Caldera Reservoir Investigations Program

by

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CASCADES DEEP GEOTHERMAL GRADIENT DRILLING PROGRAM

SOME GEOLOGIC PROBLEMS

1 Regional Heat Flow

2. Nature and Thickness of "Rain Curtain"

3. Relation of Known Heat Sources to Hydrothermal Systems

4. Nature and Location of Reservoir Rocks

5. Best Exploration Techniques

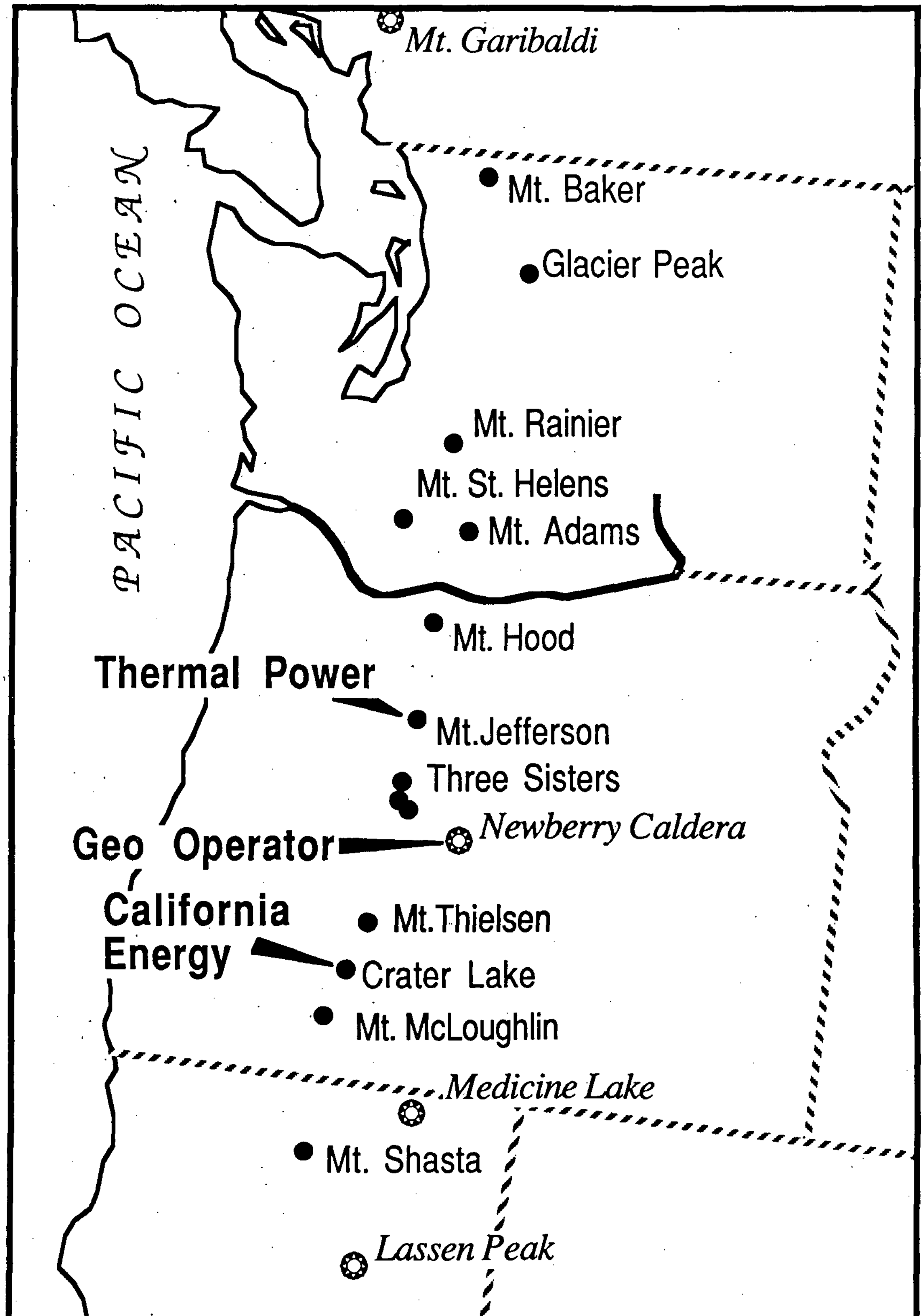
6. Drilling Methods and Costs

CALDERA RESERVOIR INVESTIGATIONS PROGRAM

Objectives

1. Obtain data on subsurface thermal and hydrologic regimes.

2. Identify exploration problems; devise and test exploration techniques.



