77
	Dresser Atlas	3900-4824	02/03/78
Neutron Porosity	GO International	580-1333	09/25/77
	Dresser Atlas	1348-3900	10/27/77
	Dresser Atlas	3900-4824	02/03/78
Caliper	GO International	573-1341	09/25/77
	Dresser Atlas	1348-3900	10/27/77
	Dresser Atlas	3900-4824	02/03/78
Induction Logs	Dresser Atlas	150-578	09/19/77
SP	GO International	574-1341	09/25/77
Short Normal	Dresser Atlas	1348-3900	10/27/77
Conductivity	Dresser Atlas	3900-4824	02/03/78
Temperature	Triangle Service Inc.	50-4824	12/13/77
	Triangle Service Inc.	50-4824	02/04/78

chips indicate this is a zone of rhyolite. The neutron log shows a high apparnet porosity primarily due to the hole enlargement.

The short normal resistivity and SP logs are influenced to a minor degree by lithologic changes. These two logs and the induction log are affected by borehole enlargement. The lower short normal resistivity, positive shift in SP and increase in conductivity is well displayed at the washouts from 1865 to 1975, 2310 to 2410 and 2585 to 2650 feet. The SP shift is not as clear at the large washout between 1435 and 1515 feet because of the soft gouge zone occurring in this interval.

The interval from 850 to 1300 feet shows almost constant 10 ohm meter short normal resistivity. For this interval the caliper log does not indicate hole enlargement while drilling rates (Fig. 5) more than doubled and gouge was noted in the cuttings from 960 to 1020 feet. The short normal and SP logs appear to be responding to the gouge in a near-vertical fault zone that is penetrated by the hole from 960 to 1020 feet and is adjacent to the hole above 960 feet and below 1020 feet. The conductivity log supports this interpretation. Very high conductivities from 820 to 970 feet indicate the tool is in permeable fractured rock. The chips indicate very weak clay alteration in the plagioclase in this interval as well. Conductivity decreases below 970 feet to a minimum at 1095 feet where the resistive, impermeable gouge is exposed edge-on in the hole. This corresponds to a rise in the short normal resistivity. The conductivity rises again and is very high from 1170 to 1290 feet. Figure 10 is a diagrammatic interpretation of this interval.

The acoustic log is displayed in Plate II. The depths in the Dresser Atlas log are in error due to mechanical problems but the ones on the GO International



INDUCTION TOOL RESPONSE IN AN IDEALIZED FAULT ZONE

(Not to scale)

Figure 10

caliper log are correct and are used as a reference. Generally the acoustic log indicates fractured zones where the signal is attenuated. The P wave first arrival was difficult to impossible to pick on the original log and the Xerox reduction presented here has further removed weak signals but the zones of high attenuation are still obvious. Generally the caliper log indicates washouts adjacent to zones of high attenuation. The exception to this is in the 2600 to 2800 foot interval where the signal is very strongly attenuated while the caliper indicates very minor hole enlargement.

One general rule holds for much of the acoustic log: the fractures are located predominantly at contacts between mafic-rich and mafic-poor rocks (indicated by the Gamma Ray curve). Below 2800 feet the frequency of fracturing would appear to be less than above 2800 feet. This is also the interval dominated by the leucogranite.

The presence of a fracture system does not mean that fluid is necessarily flowing there. Fractures pinch and swell, so while they may be fluid-filled there may be very low permeability.

Temperature logs give the best indication of fluid flow and relative heat flow. Unlike other rock properties measurable by geophysical logs, the rock temperature is a dynamic feature subject to natural change or induced shifts. Logs run immediately after circulation stops will show where maximum and minimum cooling have occurred. Subsequent logs will delineate relative rates of thermal recovery to determine zones of maximum heat flux.

