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ESL-154

INDICATIONS OF MINERAL ZONING IN A FOSSIL HYDROTHERMAL SYSTEM AT THE MEAGER CREEK GEOTHERMAL PROSPECT, BRITISH COLUMBIA, CANADA, FROM INDUCED POLARIZATION STUDIES

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May 1985

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TABLE OF CONTENTS

ABSTRACT

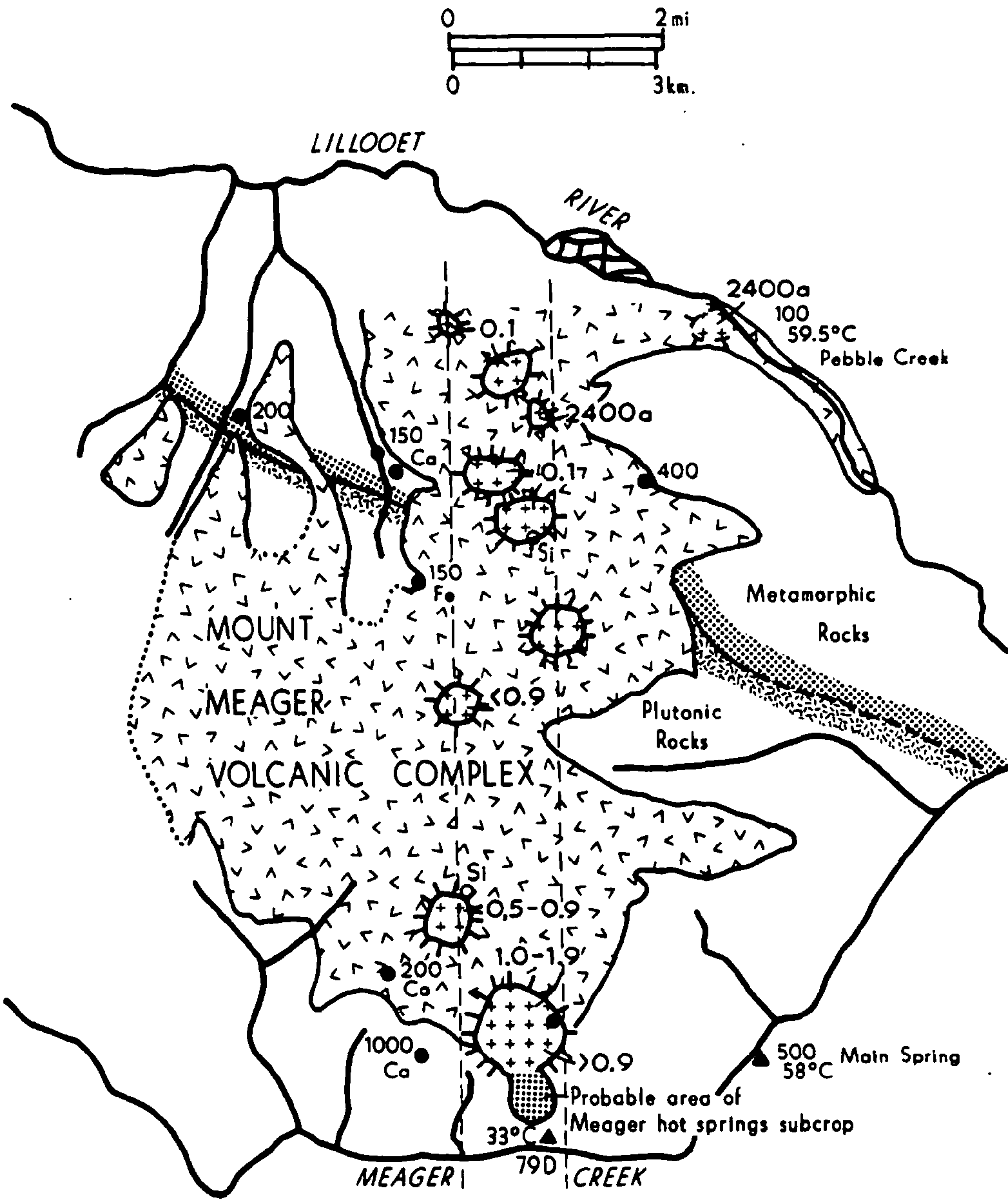
By measuring the induced-polarization parameters m (chargeability) and τ (time-constant) we have found evidence that the center of a presumed fossil hydrothermal system at Meager Creek, British Columbia, lies south of the main manifestation of the present-day convective hydrothermal system. What implication this finding has for development of the present-day system is unknown. However, some of the fractures formed during the development of the fossil hydrothermal system may serve as conduits for fluids of the present-day system. The analysis is limited by the lack of availability of a good subsurface distribution of core samples. Nevertheless, a surface induced-polarization survey is expected to yield information about the geometry of the fossil system. Such knowledge would have implications not only for Meager Creek but for other hydrothermal systems of Cascades volcano type.

INTRODUCTION

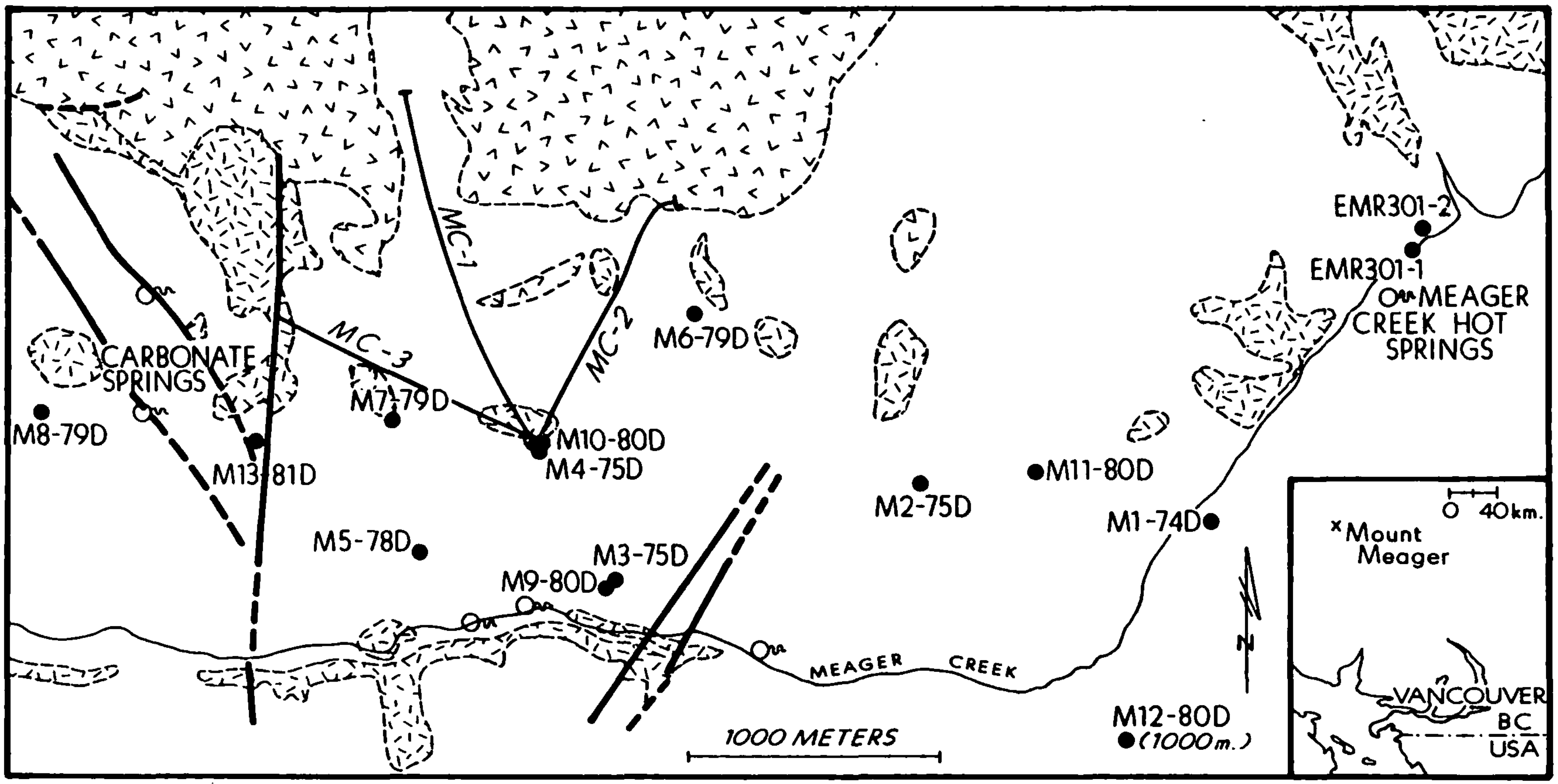
Meager Mountain, the northernmost volcano in the Cascade and Garibaldi volcanic belts of the U.S. and Canada has been the site of intensive geothermal exploration since 1973 (Fairbank et al., 1981; Souther, 1976). This Pliocene-to-Recent volcano is located approximately 150 km north of Vancouver in the Coast Mountains of southwestern British Columbia. Geothermal exploration efforts during the past ten years have been concentrated primarily on the southern flank of Meager Mountains, 8 km from an area of hot springs which discharge into Meager Creek (Figure 1). Fifteen core holes to depths to 1 140 m and three 3 000-3 500 m rotary wells have been drilled (Figure 2). One well, MC-1, is capable of sustained steam production.