High Temperature Hydrothermal System

CALDERA RESERVOIR INVESTIGATIONS PROGRAM

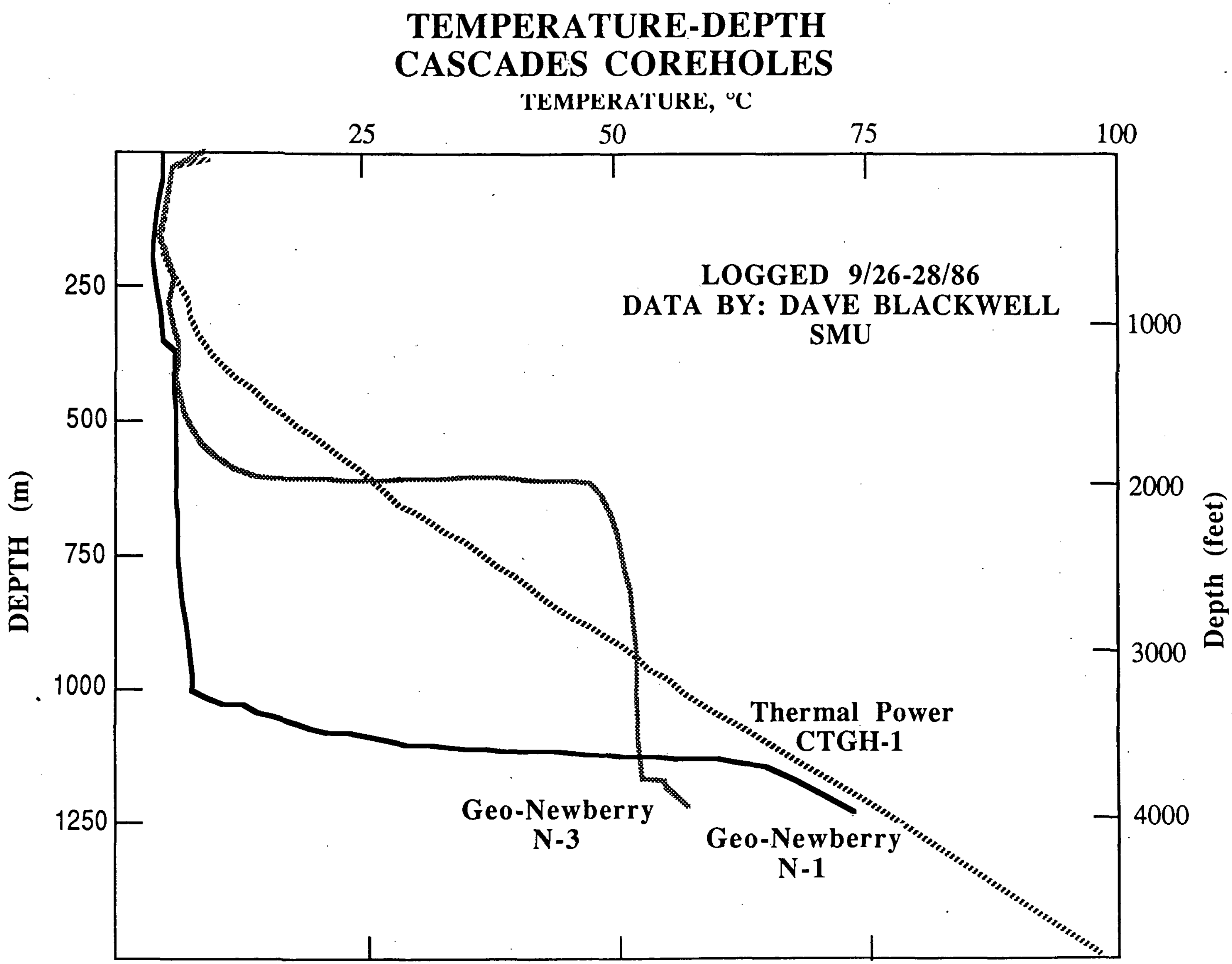
CORING SUMMARY

	GEO N-1	GEO N-3	THERMAL CTGH-1	CECI MZI-11A
Spud date	8/24/85	6/2/86	6/7/86	9/12/86
Completion Date	10/20/85	8/1/86	9/2/86	(drilling temporarily stopped)
Drilling Contractor	Tonto	Tonto	Boyles	Longyear
Core Recovery	>90%	>90%	>90%	-------
Coring Rate	69ft./day	67ft./day	66ft./day	$61/ft.
Total Depth	4550 ± ft.	4002 ft.	4800 ft.	(1354ft.)
Public Domain Data	0-4000 ft.	0-4002 ft.	0-4800 ft.	-------
Completion	1 1/2" iron pipe to T.D.	1 1/2" iron pipe to T.D.	HX rods to 4203 ft. open to T.D.	-------

