GL01846

# 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 of 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 data 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 on 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 , 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.

# DEPARTMENT OF ENERGY CASCADES DEEP GEOTHERMAL GRADIENT DRILLING PROGRAM

## OBJECTIVE:

Sponsor research to characterize the deep hydrothermal regime of the Cascades in order to define its geothermal potential.

## PROGRAM MANAGEMENT:

DOE/Idaho Operations Office

## TECHNICAL COORDINATION:

University of Utah Research Institute

## MECHANISM:

Solicitations for Cost-Shared Drilling

CASCADES DEEP GEOTHERMAL GRADIENT DRILLING PROGRAM

# STATUS

## ✡ GEO Operator Corp.

| | | |
|---|---|---|
| N-1 | (4000') | Completed 10/20/85<br>Data and samples open filed by UURI Feb 86 |
| N-3 | (4000') | Spud 6/1/86 |

## ✡ Thermal Power Company

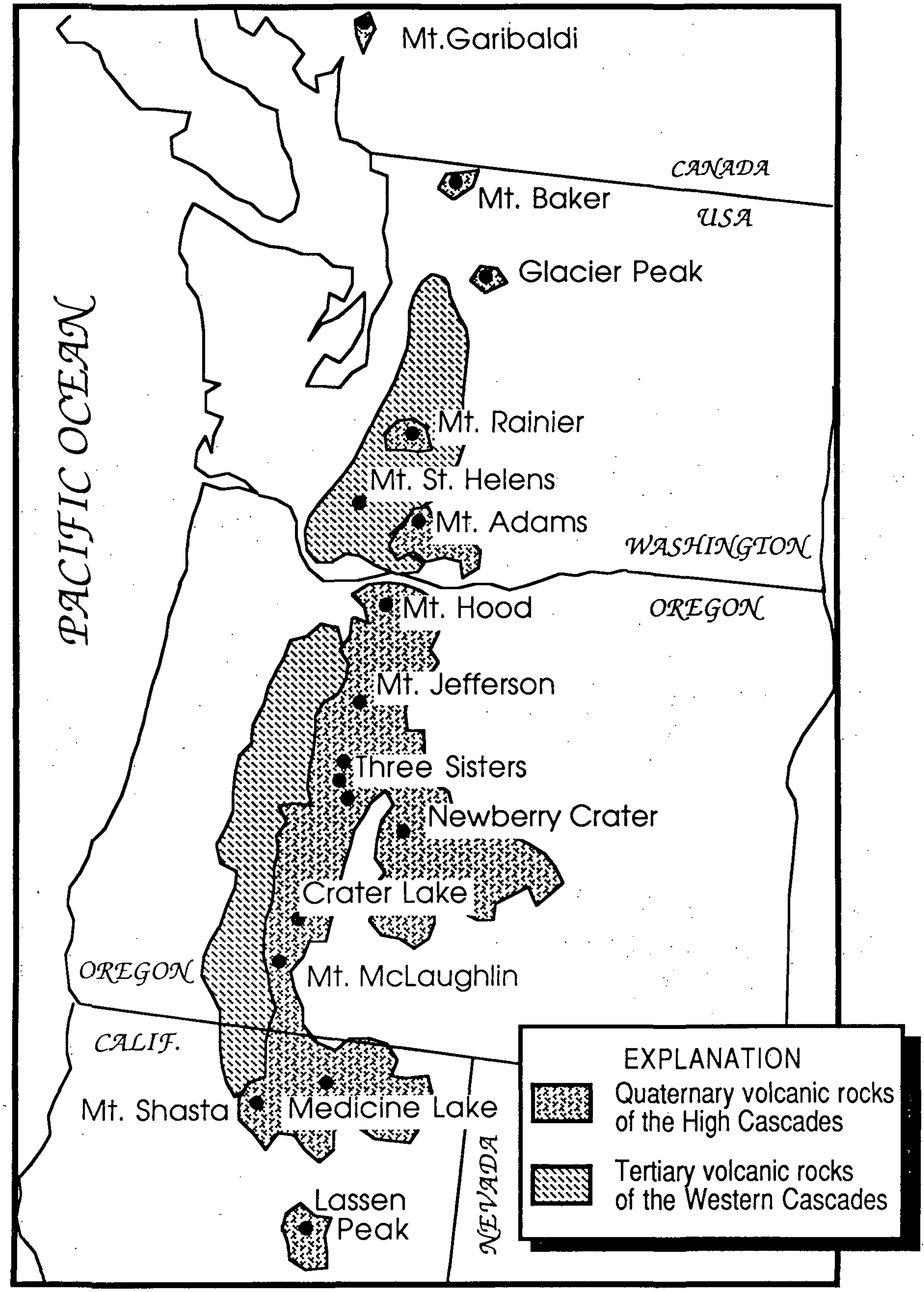
| | | |
|---|---|---|
| Clackamas | (5000') | Spud 6/1/86 |