Cuttings and core from the wells have been studied petrographically and chemically (Moore et al., 1983, 1985). These data indicate that the plutonic and metamorphic rocks underlying Meager Mountain were extensively altered prior to the onset of volcanic activity and development of the modern day geothermal system. The geochemical characteristics of these rocks are typical of those found in the zones of propylitic and sericitic alteration that characterize the outer portions of many porphyry-copper systems (Lowell and Guilbert, 1970; Rose and Burt, 1979).

This paper presents new data on the electrical properties of the altered rocks. Induced electrical polarization spectra were obtained on 25 core samples from six of the shallow drill holes and from core taken during drilling of the three deep wells. The results of these measurements have been used to locate more accurately the position of the geothermal wells relative to the principal features of the porphyry system. It seems to us that any knowledge we can gain of the porphyry, i.e. fossil-hydrothermal, system should have a



HOT SPRINGS	▲ 500 59.5°C Pebble Cr.	Flow in liters per minute Temperature Name
COLD SPRINGS	● 200 Ca	Flow in liters per minute Dominant cation in sinter
FOSSIL SPRINGS	○Si	Dominant cation in sinter
VENT	1.2	Known, inferred; age in Ma


MC-1
MC-2
MC-3
CARBONATE SPRINGS
M8-79D
M13-81D
M7-79D
M10-80D
M4-75D
M6-79D
M5-78D
M3-75D
M9-80D
M2-75D
M11-80D
M1-74D
EMR301-2
EMR301-1
MEAGER CREEK HOT SPRINGS
MEAGER CREEK
M12-80D
(1000 m.)
1000 METERS
N
0 40km.
Mount Meager
VANCOUVER
BC
USA

significant impact on understanding the present-day hydrothermal system. Indeed, it is conceivable that the fractures of the fossil system may have reopened and therefore may now serve as conduits for the present-day system.

GEOLOGIC RELATIONSHIPS AND ROCK DESCRIPTIONS

Pre-volcanic rocks exposed near the base of Meager Mountain and penetrated in the drill holes consist of metamorphic and intrusive rocks of the Mesozoic Coast Range Complex, although intrusive rocks as young as Tertiary are also present (Fairbank et al., 1981; Reed, 1979). Locally, the basement rocks are intruded by dikes of the Mount Meager Volcanic Complex. The most recent volcanic activity produced the Bridge River Ash 2 440 ± 10 years B.P. from a vent on the north side of Meager Mountain (Nasmith et al., 1967).

Dikes related to the active volcanism intrude the basement complex and range from silicic to basic in composition although intermediate compositions predominate. The dikes contain sparse phenocrysts of plagioclase, and less commonly biotite, hornblende, pyroxene, or quartz. Locally intense alteration of the dikes suggests that fractures associated with them have been important conduits for the movement of the geothermal fluids.

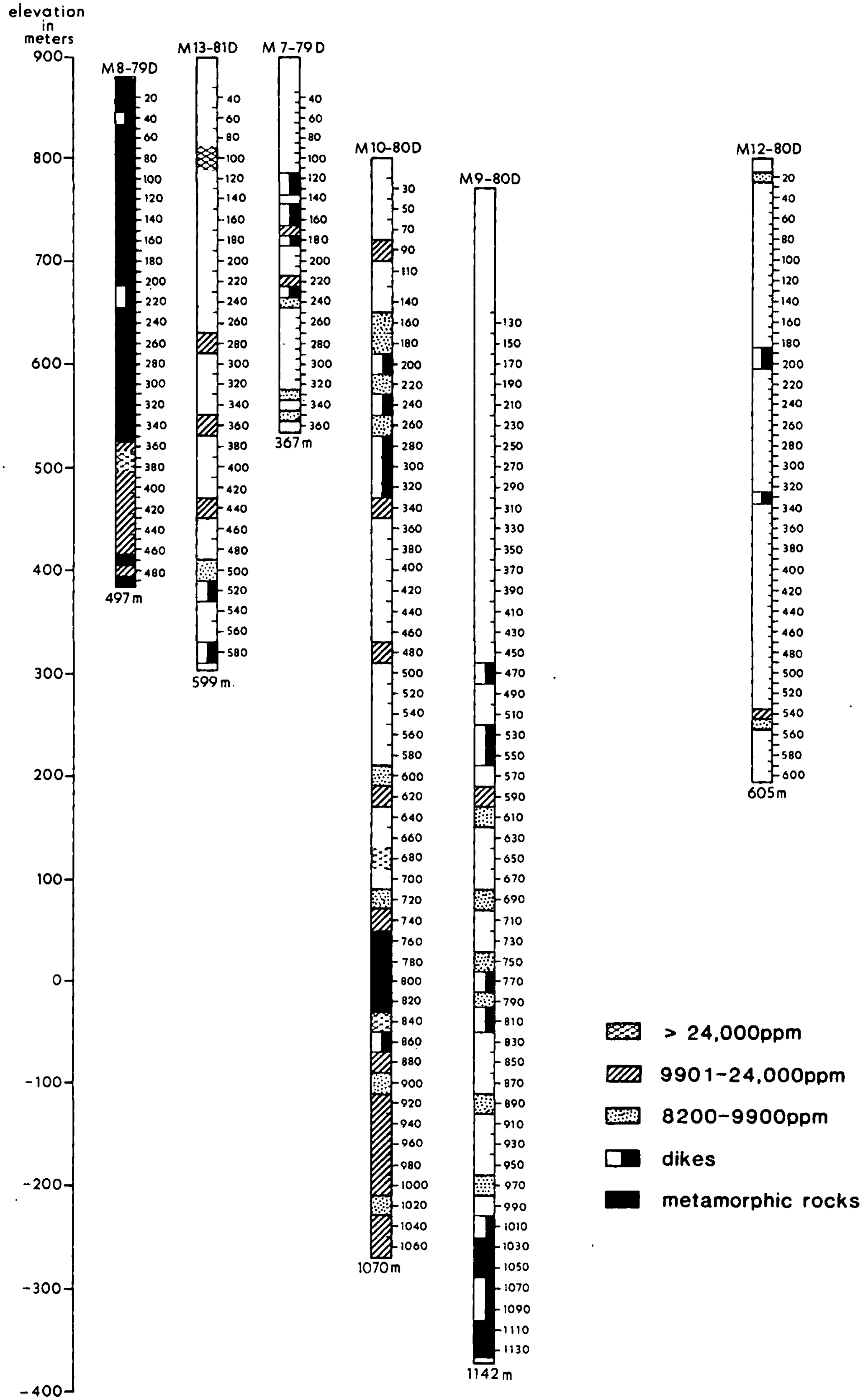
The basement rocks consist primarily of regionally metamorphosed quartz diorite characterized by the mineral assemblage quartz + hornblende + epidote + biotite + andesine + opaques. Propylitic alteration is superimposed on the metamorphic assemblage. This alteration assemblage consists of chlorite + illite + epidote + Fe-Ti oxides. Veins containing quartz, epidote, potassium feldspar, calcite, fluorite and the sulfides pyrite, chalcopyrite, sphalerite and galena occur sporadically in the metamorphosed rocks.