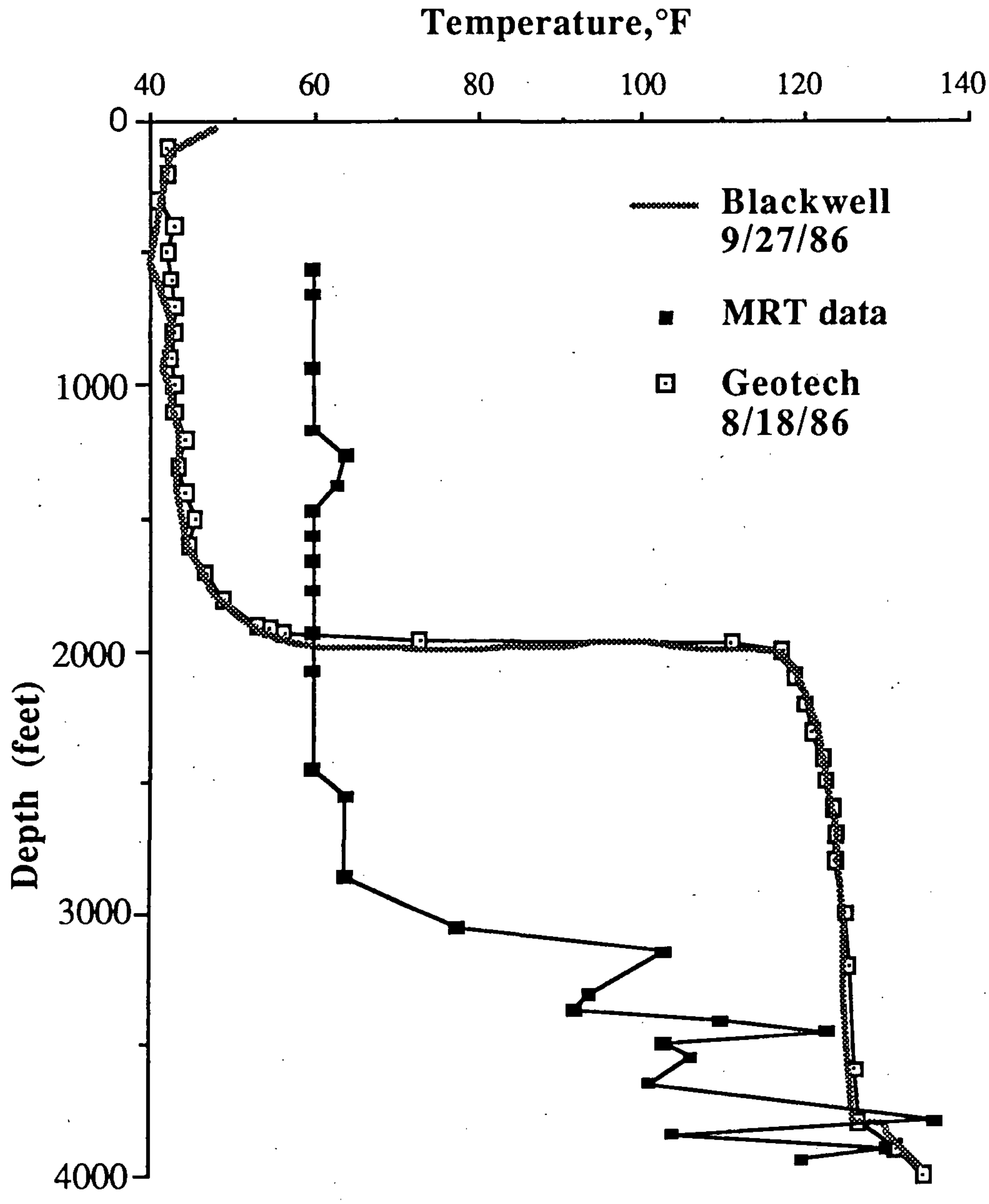
CALDERA RESERVOIR INVESTIGATIONS PROGRAM

GEOPHYSICAL WELL LOGS

	GEO N-1	GEO N-3	THERMAL CTGH-1	CECI MZI-11A
Temperature	X	X	X	o-1329'
Caliper	X	X	4100'-4800'	-
Gamma Ray	X	X	X	-
Neutron	-	-	X	-
Gamma-Gamma Density	-	-	775'-900'	-
Spontaneous Potential	X	-	4200'-4798'	-
Resistivity	X	-	4200'-4799'	-
Induced Polarization	-	-	4200'-4799'	-
Lateralog	-	-	4200'-4798'	-
Induction	X	-	-	-
Acoustic	X	X	4225'-4425'	-
Acoustic Fraclog	X	X	-	-


TEMPERATURE-DEPTH
CASCADES COREHOLES
TEMPERATURE, °C
25
50
75
100
LOGGED 9/26-28/86
DATA BY: DAVE BLACKWELL
SMU
DEPTH (m)
250
500
750
1000
1250
Depth (feet)
1000
2000
3000
4000
Thermal Power
CTGH-1
Geo-Newberry
N-3
Geo-Newberry
N-1
25
50
75