Five temperature logs were run over a fifty hour interval starting on October 27, 1977 in CGEH #1 (Fig. 8). Mud temperatures were 111°F going in the hole and 127° coming out when circulation stopped. The plot of the first log indicates maximum cooling in the hole above 2800 feet. Heat was flowing from the rock to the drilling fluid most rapidly above this depth with some peaks indicating zones of rapid recovery. Using only this log, the interpretation could have been that the rock below 2800 feet had recovered more rapidly or had been cooled less than the rock above. Subsequent logs indicate the interval below 2800 feet had been cooled less than the rocks above 2800 feet. In the 50 hour interval between the first and last log the zone between 1850 feet and 2775 feet had recovered over a temperature range greater than 100°F with an apparent maximum of 112°F at 2250 feet. This zone clearly has the highest heat flux in the hole.

The temperature log run December 13, 1977 (Fig. 8a; Pl. I) eleven days after all drilling activities ceased, shows that the highest temperatures in CGEH-1 occur in the interval from 1960 to 3500 feet with maximum temperatures at 2100 and 2750 feet of 369° and 367° respectively. The negative slope on this log below 3000 feet was not predicted by logs run periodically during drilling (Fig. 8, a, b). These logs were included in the drilling program to assist in determining if a geothermal resource had been passed and the hole was being needlessly deepened into cooler rock. The time required for the hole to recover from the effects of the circulating fluid is the controlling factor in using this technique. Perhaps if the fifty hour logging sequence run when the hole was at 4000 feet had been extended to 75 or 100 hours, this reversal would have been indicated.

CONCLUSIONS

High heat flux indicated by the highest temperature interval in the hole was encountered between the depths of 1850 and 2775 feet where drill hole CGEH-1 intersected the north-northeast open fracture or fault system. Convective heat flow and temperatures greater than 350°F appear to occur only along this structural trend, while temperature logs recorded when borehole fluids approached equilibrium with the actual thermal gradient indicate a negative thermal gradient below 3000 feet.

The water table in the vicinity of CGEH-1 is interpreted to occur at a depth of 500 feet. The hole is cased to 3488 feet and the piezometric surface is at a depth of 910 feet. Water samples taken from below 3488 feet indicate this is the same high chloride water sampled in Coso #1 at Coso Hot Springs. These data indicate that the Coso KGRA is a hot-water rather than a vapor-dominated system.

The thermal system does not appear to be related to specific rock types. Only very weak hydrothermal alteration was observed in the drill cuttings. Weak sporadic argillization occurs throughout the metamorphic rocks and in the calcic cores of plagioclase grains in the leucogranite. Minor calcite veining occurs in all rock types, occasionally with hematite.

Faults and fracture zones had a strong influence in hole direction and penetration rates and limited the type of drilling methods that could be used.

Gamma ray and neutron porosity logs indicate gross rock type and potential fluid flow zones. The temperature logs recorded during drilling failed to predict the gradient reversal below 3000 feet, but did delineate the zone of maximum heat flow between 1850 and 2775 feet.

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APPENDIX A

The field log, Appendix A, shows the terms used to record the geology during drilling. The analysis of thin sections made from the cuttings, core and surface samples has resulted in some name changes and clarification of rock types that were not identifiable in the field, however, the overall relationships have not changed. Igneous and metamorphic rock classifications are in large part based on textural analysis because bulk compositions can be identical - the small size of the chips often precluded any textural interpretation until thin sections could be made and analyzed. Metamorphic and mafic-rich rock names were used in the field for the rocks of the metamorphic sequence while the field term "white granite" identified the leucogranite pluton precisely. Alaskites cut both units. One alaskite was identified as a leucogranite in the field log.

NOTICE

The field log, Appendix A, is a detailed 48 page record of the on site lithologic logging of CGEH-1 cuttings. Much of this information is repetitive and is adequately represented by the graphic log, Plate I. Since only a small fraction of the individuals or organizations on the distribution list will actually use this information Appendix A is not included in this report but is available upon request from the Earth Science Laboratory.