At depths below 2 500 m (vertical depth) in MC-3 and at depths greater than 1 600 m (vertical depth) in MC-1, the metamorphic rocks are intruded by fresh quartz diorite. The quartz diorite consists of a porphyritic phase containing phenocrysts of plagioclase and biotite, and an equigranular phase characterized by hornblende. These rocks appear to form the core of the porphyry system.

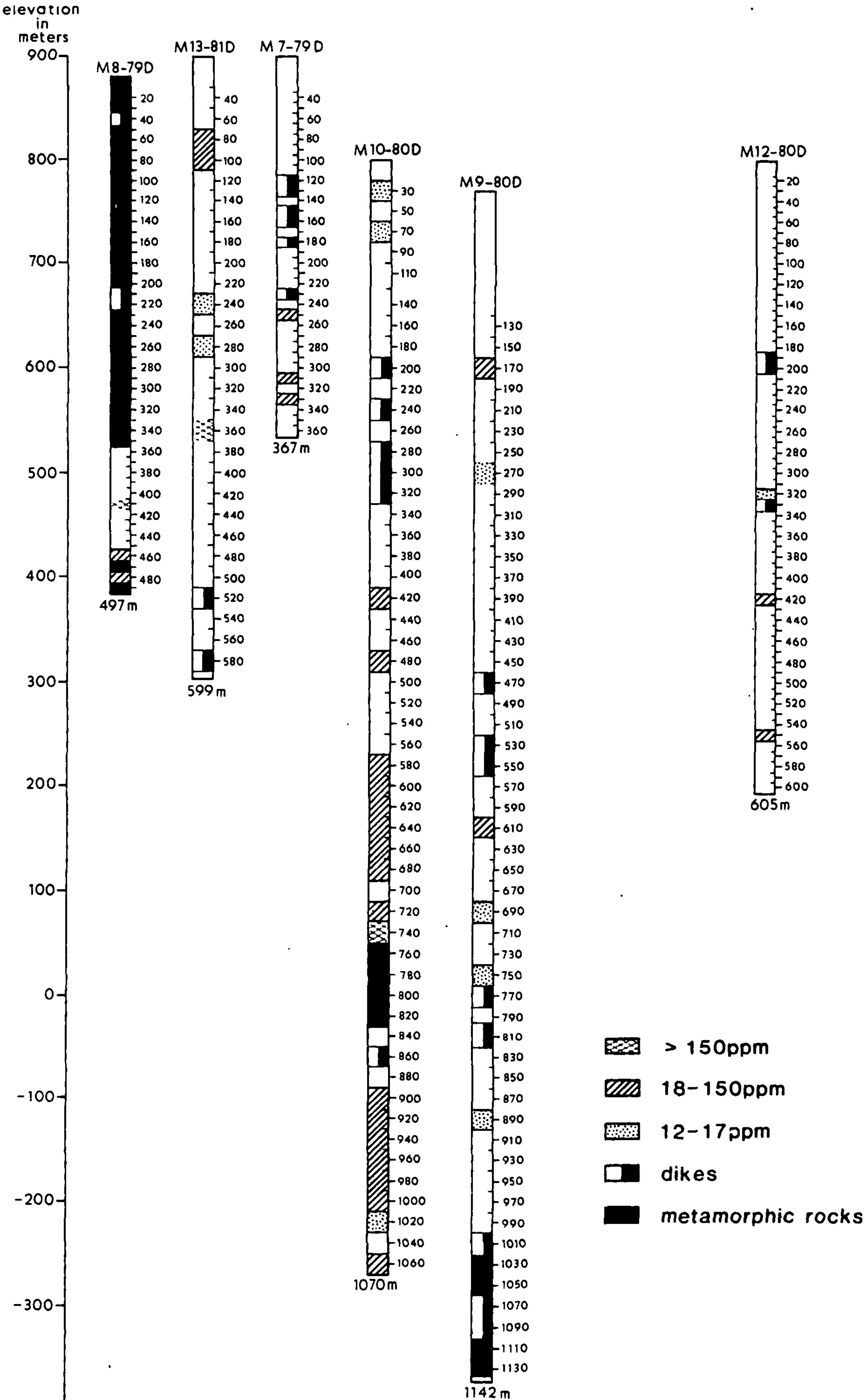
The elemental association Hg + Cu + Zn + Pb + Ba + K is diagnostic of the hydrothermally altered basement complex. Figures 3 and 4 illustrate the distribution of K and Cu in the shallow drill holes. The diagrams were prepared by plotting the distribution of samples whose concentration differed from local background values by more than one standard deviation. The threshold values for the two lower intervals are mean plus 1 standard deviation and mean plus 2 standard deviations. The highest interval contains samples within the upper 2-1/2 percent of the data. The figures display a strong correlation between K and Cu. In the altered rocks, K is present in sericite, whereas Cu occurs mainly in chalcopyrite. Chemical analyses of the volcanic dikes, hot spring deposits and geothermal scales indicate that these elements are present only in low concentrations and that they have not been significantly remobilized by the present geothermal system.

Inspection of Figures 3 and 4 shows that K and Cu are concentrated primarily near the base of M-8 and in the lower third of M-10. Similarly altered rocks are found in the deep wells M-1, M-2 and M-3. The absence of significant enrichments in M-9 and M-12, on the other hand, suggest that alteration may not extend south of Meager Creek. The apparently restricted distribution of these elements suggests that their abundance has been strongly controlled by structure.

Despite widespread evidence of fracturing and brecciation in the altered rocks, the structural features of the field and their relationship to the alteration patterns have not yet been established. In part this reflects the extensive surficial cover in the area, and in part the lack of suitable marker



elevation in meters
M8-79D
M13-81D
M 7-79D
M10-80D
M9-80D
M12-80D
497 m
599 m
367 m
1070 m
1142 m
605 m
> 24,000ppm
9901-24,000ppm
8200-9900ppm
dikes
metamorphic rocks