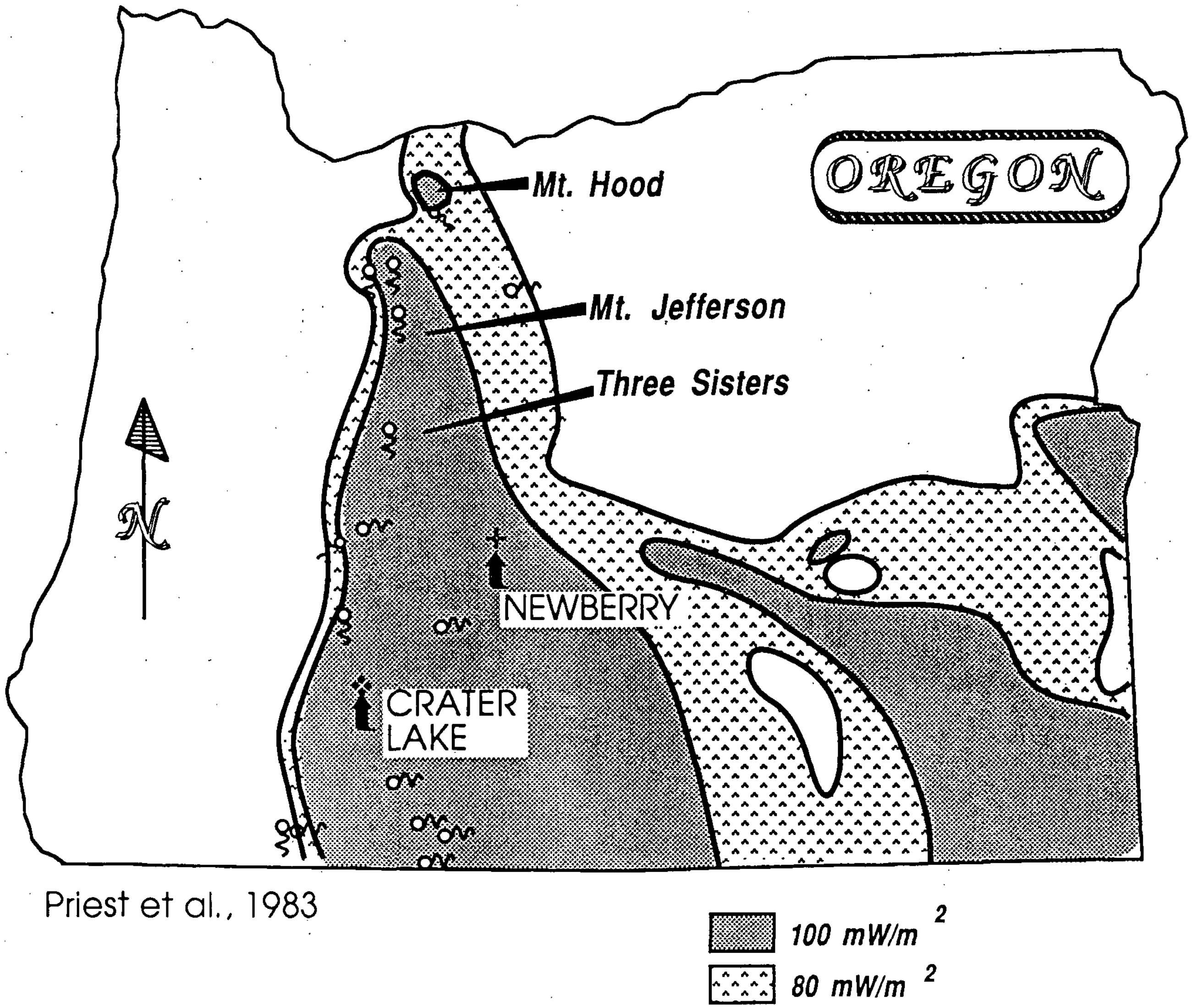
## ✡ Blue Lake Geothermal

| | | |
|---|---|---|
| Blue Lake | (4000') | Spud ? |

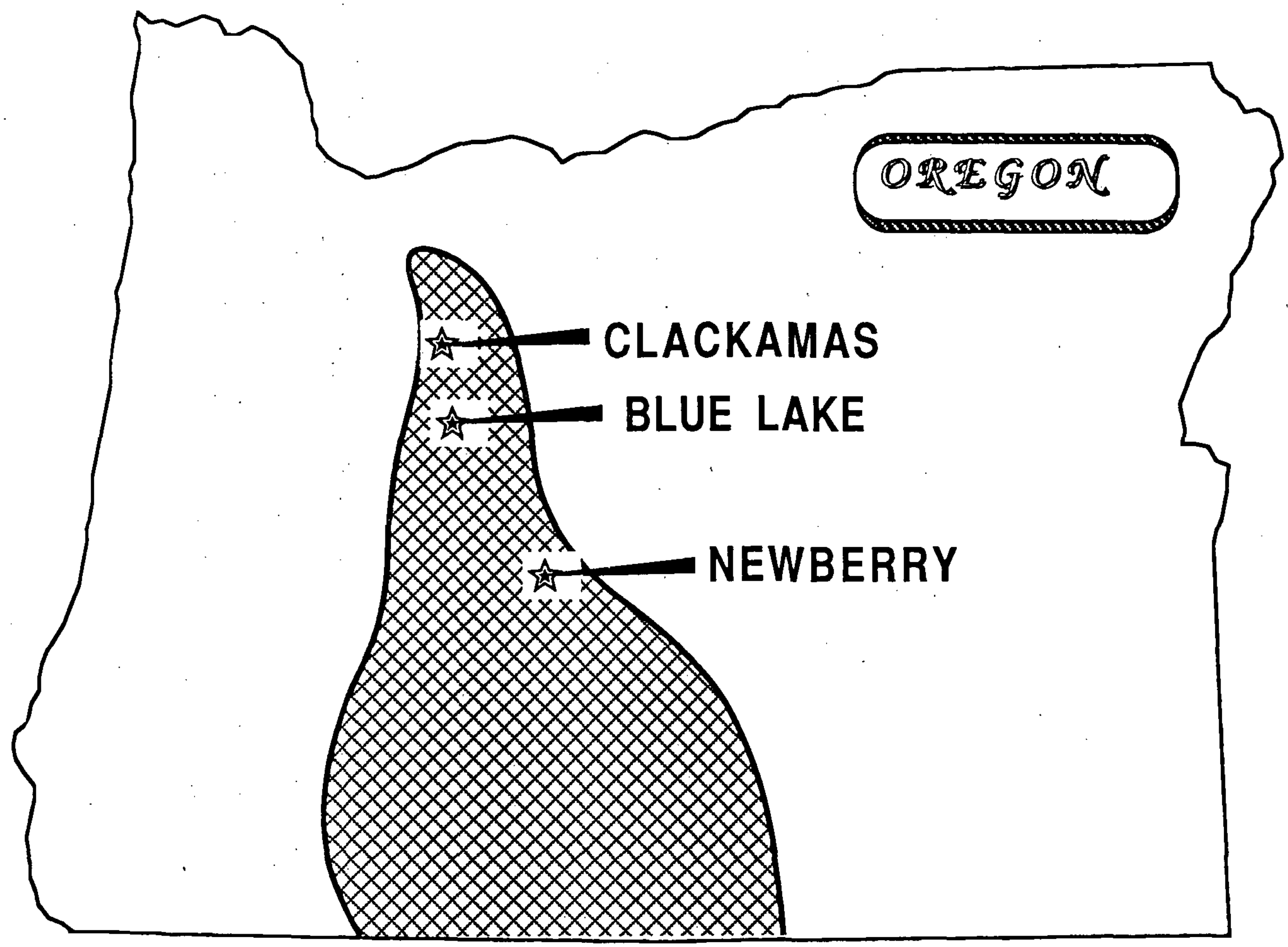
## ✡ New Solicitation: May 30, 1986

Two additional holes anticipated

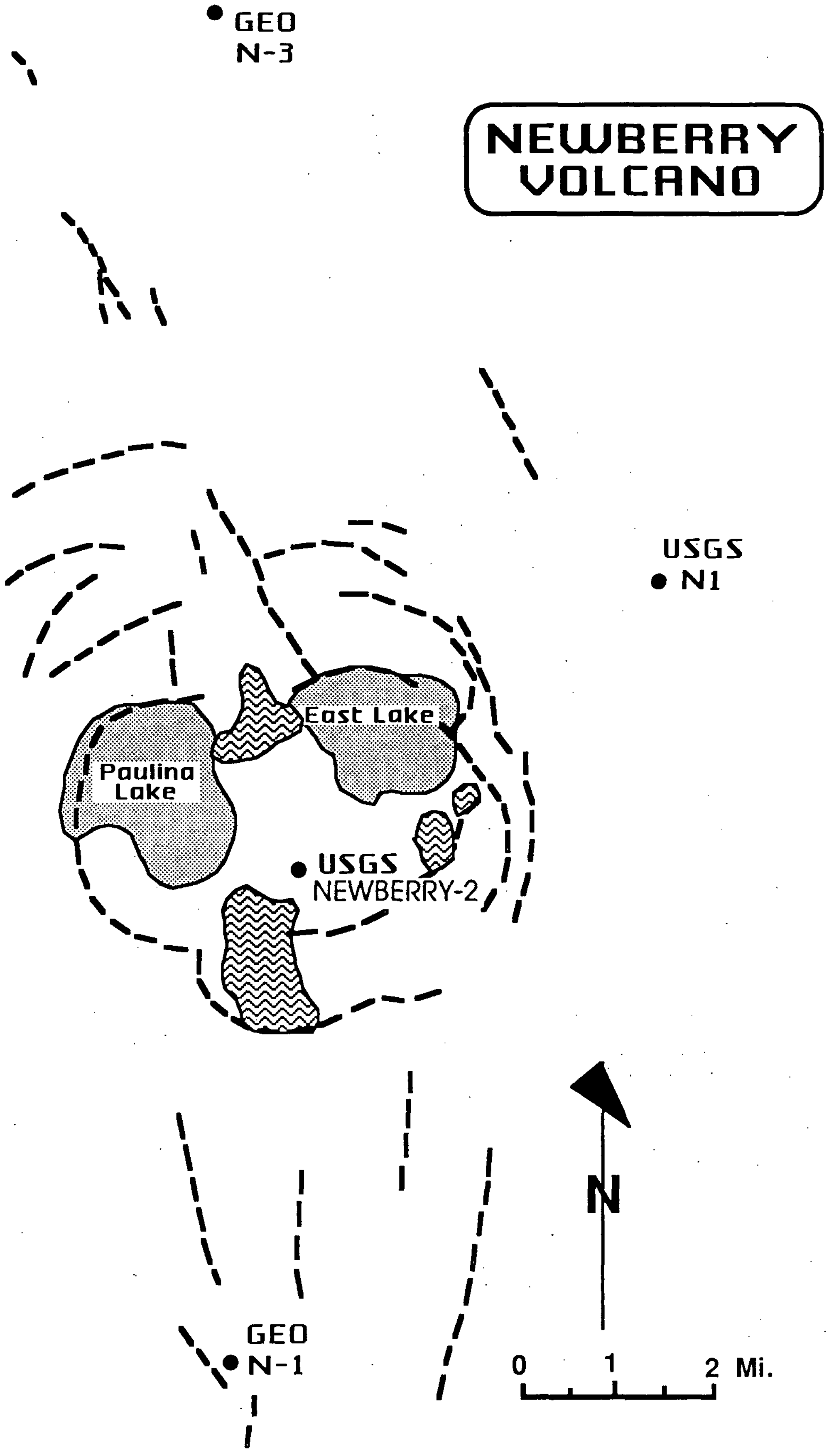

Mt.Garibaldi
CANADA
USA
Mt. Baker
Glacier Peak
PACIFIC OCEAN
Mt. Rainier
Mt. St. Helens
Mt. Adams
WASHINGTON
OREGON
Mt. Hood
Mt. Jefferson
Three Sisters
Newberry Crater
Crater Lake
OREGON
Mt. McLaughlin
CALIF.
Mt. Shasta
Medicine Lake
NEVADA
Lassen Peak
EXPLANATION
Quaternary volcanic rocks of the High Cascades
Tertiary volcanic rocks of the Western Cascades