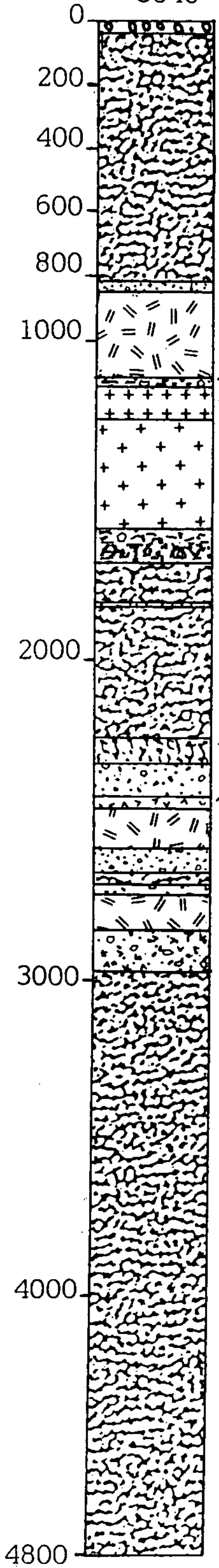
Geo-Newberry N-3
Temperature Logs



CORE ANALYSES

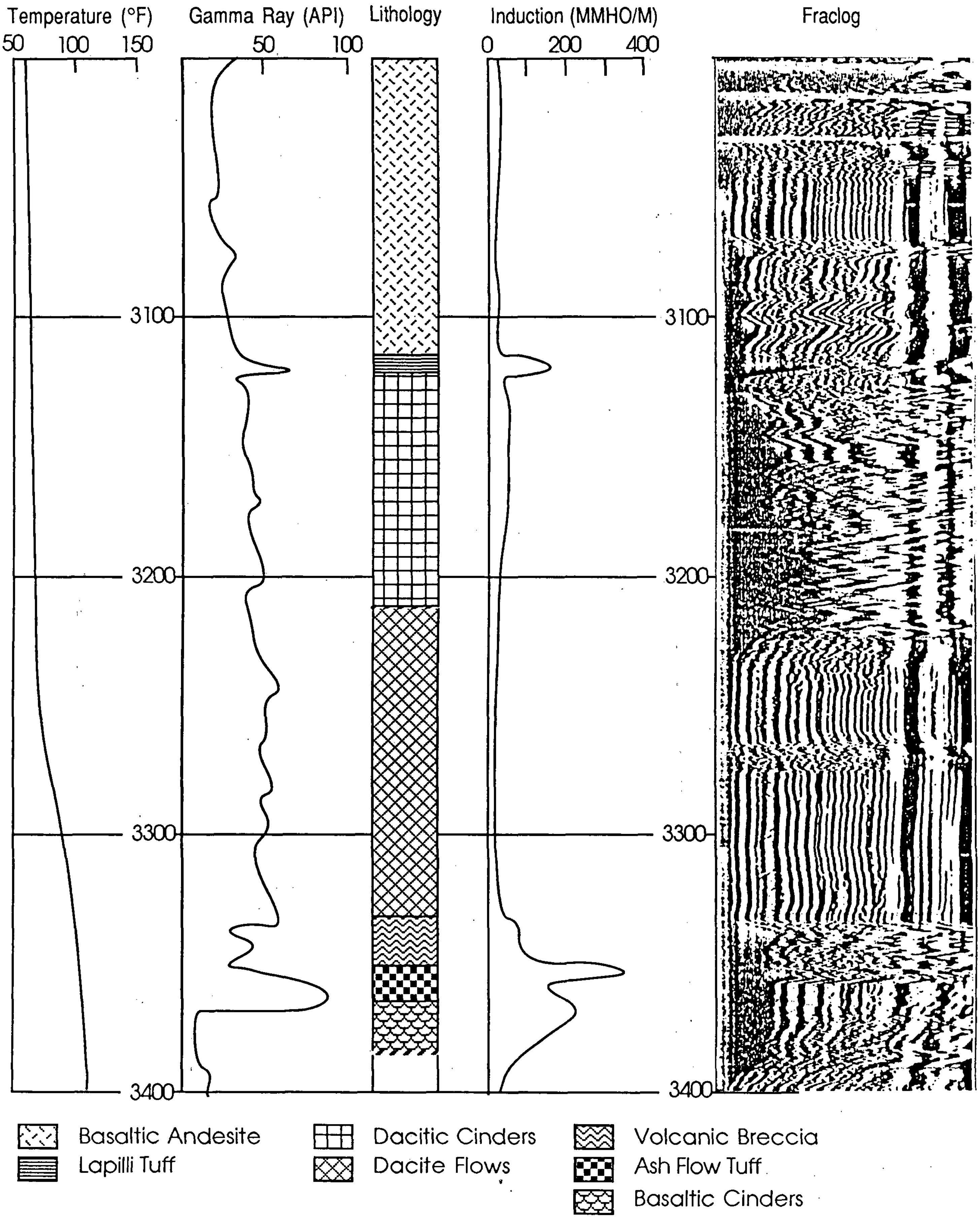
Analysis	Institution(s)	Detailed Sampling	Selected samples	Finish Date
Lithology	UURI	X		Dec 87
X-Ray	USGS, UURI, U of W	X		Apr 88
Hydrothermal Alteration	USGS, UURI	X		Apr 88
Geochemistry (major, minor, trace elements)	U of Wyoming		X	Apr 88
Fluid Inclusions	UURI		X	Dec 87
Electrical Resistivity/IP	UURI, USGS, MCMST		X	Apr 88
Cation Exchange Capacity	UURI		X	Apr 88
Thermal Conductivity	SMU		X	Apr 88
Magnetic Properties	UURI	X		Dec 87
Density	UURI		X	Dec 87