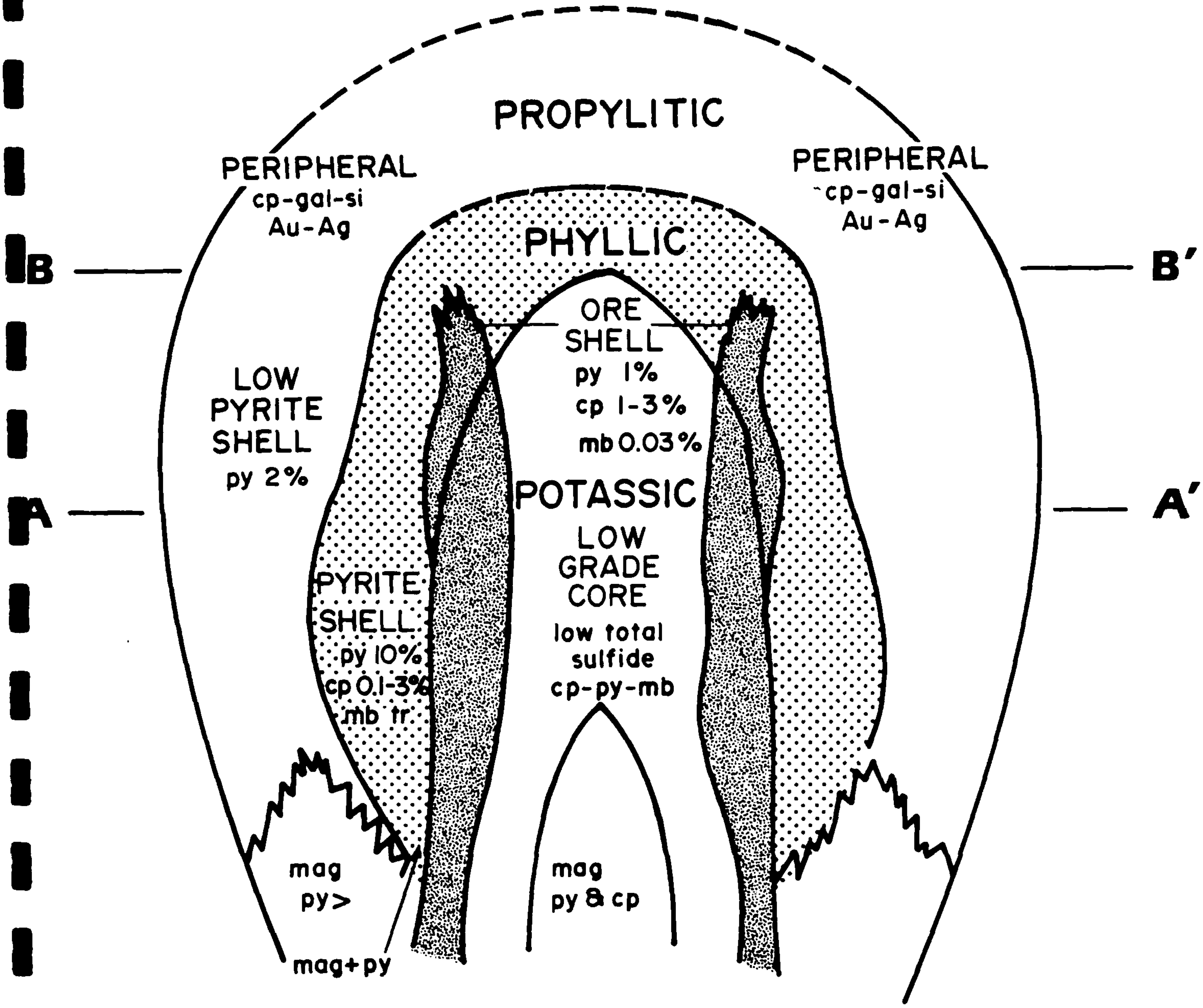

elevation in meters
900
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
M8-79D
497m
M13-81D
599m
M 7-79 D
367m
M10-80D
1070m
M9-80D
1142m
M12-80D
605m
> 150ppm
18-150ppm
12-17ppm
dikes
metamorphic rocks

horizons at depth. Fairbank et al. (1981) concluded that northerly and easterly trending faults are the dominant fault directions on the southern flank of Meager Mountains. The striking alignment of volcanic vents across Meager Mountains (Figure 1; Reed, 1979), however, suggest that the northerly trending faults are a reflection of a deep-seated zone of weakness beneath the volcano. Consequently, they may have been of particular significance in localizing both the past and present hydrothermal systems.

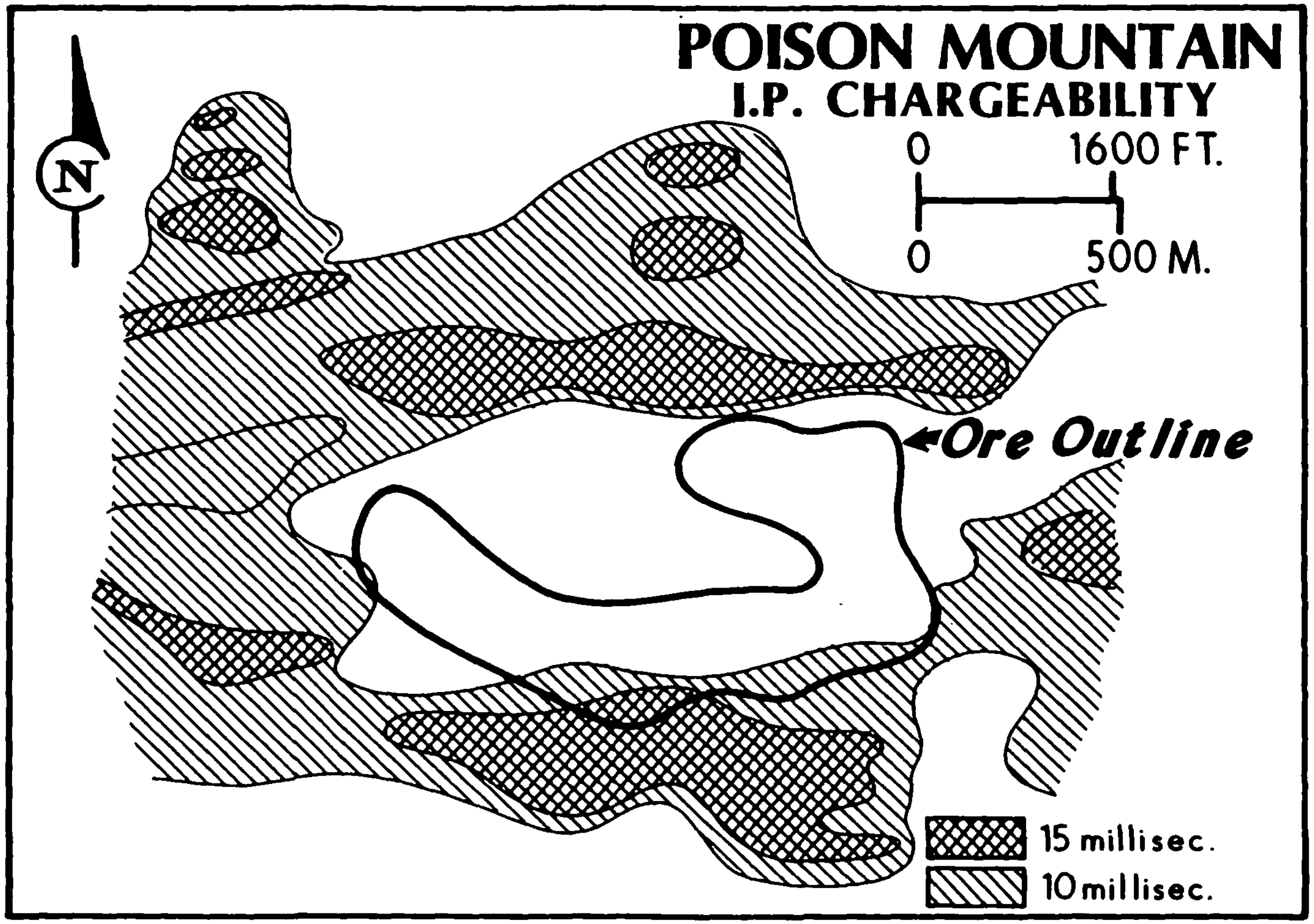
THE LOWELL-GUILBERT MODEL OF A PORPHYRY SYSTEM AND ITS IP SIGNATURE

Figure 5 portrays the Lowell and Guilbert (1970) model of a porphyry copper system. The propylitic zone is typically low in pyrite and other electrically polarizable minerals. The phyllic zone contains abundant pyrite, sometimes up to 20 percent, and hence is highly polarizable. An argillic zone, sometimes present between the phyllic and propyllitic zones, is polarizable due to the presence of pyrite plus kaolinite, montmorillonite, and other clay minerals. The moderately polarizable chalcocite-bornite-chalcopyrite ore occurs as a shell localized just inside the potassic core. The inner part of the core is relatively barren and only slightly polarizable. If such a porphyry system is eroded to, say A-A' of Figure 5, then the classical IP plan view of Figure 6 occurs. The pyrite halo is clearly visible in the IP data but the location of the ore must be inferred from this data by reference to the Lowell and Guilbert model of Figure 5. On the other hand, if erosion has only proceeded to level B-B' of Figure 5, then the plan view of Figure 7 occurs; the response of the cap of pyrite obscures the response of the shell of mineralization within it. Many variants on these two patterns may be seen for the classical Lowell and Guilbert model (Ward, 1982). The model of Lowell and Guilbert was derived from a reconstruction of the San Manual-Kalamazoo quartz monzonite system which had been tilted by 70 degrees and then faulted roughly along the overturned axis.