Priest et al., 1983




DOE GEOTHERMAL CASCADES DRILLING PROGRAM



NEWBERRY VOLCANO
GEO N-3
USGS N1
East Lake
Paulina Lake
USGS NEWBERRY-2
N
GEO N-1
0
1
2 Mi.

CASCADES DEEP GEOTHERMAL GRADIENT DRILLING PROGRAM

# DATA ON GEO N-1

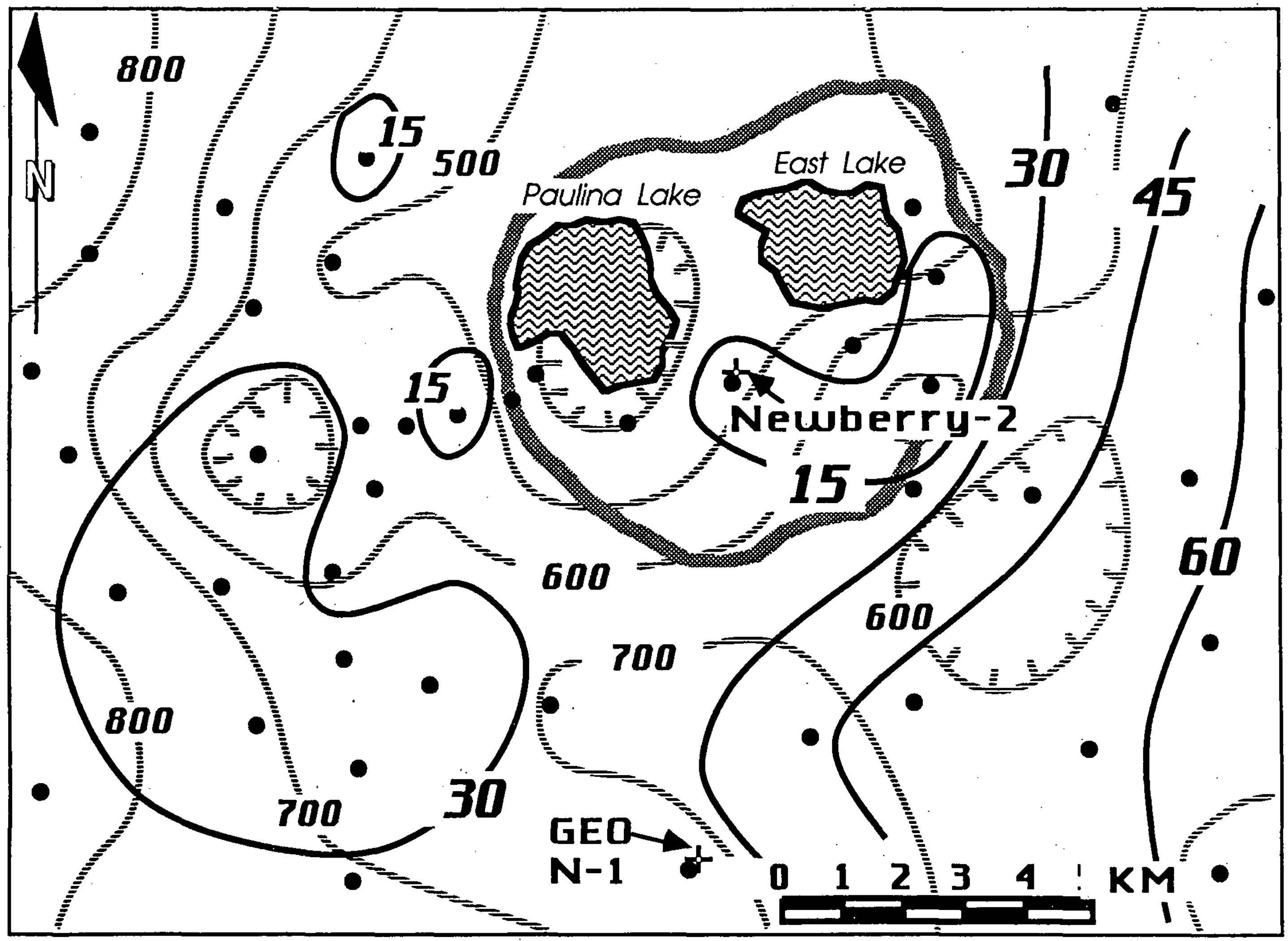
| | | |
|---|---|---|
| Spud date | | 8/24/85 |
| Completion Date | | 10/20/85 |
| Drilling Contractor | | Tonto |
| Core Recovery | | >90% |
| Cost ——————— | rotory 0-487 | $96/ft. |
| | coring 487-4000 ft. | $66/ft. |
| Drilling Rate | | 69ft./day |
| Total Depth | | 4550 ± ft. |
| Public Domain Data | | 0-4000 ft. |
| Completion | | 1 1/2" iron pipe to T.D. |