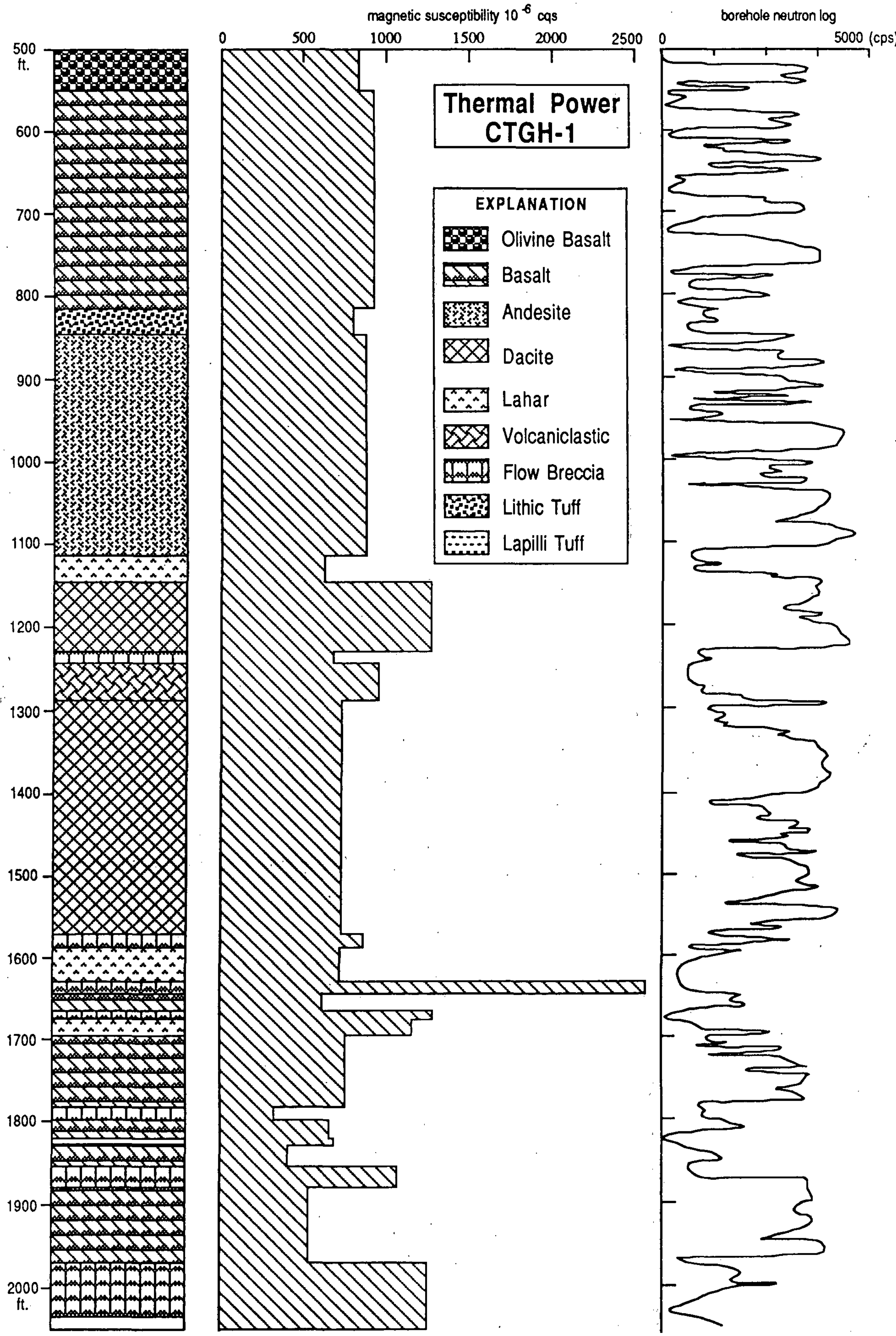
CLACKAMAS CTGH-1



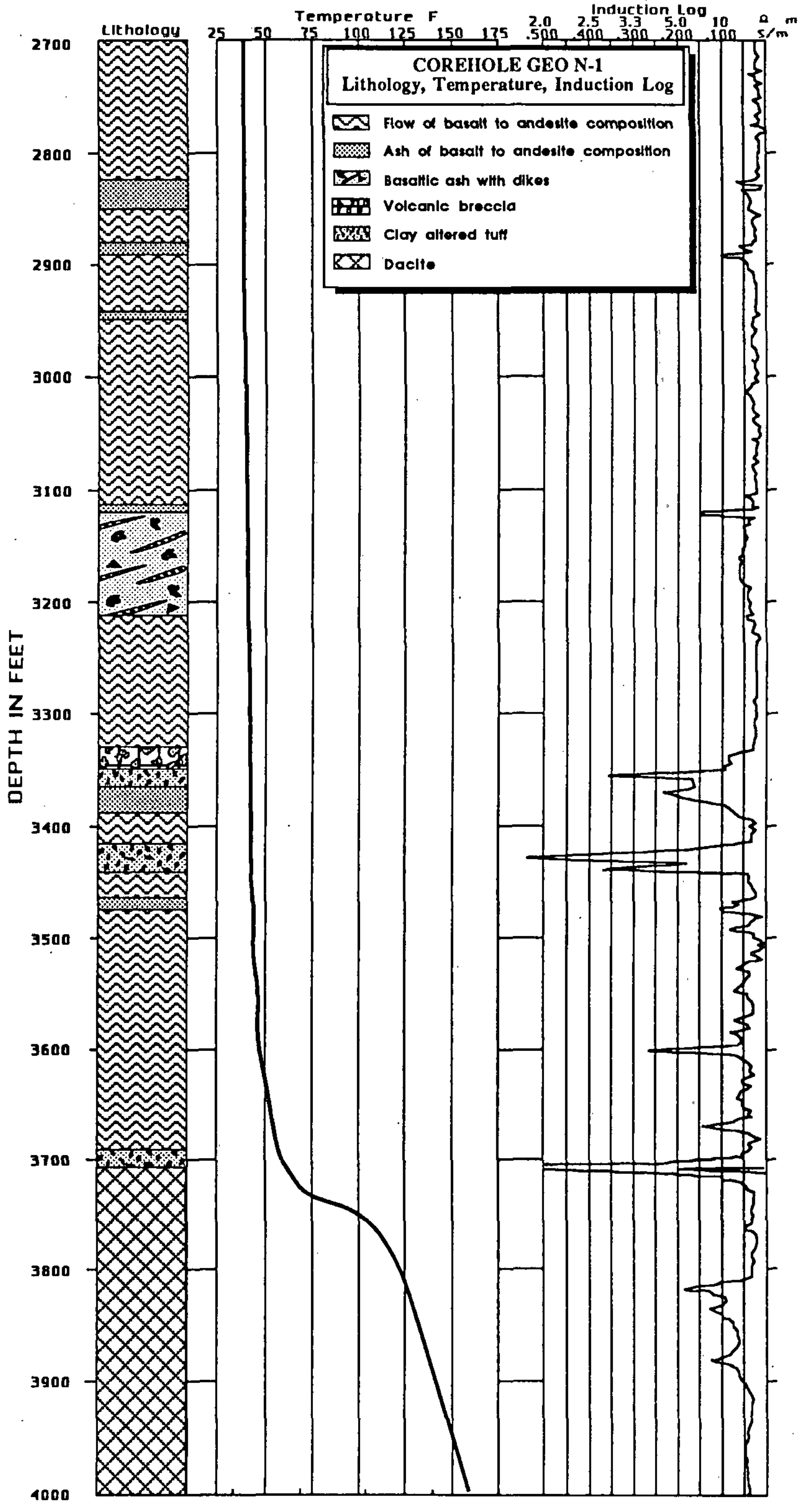
UNIT INTERVAL	LITHOLOGIC DESCRIPTION
0-40	Basaltic boulders, till.
40-815	Basalt Flows 0 to 2% 1mm plag, dark gray, fine grain diktytaxitic, vesicular, 25' thick flows, gray to grayish red flow breccias.
815-846	Lithic Tuff nonwelded, gray to brn lapilli + yel ash.
846-1114	Andesite (?) Flow fine grain, 20% 1mm plag + pxn, Pyrolucite and pink clay on fractures.
1114-1138	Lahar crude beds, vol. clasts, carbon, tuff-clay matrix.
1138-1243	Dacite Flow 10% 1-3mm pheno, grn-blk, vesicular.
1243-1587	Dacite Flow or Dome 2% 1mm crystals, 50' top breccia.
1587-1694	Lahars lapilli + blocks in ash + clay matrix, rnd clasts, and Basalt Flow vesicular, 2% 2mm plag 1629-1673.
1694-1820	Basalt (?) Flow nonporphyritic, olive-black.
1820-1826	Lapilli Tuff clay alt. waxy, red-brn-orange.