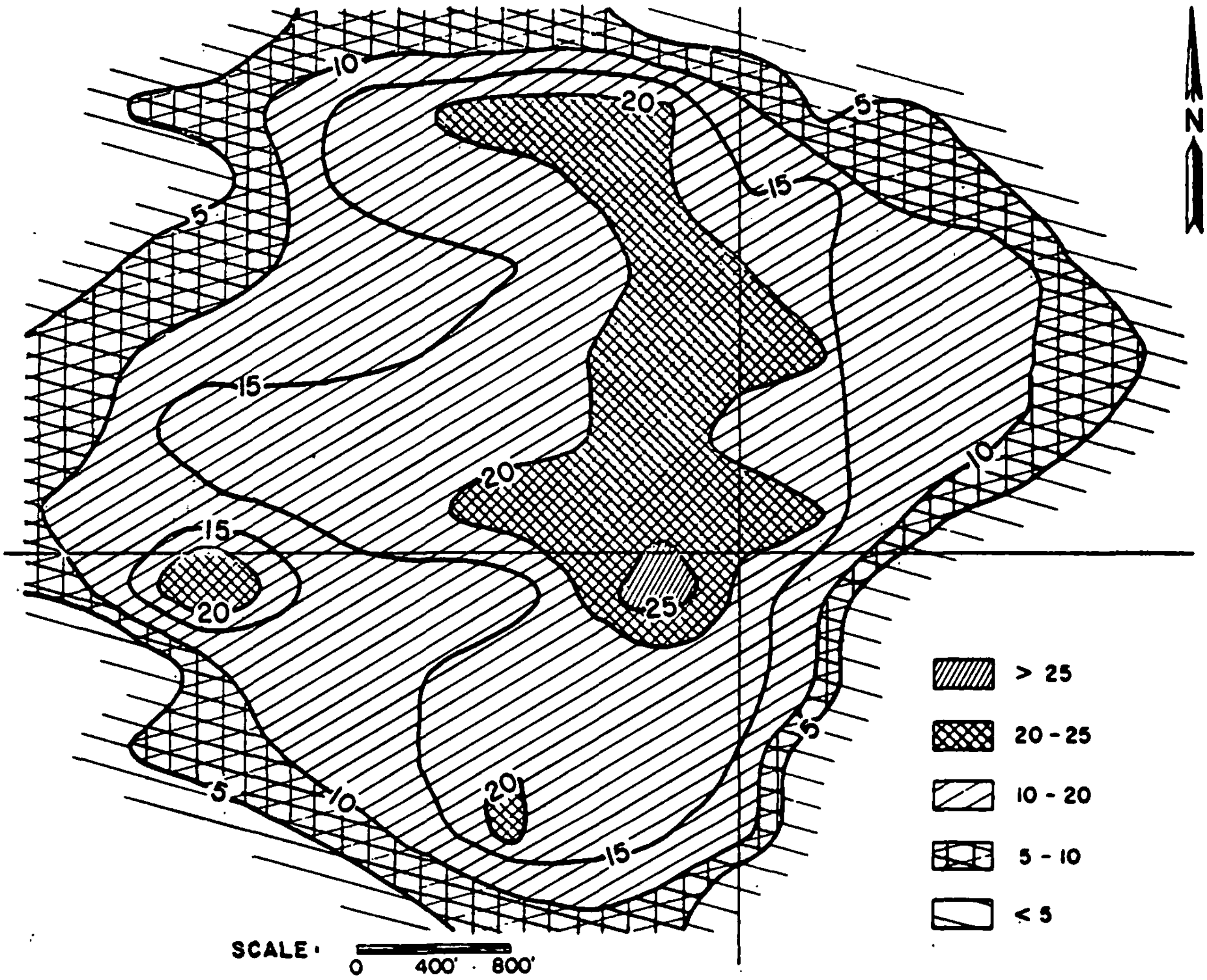
The mineral zoning of the Lowell and Guilbert model is typical of porphry systems occurring in continental interiors such as that of the southwestern U.S.A. When porphyries develop in marine-sediment environments of coastal margins, then the compositions of the intrusive and the mineral zoning will be different. The diorite model of Hollister (1975) pertains to such environ-


PROPYLITIC
PERIPHERAL
cp-gal-si
Au-Ag
PERIPHERAL
cp-gal-si
Au-Ag
B
B'
PHYLLIC
ORE
SHELL
py 1%
cp 1-3%
mb 0.03%
LOW
PYRITE
SHELL
py 2%
A
A'
POTASSIC
LOW
GRADE
CORE
low total
sulfide
cp-py-mb
PYRITE
SHELL
py 10%
cp 0.1-3%
mb tr
mag
py>
mag
py & cp
mag+py

SW/ThL-001


POISON MOUNTAIN
I.P. CHARGEABILITY
0
1600 FT.
0
500 M.
N
Ore Outline
15 millisec.
10 millisec.

SW/BC-018



N
> 25
20 - 25
10 - 20
5 - 10
< 5
SCALE
0 400' 800'

ments. The Afton deposit in British Columbia and the Skouries deposit in Greece are of this type. The occurrence of a pyrite halo still dominates the induced polarization signature for these deposits. When porphyries of either the Lowell and Guilbert or Hollister descriptions invade limestones, then skarn mineralization occurs in the vicinity of the intrusive-limestone contact. This results in additional zones of polarizable mineralization which may be rich in lead-zinc, iron-copper, or both (Einaudi et al., 1981). These additional zones of mineralization enlarge the size and change the pattern of the zone of polarizable materials. Also, when a porphyritic intrusive invades a batholith, the pyrite halo may be subdued and only the economic mineralization will produce a significant IP anomaly (Ward, 1982). Finally, when a mineralizing porphyry invades a highly faulted terrain, the IP patterns in plan view are apt to be elongate (Pelton and Smith, 1976).

PURPOSE OF STUDY

The Meager Creek hydrothermal prospect is located in rugged terrain of rain forests and glaciers in which earth slides are common. Hence, performing electrical resistivity and IP surveys, is extremely difficult (Shore, 1978). Thus we have chosen to make laboratory measurements on core samples in order to ascertain if IP may contribute to delineation of the fossil hydrothermal system. If these pilot laboratory experiments provide useful information on the trends of mineral zoning in the fossil hydrothermal system, then field IP surveys may be warranted. The implications for application of IP surveys in other convective hydrothermal systems of the Cascades are unknown. We maintain, however, that fundamental studies such as this are essential if we are ever to arrive at exploration architecture suitable for delineation of hydrothermal systems of the Cascades volcanoes.