# Geophysical Well Logs
# GEO N-1

(Dresser Atlas, logged 11/2-3/85 unless noted)

| | | |
|---|---|---|
| Temperature | 1 | DA |
| | 2 | Geotech Data 11/9/86 |
| Caliper | | 4-arm |
| Gamma Ray | | |
| Spontaneous Potential | | large portions off scale |
| Resistivity | | 16 in. short normal |
| Induction | | |
| Acoustic | | Borehole compensated |
| Acoustic Fraclog | | Borehole compensated |

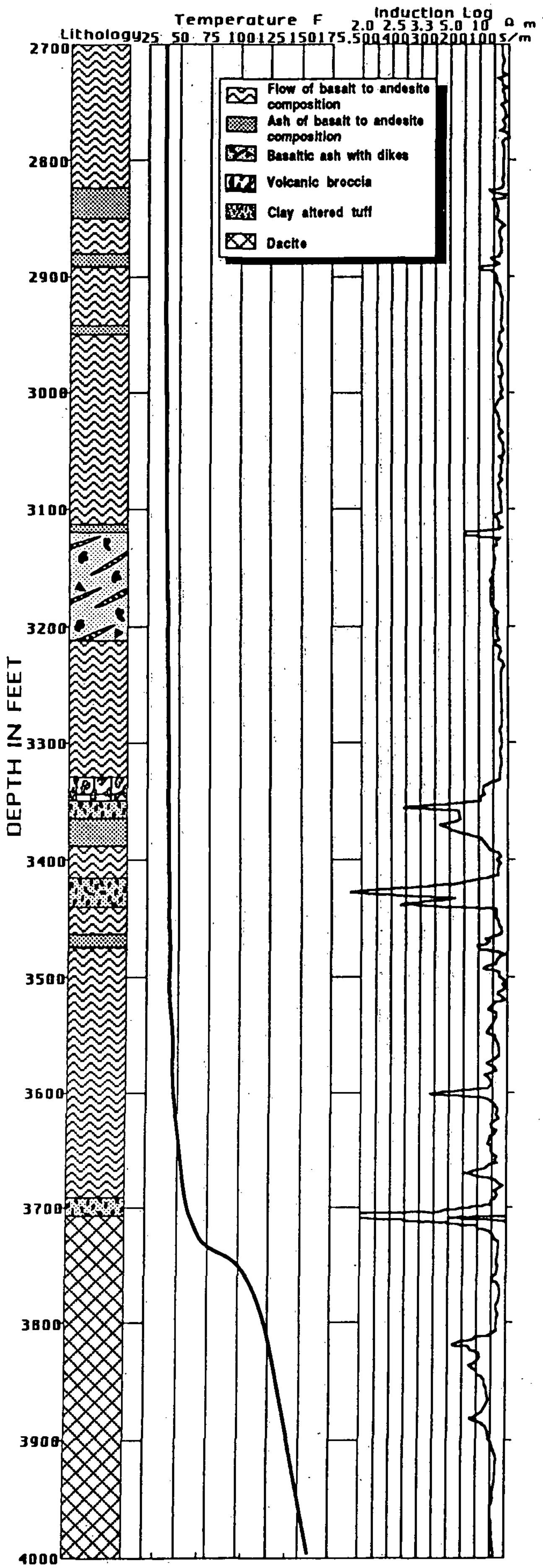
# Time-Domain Electromagnetic Survey




(Fitterman, 1983;
Fitterman et al. 1985)

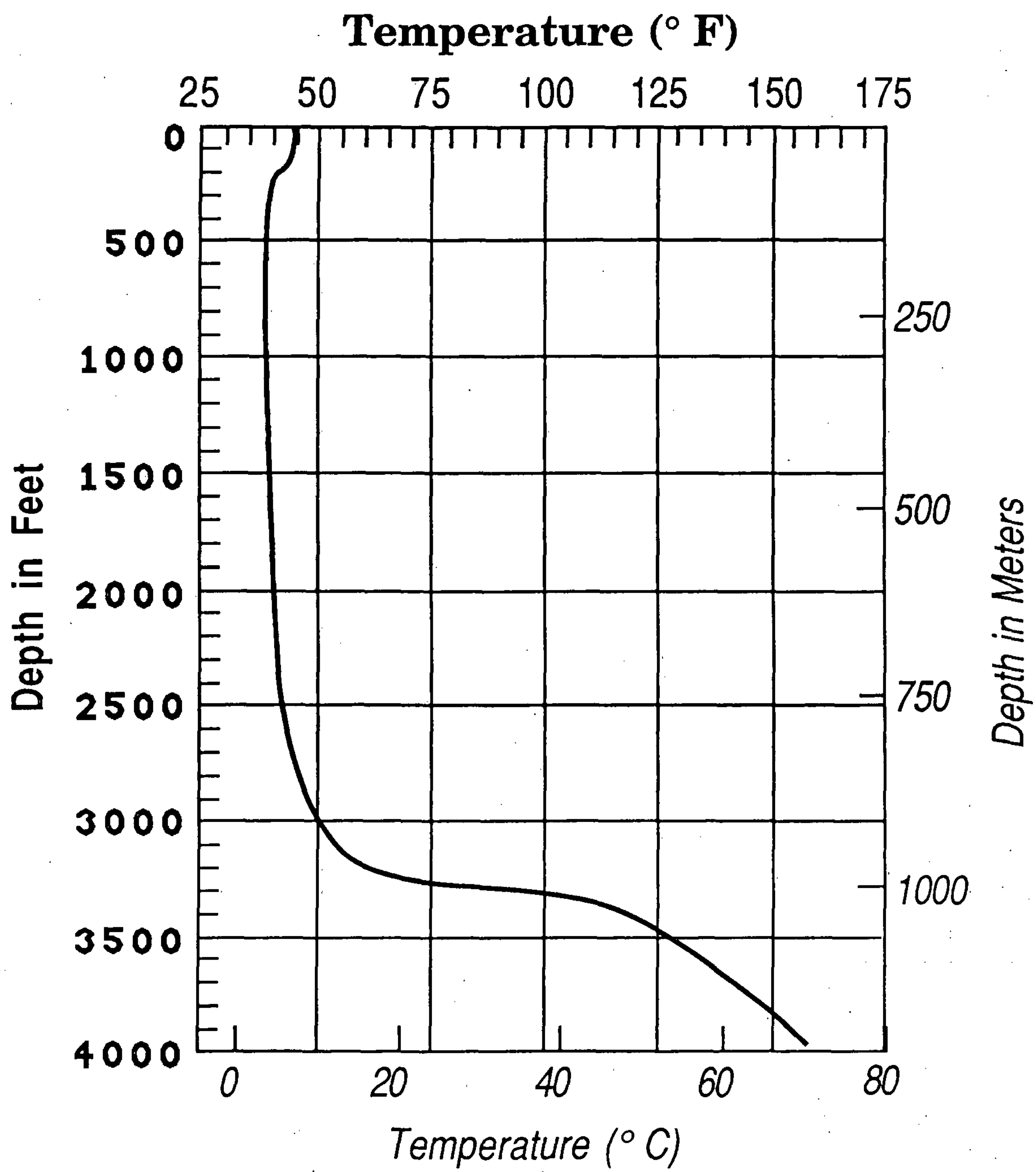
Resistivity of conductive horizon (ohm-m)