1826-2240	Basalt Flow vesicular, dk-gray-black, nonporphyritic, strong chloritization, clay amygdules, zeolite.
2240-2318	Basaltic Flow Breccia vesicular, zeolite, chloritized.
2318-2419	Lahar minor ash + vol. Breccia, chlorite and clay.
2419-2454	Andesitic Breccia chloritized, 6' Ash Flow Tuff interbed.
2454-2586	Andesite Flows 15% 2mm plag, chloritzed, dk grn-gray.
2586-2657	Lithic Tuffs lapilli and crystal rich, fiamme, 10% xls.
2657-2694	Olivine Basalt 10% 2mm olivine, zeolite amygdules.
2694-2726	Lahars & Lapilli Ash mixed vol. lithologies, rnd clasts.
2726-2842	Andesite Flow 5% 2mm pxn, 2% plag, zeo, celadonite, chl.
2842-2966	Volcanoclastic or Lahar mixed litho. nonsorted, clay alt. Ash or Tuff 2935-2952, trace plag. xls, gray-red.
2966-4800	Basalt Flows vesicular, 2% 1mm plag, gray to olive black. 5-10' flow centers and equal or thicker flow breccias, chalcedony and celadonite amygdules, 30% of vesicles open, chlorite and zeolite. Upper contact is a minor fault.