PROCEDURES

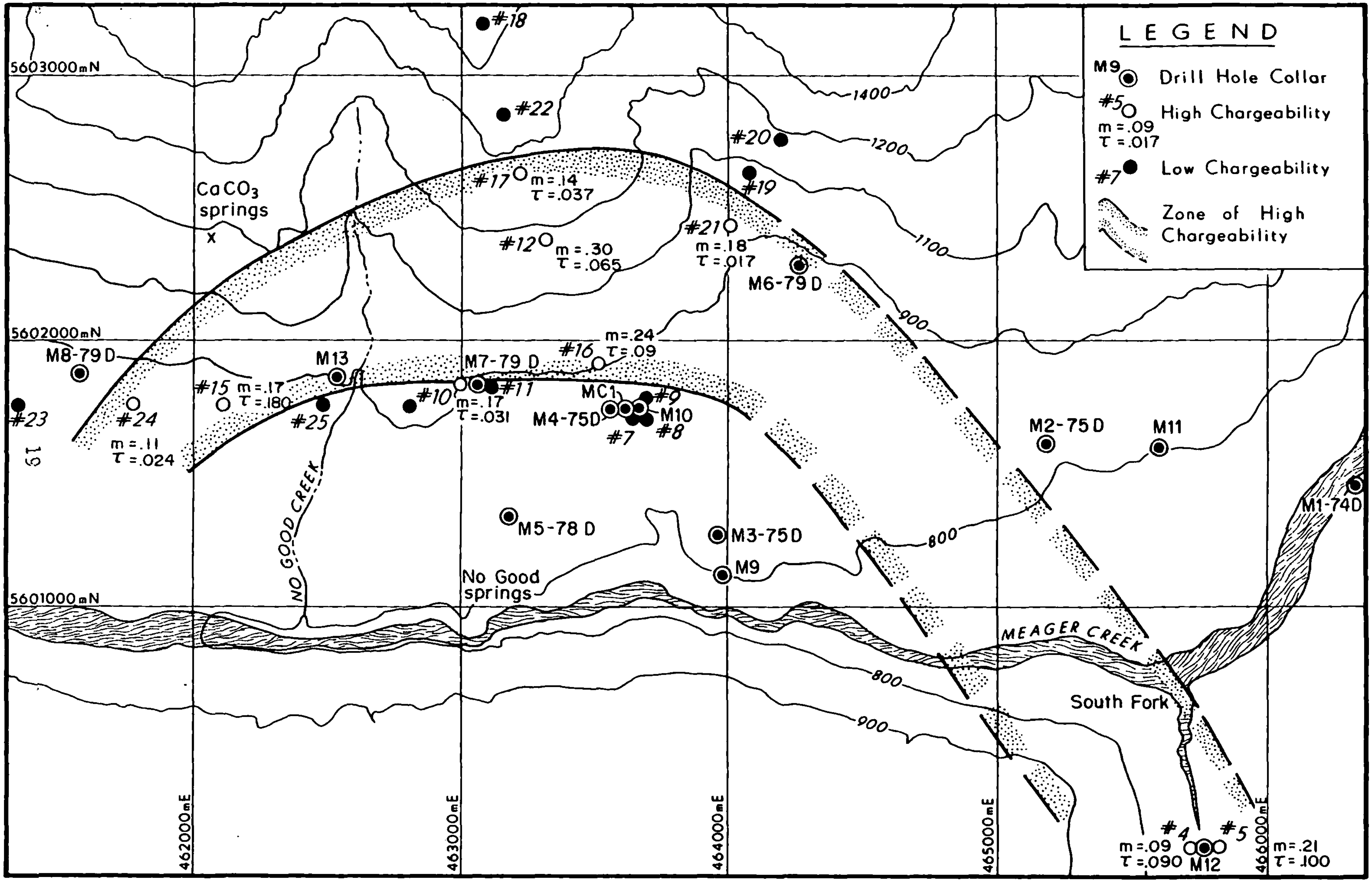
The samples were selected on the basis of their petrologic characteristics and spatial distribution in order to correlate the induced electrical polarization (IP) measurements with the porphyry system. Table 1 shows that the samples represent the various rock types in the Meager Creek area. The variation in the intensity of alteration in Table 1 reflects the fact that the different zones in the hydrothermal system are also represented. The sample location map (Figure 8) confirms that the samples cover a sparse distribution of the study area; additional core samples were not available.

The core samples were cut into parallel-faced slabs for mounting in a standard four-electrode sample holder. The geometric factor, the ratio of area to thickness, ranged from 0.15 to 0.50 m. They were then vacuum-saturated and measured at NaCl concentrations of 0.05, 0.15, 0.30 and 0.45 molar. These NaCl concentrations were chosen by calculating the resistivity of the in-situ pore fluid as derived from water chemistry.

Measurements of the amplitude and phase of electrical resistivity were made at binary frequency steps over the range of 1/256 to 1 024 Hz using an instrument manufactured by the Zonge Engineering and Research Organization. The data reduction and amplitude-drift correction was performed on an Hewlett Packard 9825A desktop computer. From our experience the drift correction yielded accurate amplitude if the total drift was kept below 5 percent of the amplitude. The drift was kept to a minimum by letting the temperature of the sample holder equilibrate to room temperature for a period of three to four hours prior to measurement.

TABLE 1 SAMPLE LOCATIONS, DESCRIPTIONS, MINERALOGY, AND IP PARAMETERS

SAMPLE NUMBER	ROCK TYPE	Smectite	Illite-Smectite	Illite	Chlorite	Quartz	K-feldspar	Epidote	Calcite	Iron Oxides	Pyrite	Cpy.	Bornite	Intensity	m (For mol. concentration)				τ (For mol. concentration)			
															.05	.15	.30	.45	.05	.15	.30	.45
4 (M-12-190)	dike	X							X					S		.090	.055	.030		.090	.056	.061
5 (M-12-90)	m·q·d	X	X	X	X			X	X	X				W		.21	.15	.13		.100	.047	.038
6 (M-12-150)	m·q·d			X	X			X	X					M								
7 (M-10-280)	dike		X	X	X	X			X	X				S								
8 (M-10-480)	h.b			X	X				X		X			S								
9 (M-10-140)	m.q.d	X		X	X			X	X	X				W								
10 (M-7-130)	dike	X	X	X	X	X			X	X				S	.18	.17	.12	.10	.035	.031	.024	.021
11 (M-7-330)	m.q.d			X	X			X	X	X	X			M								
12 (MC-1-1539.3)	m.q.d			X	X	X		X	X	X	6	X		S	.32	.30	.25	.25	.098	.065	.030	.030
14 (MC-3-1380.5)	m.q.d			X	X			X		X				M								
15 (MC-3-2369.8)	q.diorite			X	X						7	3		M	.20	.17	.13	.08	.710	.180	.100	.080
16 (MC-1-820)	m.q.d			X	X	X		X	X		4	X	2	S		.24				.090		
17 (MC-1-2030.2)	q.diorite											X		W		.14				.037		
18 (MC-1-3039.7)	q.diorite			X	X			X	X		X			W								
19 (MC-2-2626.2)	m.q.d			X	X	X	X	X	X					W								
20 (MC-2-3501.5)	m.q.d				X			X						W								
21 (MC-2-2220.4)	m.q.d			X	X	X	X	X			X	X		M		.12				.017		
22 (MC-1-2437.1)	q.diorite			X	X			X				X		W								
23 (MC-3-3500.7)	q.diorite				X									W								
24 (MC-3-2871.0)	m.q.d			X	X				X		5			M		.11				.024		
25 (MC-3-1857.3)	m.q.d			X	X			X			X			W								


LEGEND
M9 Drill Hole Collar
#5 High Chargeability
m = .09
τ = .017
#7 Low Chargeability
Zone of High Chargeability
5603000mN
5602000mN
5601000mN
462000mE
463000mE
464000mE
465000mE
466000mE
1400
1200
1100
900
800
800
900
CaCO3 springs
No Good springs
NO GOOD CREEK
MEAGER CREEK
South Fork
#18
#22
#20
#19
#17 m = .14 τ = .037
#12 m = .30 τ = .065
#21 m = .18 τ = .017
M6-79 D
#16 m = .24 τ = .09
M8-79 D
M13
M7-79 D
#11
#15 m = .17 τ = .180
#23
#24 m = .11 τ = .024
#25
#10
m = .17 τ = .031
MC1
#9
M10
M4-75D
#7
#8
M2-75 D
M11
M1-74D
M5-78 D
M3-75 D
M9
#4
#5
m = .09 τ = .090
M12
m = .21 τ = .100