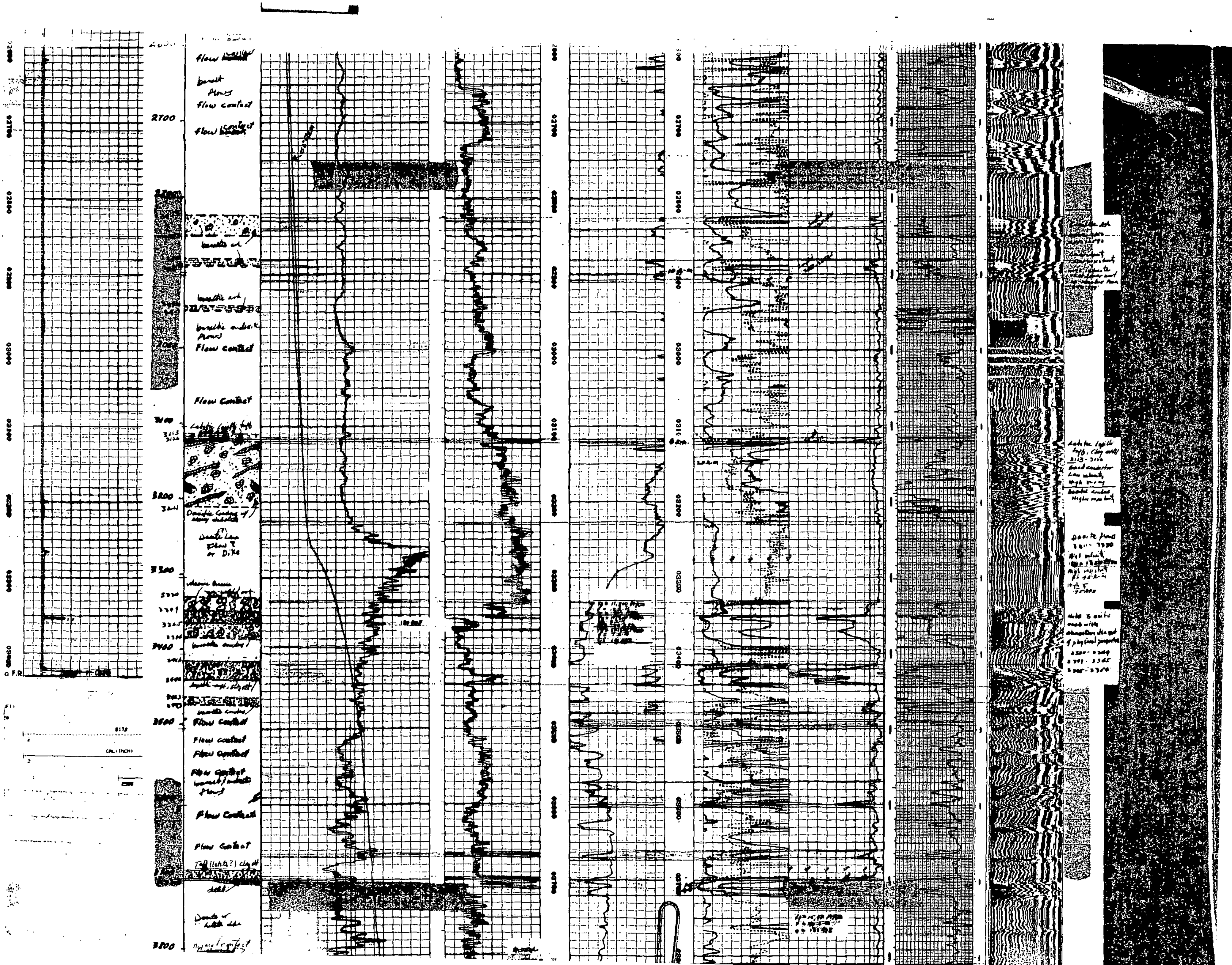
Depth to conductive horizon (m)




**COREHOLE GEO N-1**

# TEMPERATURE - DEPTH LOG
# GEO N-1





2700
Flow contact
Flow Contact
3100
3200
Dacite Lava Flow ? or Dike
3300
3400
3500
Flow Contact
Flow contact
Flow Contact
Flow Contact
Flow Contact
3800