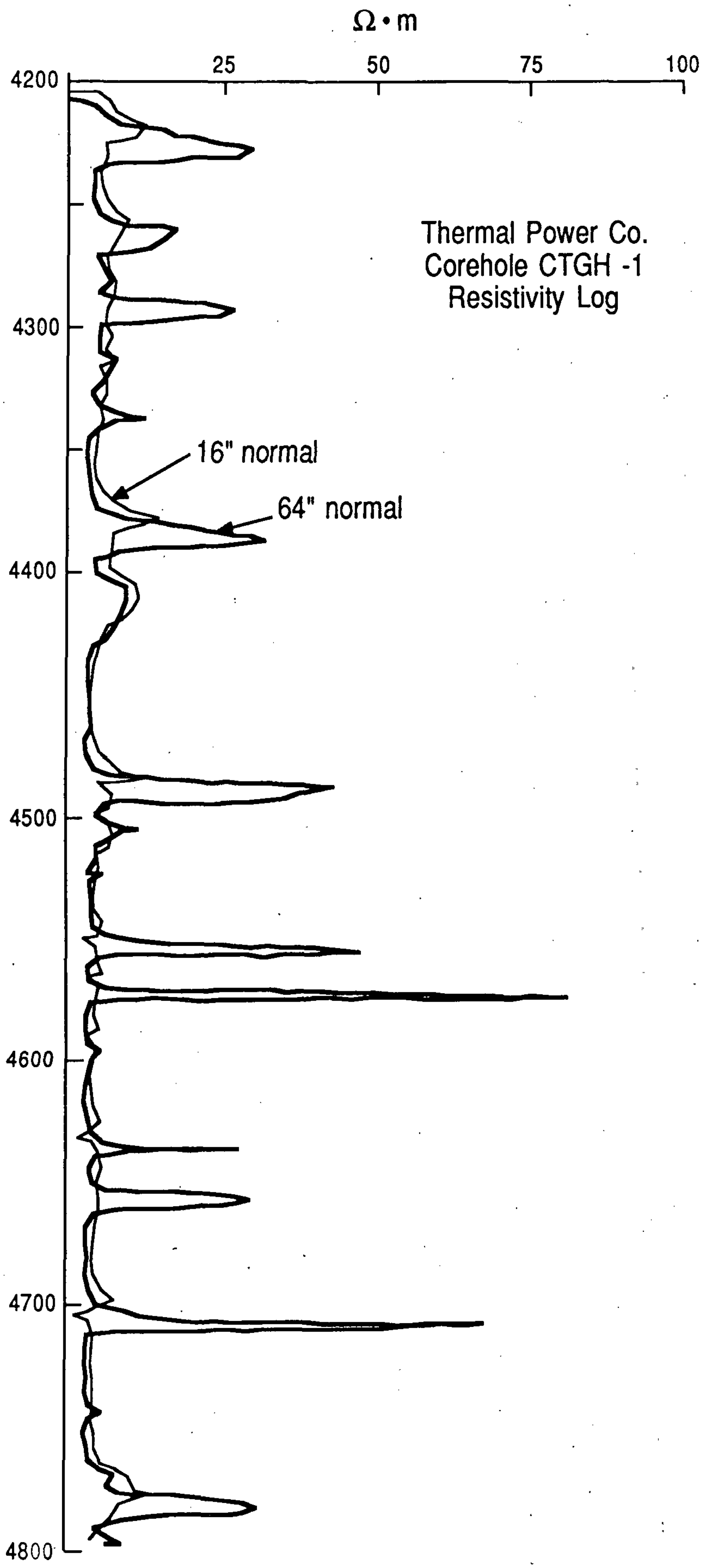
GEO-NEWBERRY N-1





magnetic susceptibility 10 -6 cgs
borehole neutron log
0
500
1000
1500
2000
2500
0
5000 (cps)
500 ft.
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000 ft.
Thermal Power CTGH-1
EXPLANATION
Olivine Basalt
Basalt
Andesite
Dacite
Lahar
Volcaniclastic
Flow Breccia
Lithic Tuff
Lapilli Tuff


CORHOLE GEO N-1
Lithology, Temperature, Induction Log
Flow of basalt to andesite composition
Ash of basalt to andesite composition
Basaltic ash with dikes
Volcanic breccia
Clay altered tuff
Dacite
Lithology
Temperature F
25 50 75 100 125 150 175
Induction Log
2.0 2.5 3.3 5.0 10 Ω m
.500 .400 .300 .200 .100 S/m
DEPTH IN FEET
2700
2800
2900
3000
3100
3200
3300
3400
3500
3600
3700
3800
3900
4000


Ω • m
25
50
75
100
4200
4300
4400
4500
4600
4700
4800
Thermal Power Co.
Corehole CTGH -1
Resistivity Log
16" normal
64" normal

THERMAL POWER CTGH-1

SUMMARY OF CORE MEASUREMENTS

Sample Depth (ft.)	D (cm)	L (cm)	Porosity (%)	ρ_r (Ωm) in $\rho_w = 1\Omega m$	ρ_r (Ωm) in $\rho_w = 5\Omega m$	ρ_r (Ωm) extrapolated to $\rho_w = 10\Omega m$
4228	4.7	12.3	0.5 (?)	245	236 (?)	240
4450	4.7	11.9	10.6	11.5	15.0	17
4625	4.7	6.9	14.8	16.1	28.4	36
4733	4.7	12.3	16.3	12.8	18.5	22