RESULTS

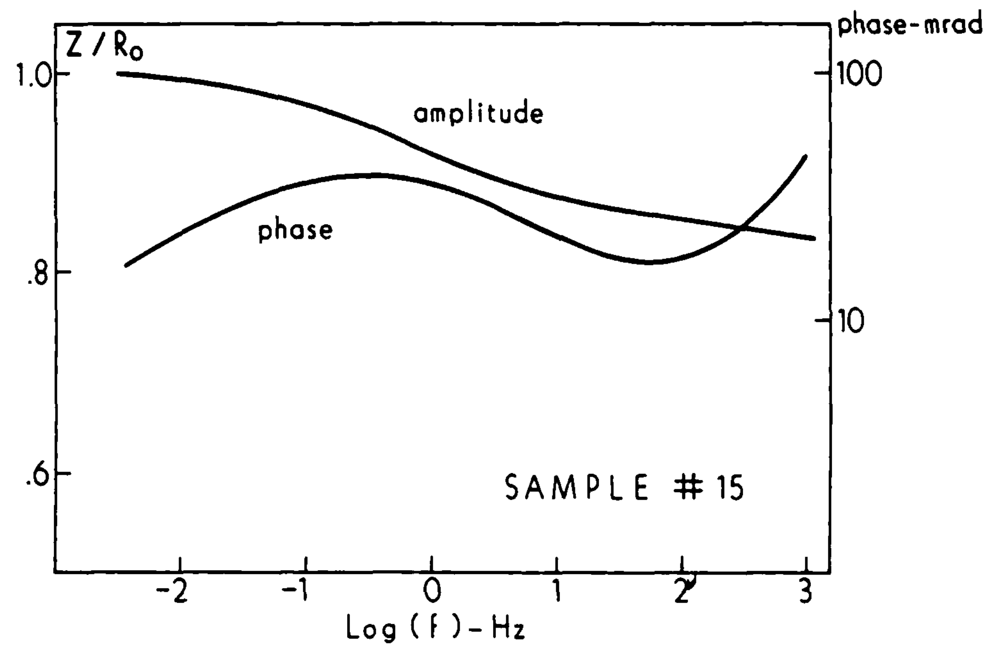
Nine of the twenty-three samples measured displayed appreciable chargeabilities (m), as displayed in Figure 8, for NaCl concentrations ranging from 0.5 to 0.45. The chargeabilities (m), the time constants (τ), for a concentration of NaCl (molar) of 0.15 are all plotted in Figure 8 opposite each sample measured. The values of high chargeability all occur in an arcuate zone which trends from northeast in the west to southeast in the east, and which is therefore concave to the south. Clearly the sampling is not as thorough as one might wish, but this is solely controlled by *available* core. The chargeabilities range from m = 0.09 to m = 0.30 with a mean of 0.18. The time constants range from 0.017 to 0.180 with a mean of 0.07. There is no systematic geographic pattern to either m or τ.

A typical example of resistivity spectra phase and amplitude is shown in Figure 9. The amplitude data has been normalized by the amplitude at the lowest frequency and the phase is plotted on a logarithmic scale. The amplitude of the resistivity decreases with increasing frequency as is typical of an induced polarization response. The phase has a characteristic IP mid-frequency ($\sim 10^{-1}$ Hz) high and a high frequency "phase tail" which is attributed to the effect of the sample-holder.

The data was modeled using a Cole-Cole dispersion multiplied by an asymptotic phase expression which represents the high-frequency "phase tail". The mathematical expression for the model is

$$Z(\omega) = R_0[1 - m\ (1 + \frac{1}{1 + (i\omega\tau_1)^{c_1}})]\ [\frac{1}{1 + (i\omega\tau_2)^{c_2}}]\ , \qquad (1)$$

where


Z / Ro
1.0
.8
.6
phase-mrad
100
10
amplitude
phase
SAMPLE # 15
-2
-1
0
1
2
3
Log (f) - Hz

$Z(\omega)$ = complex impedance ($\Omega \cdot m$)

R_0 = low frequency asymptotic resistivity ($\Omega \cdot m$)

R_∞ = high frequency asymptotic resistivity ($\Omega \cdot m$)

$m_i = 1 - \frac{R_\infty}{R_0}$ = chargeability (dimensionless)

τ_1 = time constant (s)

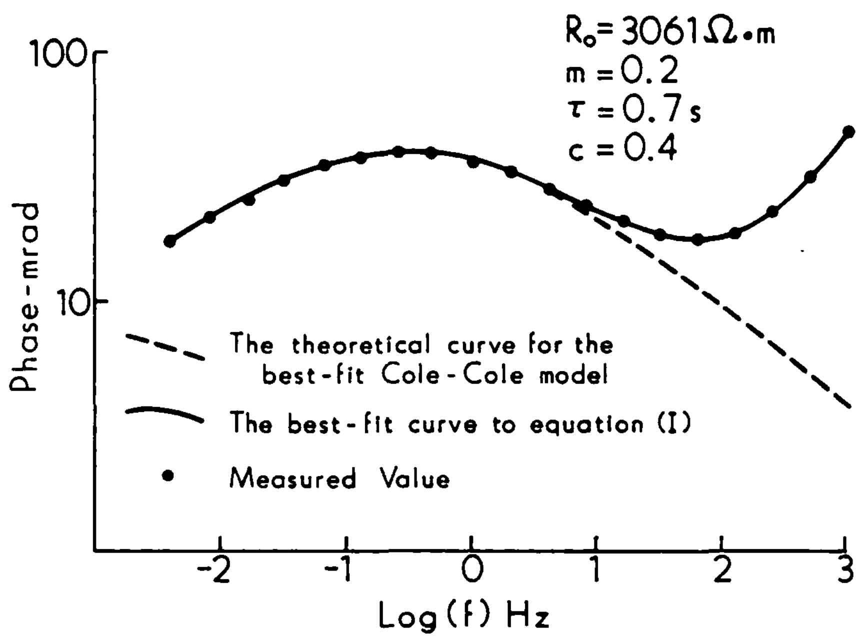
c_i = frequency dependence (dimensionless)

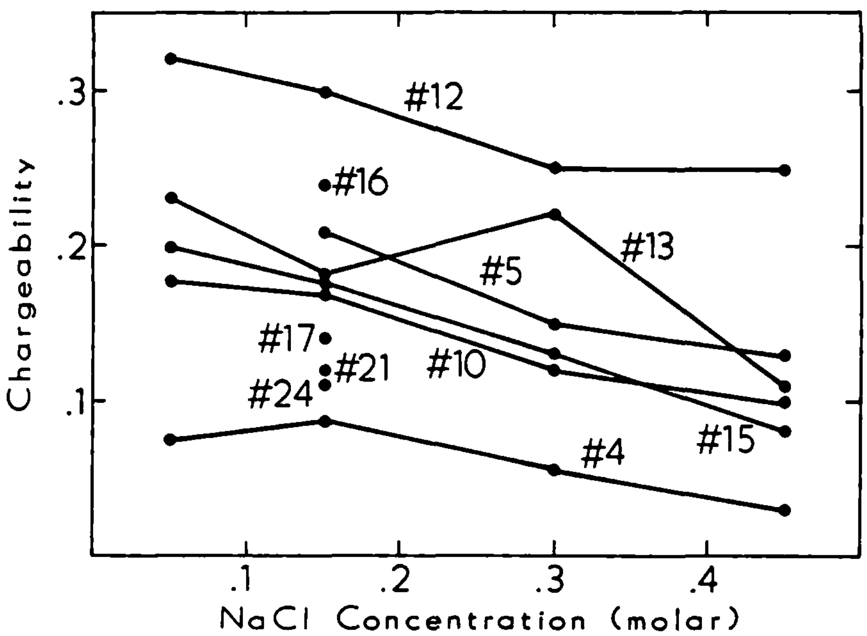
ω = angular frequency (rad/s)