CASCADES DEEP GEOTHERMAL GRADIENT DRILLING PROGRAM

# DOE SUPPORTED SCIENTIFIC STUDIES

University of Utah Research Institute

Oregon Department of Geology and Mineral Industries

Southern Methodist University

U.S. Geological Survey

GEO Operator Corp

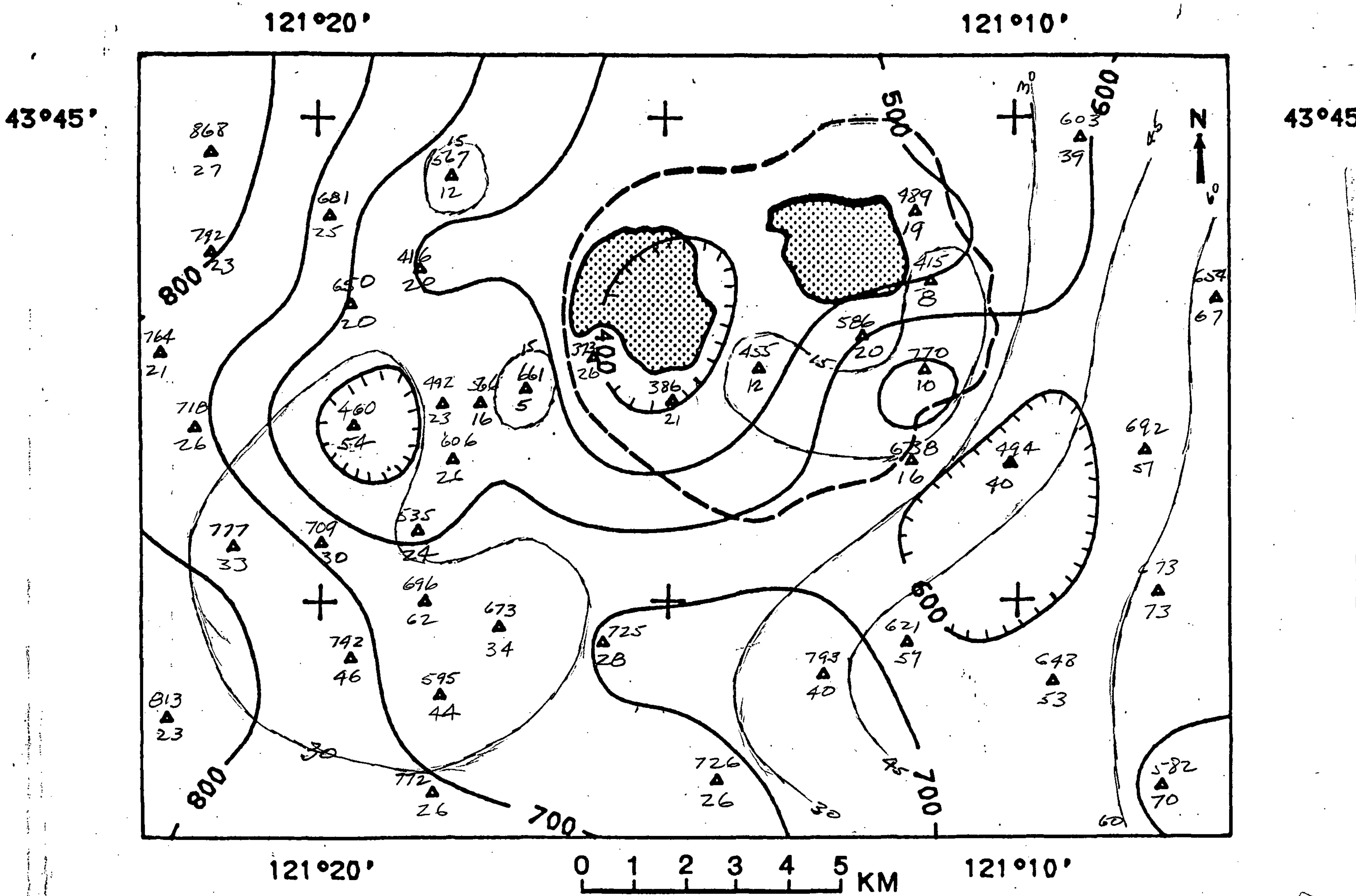
Thermal Power Company

Blue Lake Geothermal

CASCADES DEEP GEOTHERMAL GRADIENT DRILLING PROGRAM

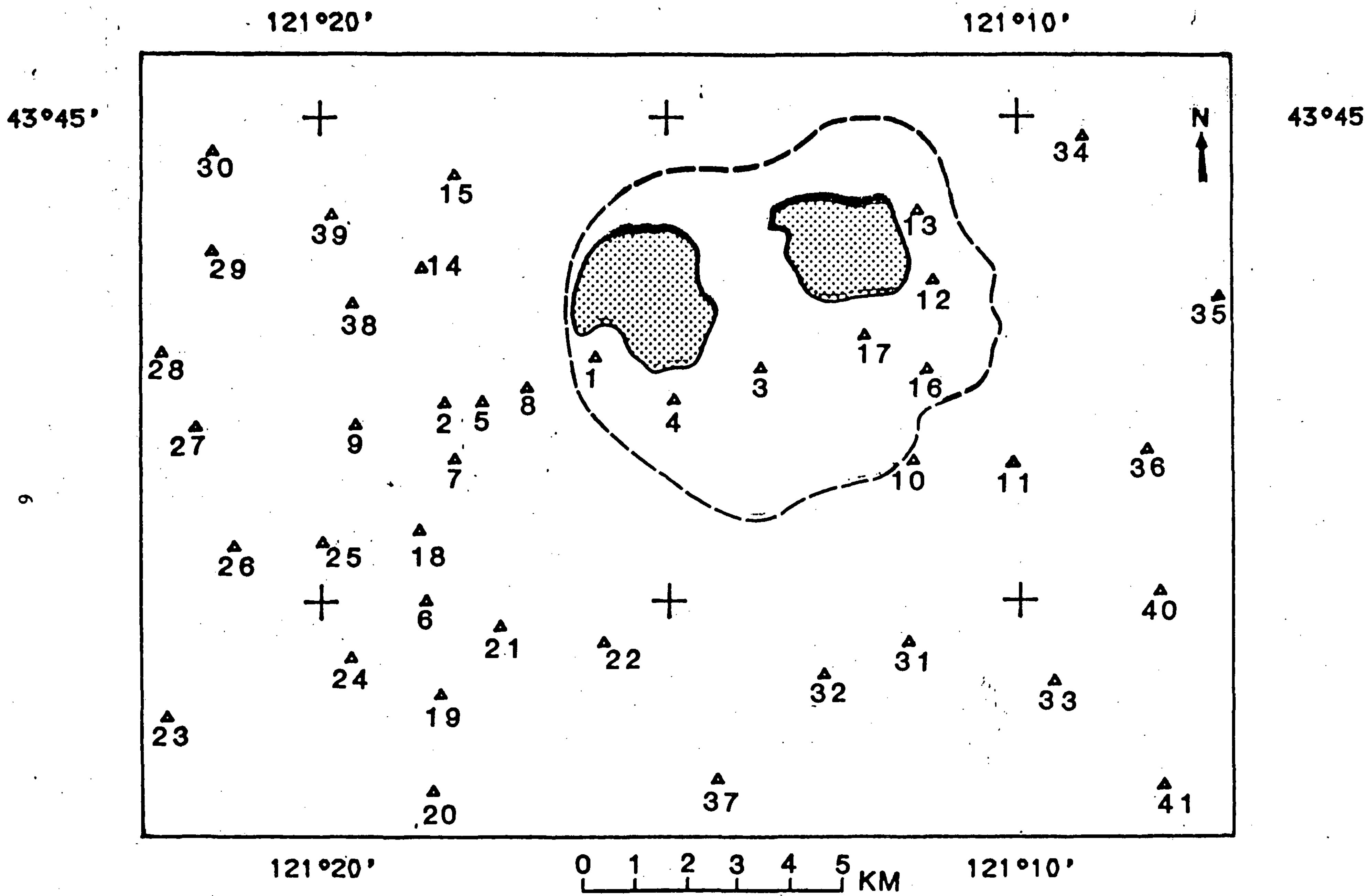
# OPPORTUNITIES

- Holes available for experiments for one year following completion
- Splits of core stored at UURI available for study
- Geophysical well logs