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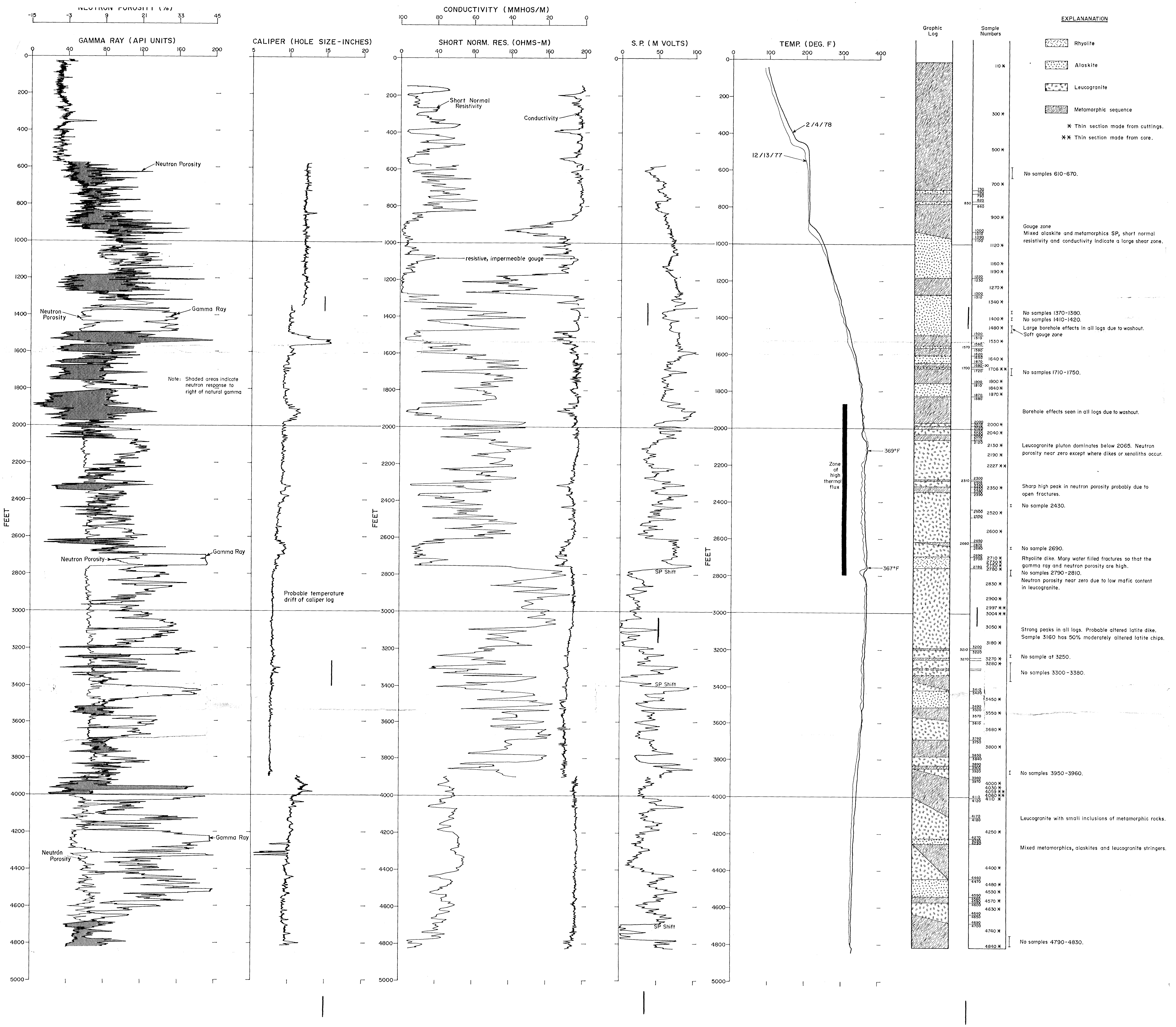

COMPOSITE GEOPHYSICAL LOGS AND GEOLOGIC GRAPHIC LOG FOR CGEH I

PLATE II
CALIPER AND SONIC VELOCITY LOGS
CGEH-1