ρ_w = measured resistivity of saturating solution

$\rho_r = a \rho_w \phi^{-bm}$ (Archie's Law)

X-RAY DIFFRACTION

Sample Depth (ft.)	quartz	plag.	clino-pyrox	mordenite	smectite	celadonite	Amorph
4228	1	41	10	0	0	0	48
4733	2	47	10	3	13	Tr	25

Read or Scan:

NOTES ON GEO N-1 GEOPHYSICAL WELL LOGS

CALIPER LOG

The caliper log shows a highly uniform hole diameter and shape over most of the length of the hole. There are a few areas of enlargement that correspond for the most part to flow boundaries or to suspected fractures. The interval immediately adjacent to the bottom of the rain curtain at 3260 is enlarged to 5 in, and the largest washout occurs at 3429, where the hole diameter is 9.7 in.

TEMPERATURE LOGS

There were two temperature logs run in the well. The first was run on 2 Nov 85 during the course of the Dresser Atlas logging. The second temperature log was run on 9 Nov 85 by Geotech Data od Poway, Ca. This second log used a tool having an apparent sensitivity of about 0.01 C, which is believed to be considerably better than the sensitivity of the usual logging tool temperature probe. In addition, the second tool is likely to be better calibrated. The last fluid circulation is estimated to have occurred when the black iron pipe was set, which was completed on 8 Nov 85, one day earlier. Neither of the temperature logs is an equilibrium log. Nevertheless, they do yield date of significance.

The upper 200 ft of the hole shows temperatures about 45 F, which decrease downward to about 41 F and then begin a very show buildup such that at 2000 ft temperature is 42 F, and at 3000 ft temperature is 51 F. Between 3260 and 3300 ft, there is a very rapid increase in temperature to 103 F, and thereafter a more uniform gradient to a temperature of 160 F at 4000 ft. This area is in a fairly massive dacite unit. The abrupt temperature increase apparently signifies the bottom of the level of cold water circulation called the rain curtain. The average gradient below 3300 ft corresponds to 115 C/km. Average thermal conductivities for the rocks below 3300 ft are 4.3 mcal/cm-sec-deg C, so that the indicated heat flow is about 5 HFU. We must remeber that the temperature profile is not equilibrium, however, and this heat flow value is only an indication of the true value below 4000 ft.

GAMMA RAY LOG

This log shows counts in standard API units. Basalt and andesite flows are fairly uniform, but some individual flows can be differentiated. Typical values of the basalts are 20-40 API units. A dacite ash at 1982 is clearly delineated. Several thin clay-altered units below about 3100 ft show high response. Dacite flows at 3211-3330 ft and 3708-4000 ft show increased response, averaging 130 API units. This log appears to be successful at differentiating the felsic and/or altered units from the basalt and basaltic-andesite flows.

ELECTRIC LOGS

The electric logs comprise an SP log, a 16-in short normal resistivity log and an induction log. The SP log was off scale for much of the upper part of the hole and appears to be of limited use for quantative interpretation in any case. It will not be discussed further. The resistivity of the borehole fluid at the time of the logging was not measured, and so the interpretations that can be placed of the resistivity and induction logs are somewhat compromised. The induction log is the more useful of the two remaining logs in yielding representative values of resistivity for the formations because of its greater depth penetration.

Both the resistivity and induction logs indicate the presence of conductive horizons below a depth of about 2800 ft. The conductors become more numerous and of higher conductivity down hole. The average resistivity of the upper 2000 ft of the hole is 50-70 ohm-m. Below this there is a systematic decrease in resistivity with depth. Below 2800 ft, there are at lease 15 separately identifiable horizons having resistivities below 10 ohm-m, and one horizon has a resistivity value of 1.2 ohm-m. The thickness of these horizons varies from a few feet to a few tens of feet. These conductive horizons correspond, for the most part, to clay-altered basaltic ash and felsic tuff units. The chief alteration type is smectite which has apparently developed at low temperature.

The conductive horizons observed on the electric logs are believed to be responsible for the occurrence of anomalies in interpreted conductivity on surface TDEM surveys reported by Dave Fitterman of the USGS. The surface surveys indicate a widespread area underlain by conductive horizons around the Newberry volcano. Part of the anomaly must correspond to the high-temperature hydrothermal system found in USGS Newberry-2 corehole which was drilled in the caldera. However, part of the anomaly must also correspond to the conductors found in GEO N-1.

ACOUSTIC LOGS

Two acoustic logs were run in the well--an acoustic velocity log and an acoustic fraclog. Both of these logs are useful in detecting flow boundaries and differentiating areas of uniform, probably low porosity/permeability from porous/permeable horizons that correspond for the most part to flow boundaries and, to a lesser extent, to fractures.

INTERPRETATION OF THE LOGS

These logs will be very useful when correlated with the core in calibrating log response in this sequence of basalt and basaltic-andesite flows with separate ash and tuff units. UURI is involved with this work at the present time. We plan to make detailed log correlations with the core, make such measurements as resistivity and perhaps IP effect on selected core specimens, and study cross plots.