TDEM Soundings - Fitterman
Resistivity lower layer Ω-m
Ink contours - depth to conductor

Figure 25



121°20'
121°10'
43°45'
43°45'
N
30
15
39
29
14
38
28
27
9
2
5
8
7
1
3
4
13
12
17
16
10
11
34
35
36
26
25
18
6
21
22
24
19
23
20
37
32
31
33
40
41
121°20'
121°10'
0 1 2 3 4 5 KM


Figure 1

| Sounding | Upper Layer | | Middle Layer | | Lower Layer |
|---|---|---|---|---|---|
| | Thickness | ρ | Thickness | ρ | ρ |
| 19 | 130 | 1652 | 465 | 509 | 43 |
| 20 | 132 | 848 | 639 | 375 | 26 |
| 21 | 169 | 4992 | 504 | 300 | 34 |
| 22 | 165 | 1689 | 538 | 369 | 28 |
| 23 | 813 | 953 | — | — | 53 |
| 24 | 741 | 483 | — | — | 46 |
| 25 | 120 | 2770 | 589 | 280 | 30 |
| 26 | 150 | 2232 | 626 | 388 | 33 |
| 27 | 122 | 1850 | 595 | 218 | 26 |
| 28 | 119 | 1293 | 645 | 268 | 21 |
| 29 | 291 | 413 | — | — | 23 |
| 30 | 868 | 370 | — | — | 27 |
| 31 | 100 | 1015 | 520 | 403 | 57 |
| 32 | 793 | 456 | — | — | 40 |
| 33 | 648 | 1364 | — | — | 53 |
| 34 | 90 | 275 | 573 | 291 | 39 |
| 35 | 654 | 1424 | — | — | 67 |
| 36 | 692 | 2248 | — | — | 51 |
| 37 | 726 | 2722 | — | — | 26 |
| 38 | 100 | 909 | 550 | 216 | 20 |
| 39 | 130 | 1590 | 551 | 289 | 25 |
| 40 | 672 | 1956 | — | — | 73 |
| 41 | 582 | 1368 | — | — | 20 |

Average $\rho$ 2800 to 4000'

| interval | $\bar{\rho}$ | interval | $\bar{\rho}$ | interval | $\bar{\rho}$ |
|---|---|---|---|---|---|
| 2800 - 20 | 47 | 3300 - 20 | 40 | 3800 - 20 | 10×30 / 10×8 |
| -40 | 25 | -40 | 10×35 / 10×20 | -40 | 10 |
| -60 | 30 | -60 | 8 | -60 | 15 |
| -80 | 40 | -80 | 5 | -80 | 15 |
| -100 | 20 | -100 | 10×20 / 10×50 | -100 | 18 |
| 2900 - 20 | 35 | 3400 - 20 | 12×35 / 8×15 | 3900 - 20 | 30 |
| -40 | 45 | -40 | 3 | -40 | 30 |
| -60 | 37 | -60 | 35 | -60 | 25 |
| -80 | 35 | -80 | 18 | -80 | 25 |
| -100 | 42 | -100 | 10×50 / 10×12 | -100 | 30 |
| 3000 - 20 | 35 | 3500 - 20 | 50 | 4000 | — |
| -40 | 27 | -40 | 25 | | |
| -60 | 45 | -60 | 30 | | |
| -80 | 40 | -80 | 25 | | |
| -100 | 40 | -100 | 15 | | |
| 3100 - 20 | 30 | 3600 - 20 | 30 | | |
| -40 | 10-20 / 10-6 | -40 | 35 | | |
| -60 | 20 | -60 | 20 | | |
| -80 | 18 | -80 | 10×12 / 10×20 | | |
| -100 | 30 | -100 | 25 | | |
| 3200 - 20 | 36 | 3700 - 20 | 5 | | |
| -40 | 40 | -40 | 30 | | |
| -60 | 45 | -60 | 38 | | |
| -80 | 42 | -80 | 40 | | |
| -100 | 40 | -100 | 30 | | |

$$\frac{\Sigma \rho h}{\Sigma h} = 28\ \Omega\text{-m}$$

Table 5.1. Chemical composition of thermal waters at Newberry volcano*
(Source: Mariner and others, 1980)

TDS

| | East Lake Hot Springs | East Lake Hot Springs | Paulina Hot Springs | Little Crater Campground Warm Well |
|---|---|---|---|---|
| Date of sampling | 1973 | 8/1975 | 7/1977 | 8/1975 |
| Specific conductivity | 396 | 767 | - | 900 μmho/cm |
| Temp°C | 62.0 | 49. | - | 35.5 |
| pH | 6.49 | 6.42 | 6.82 | 6.46 |
| $SiO_2$ | 36. | 100. | 205. | 161. |
| $Na^+$ | 32. | 53. | 140. | 83.+ |
| $K^+$ | 3.8 | - | 17. | 10.+ |
| $Ca^{++}$ | 38. | 70. | 56. | 54.++ |
| $Mg^{++}$ | 16. | 34. | 60. | 48.++ |
| $HCO_3^-$ | 184 | 547 | 856 | 679.- |
| $SO_4^=$ | 58. | 28. | <1. | <1. |
| $Cl^-$ | 0.4 | 1.7 | 6.0 | 5.1 |
| $F^-$ | 0.2 | 0.16 | 0.57 | 0.6 |
| B | 0.93 | 1.1 | 0.87 | 2.5 |
| Li | 0.01 | 0.04 | 0.22 | 0.12 |
| Rb | <0.02 | 0.03 | 0.04 | 0.02 |
| Cs | <0.1 | <0.1 | <0.1 | <0.1 |
| Sr | 0.14 | - | - | - |
| Al | - | 0.008m | - | 0.002m |
| Fe | <0.02 | 0.66 | - | 4. |
| Mn | 0.10 | 0.90 | - | 0.25 |
| Hg | 0.0003 | - | - | 0.0001 |

* Concentrations in mg/l; m denotes monomeric aluminum.

Resistivity = 11 Ω-m @ 96°F

$900 \frac{\mu mho}{cm} = 900 \frac{\mu S}{cm}$

$= 900 \times 10^{-6} \times 10^{2} \frac{S}{M}$

$= 900 \times 10^{-4} \frac{S}{M}$

$= 0.09 \frac{S}{M} = 11 \, \Omega\text{-m} \; @ \; 96°F$

10 Ω-m @ 200 ppm, 50°F

at 50°F, Ω = 22 Ω-m

Water Resistivity Calculations

1. For Little Crater CG warm well

(a) $\sigma = 900 \frac{\mu S}{cm}$ measured

$= 900 \times 10^{-4} \frac{S}{m}$

$\rho = 11\ \Omega\text{-m}$ @ 35.5°C = 96°F
$R_w = 22\ \Omega\text{-m}$ @ 50°F

(b) by chemical analysis

$\Sigma cat = 10.69$   $\Sigma an = 11.30$

from Keast & Nelson p 86   $R\ (\text{ohm-m}) \cong \frac{100}{\Sigma C_e \frac{meq}{L}}$ @ 25°C

$R|_{25°C} = \frac{100}{10.69 + 11.3} = 4.6\ \Omega\text{-m}|_{25°C}$

also $R_w|_{T_2} = R_w|_{T_1} \frac{T_1 + 6.77}{T_2 + 6.77}$

$R|_{50} = R|_{77} \frac{77 + 6.77}{50 + 6.77} = 4.6 \times 1.48 = 6.8\ \Omega\text{-m}$

$R_w = 6.8\ \Omega\text{-m}|_{50°F}$

or perhaps $C_e = 11$

then $R|_{25} = \frac{100}{11} = 9.1\ \Omega\text{-m}$

$R|_{50°F} = 9.1 \times 1.48 = 13.5$

(a) $R_o = 70\ \Omega\text{-m}$

$R_w = 14\ \Omega\text{-m}$ | 50°F

$\frac{R_o}{R_w} = \phi^{-2}$ Archies Law

$\phi = \sqrt{\frac{R_w}{R_o}} = \sqrt{\frac{14}{70}} = 0.45 = 45\%$

this is much too high

(b) Sim for $R_w = 22\ \Omega\text{-m}$

$\phi = \sqrt{\frac{22}{70}} = 0.56$

(c) For $R_w = 6.8$ as per chem analyses

$\phi = \sqrt{\frac{6.8}{70}} = 0.31$

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$\phi = \sqrt{\frac{7}{50}} = 0.37$

**********************************************************************

LITTLE CRATER CAMPGROUND
WARM WELL

**********************************************************************

| SPECIES | CONCENTRATION (ppm) | ANALYTICAL METHOD | DETECTION LIMITS | | CONCENTRATION (MOL/L) |
|---|---|---|---|---|---|
| Na | 83.00 | 1 | .61 | | .361E-02 |
| K | 10.00 | 1 | 1.22 | | .256E-03 |
| Ca | 54.00 | 1 | .24 | | .135E-02 |
| Mg | 48.00 | 1 | .49 | | .197E-02 |
| Fe | 4.00 | 1 | .02 | | .716E-04 |
| Al | N.D. | 1 | .61 | < | .741E-07 |
| SiO2 | 161.00 | 1 | .52 | | .268E-02 |
| B | 2.50 | 1 | .12 | | .231E-03 |
| Li | .12 | 1 | .05 | | .173E-04 |
| Sr | N.D. | 1 | .01 | < | .000E+00 |
| Zn | N.D. | 1 | .12 | < | .000E+00 |
| Ag | N.D. | 1 | .05 | < | .000E+00 |
| As | N.D. | 1 | .61 | < | .000E+00 |
| Au | N.D. | 1 | .10 | < | .000E+00 |
| Ba | N.D. | 1 | .61 | < | .000E+00 |
| Be | N.D. | 1 | .00 | < | .000E+00 |
| Bi | N.D. | 1 | 2.44 | < | .000E+00 |
| Cd | N.D. | 1 | .06 | < | .000E+00 |
| Ce | N.D. | 1 | .24 | < | .000E+00 |
| Co | N.D. | 1 | .02 | < | .000E+00 |
| Cr | N.D. | 1 | .05 | < | .000E+00 |
| Cu | N.D. | 1 | .06 | < | .000E+00 |
| La | N.D. | 1 | .12 | < | .000E+00 |
| Mn | .25 | 1 | .24 | | .455E-05 |
| Mo | N.D. | 1 | 1.22 | < | .000E+00 |
| Ni | N.D. | 1 | .12 | < | .000E+00 |
| Pb | N.D. | 1 | .24 | < | .000E+00 |
| Sn | N.D. | 1 | .12 | < | .000E+00 |
| Sb | N.D. | 1 | .73 | < | .000E+00 |
| Te | N.D. | 1 | 1.22 | < | .000E+00 |
| Th | N.D. | 1 | 2.44 | < | .000E+00 |
| Ti | N.D. | 1 | .12 | < | .000E+00 |
| U | N.D. | 1 | 6.10 | < | .000E+00 |
| V | N.D. | 1 | 1.22 | < | .000E+00 |
| W | N.D. | 1 | .12 | < | .000E+00 |
| Zr | N.D. | 1 | .12 | < | .000E+00 |

| | | |
|---|---|---|
| TOTAL | 11.27268 | 100.00000 |

is minimized if the index solution is lowered to approximately 0.1 *M* during the final two saturation washes. The error is eliminated if the quantities of index salt are analytically determined instead.

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## *QUESTIONS AND PROBLEMS*

1. The following distribution of cations and anions exists near a soil colloid surface:

| | 4.0 nm | 3.0 nm | 2.0 nm | 1.0 nm | 0.5 nm | 0.25 nm |
|---|---|---|---|---|---|---|
| Cation concentration (mole (+) $L^{-1}$) | 0.10 | 0.12 | 0.17 | 0.35 | 1.0 | 2.0 |
| Anion concentration (mole (−) $L^{-1}$) | 0.10 | 0.08 | 0.06 | 0.04 | 0.01 | 0.00 |

   Assuming that the excess of cations reported for each increment represents the entire increment (e.g., that the cation concentration is 2.0 moles charge $L^{-1}$ from the colloid surface to 0.375 nm from the surface, etc.), estimate the CEC for a colloid having $800 \times 10^3$ $m^2$ $kg^{-1}$ of reactive surface (Ans. = 12.0 mmoles charge $kg^{-1}$).

2. Based upon the data of Table 6.4, what proportion of the cross-sectional area of a cylindrical soil pore of radius 15 $\mu m$ is influenced by the electric double layer if monovalent ions predominate at a salt concentration of $10^{-1}$ *M*?

3. If all water of a desaturated soil at 20% water content is spread uniformly over $100 \times 10^3$ $m^2$ $kg^{-1}$ of reactive surface, what proportion of that water is influenced by the electric double layer for the chemical conditions specified in Problem 2?

4. A soil is equilibrated with a solution of SAR = 20. Based upon the Gapon equation, what would be its equilibrium exchangeable sodium per-