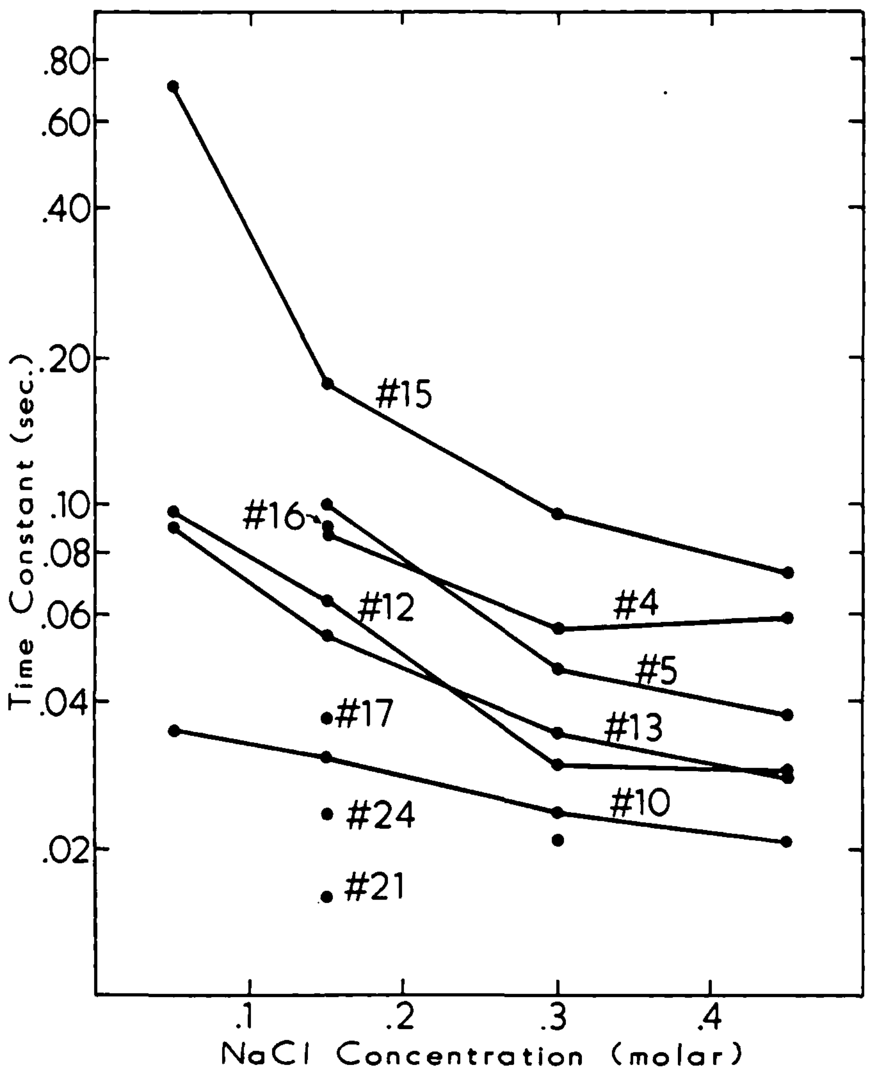
$i = \sqrt{-1}$

The data was fit to this model using a Marquardt least-squares inversion algorithm. Figure 10 shows the fit to a data set where the dashed line shows the theoretical data of the Cole-Cole model with the effect of the sample-holder removed.

The time constant (τ) and chargeability (m) parameters have been shown (Pelton et al., 1978) to be functions of the particle size and distribution of the sulfide mineralization as well as the ionic concentration of the pore fluid. In an effort to determine the effect of pore fluid concentration on the time constant and the chargeability, samples were measured at different pore fluid concentrations of the NaCl. The results are plotted in Figures 11 and 12. The chargeability and the time constant both decrease with increasing pore fluid concentration, as expected. Without knowing the precise fluid chemistry underground, we cannot say which are the correct values of chargeability and time constant to use in subsequent analysis. However, it may be seen that for each concentration the chargeabilities and time constants remain relatively the same for each sample. Thus when we later say that the chargeability of a sample is high, intermediate, or low, it refers to any concentration within the range studied.


R_o= 3061Ω•m
m = 0.2
τ = 0.7 s
c = 0.4
100
10
Phase - mrad
The theoretical curve for the best-fit Cole-Cole model
The best-fit curve to equation (I)
Measured Value
-2
-1
0
1
2
3
Log (f) Hz

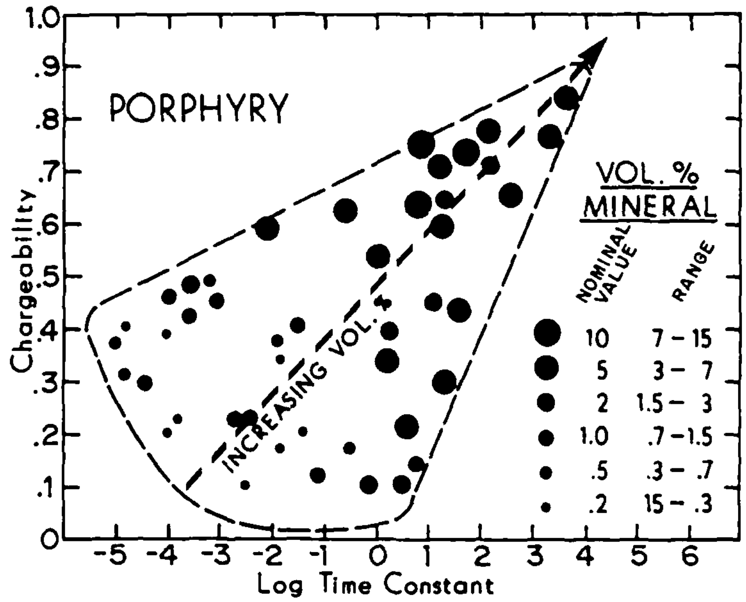

#12
#16
#13
#5
#17
#21
#10
#24
#15
#4
.3
.2
.1
Chargeability
.1
.2
.3
.4
NaCl Concentration (molar)



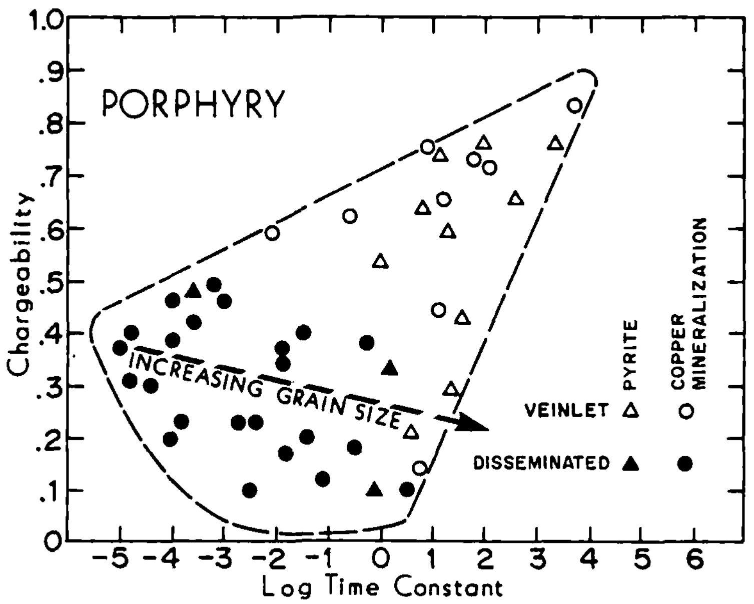
.80
.60
.40
.20
.10
.08
.06
.04
.02
Time Constant (sec.)
#15
#16
#12
#4
#5
#17
#13
#24
#10
#21
.1
.2
.3
.4
NaCl Concentration (molar)

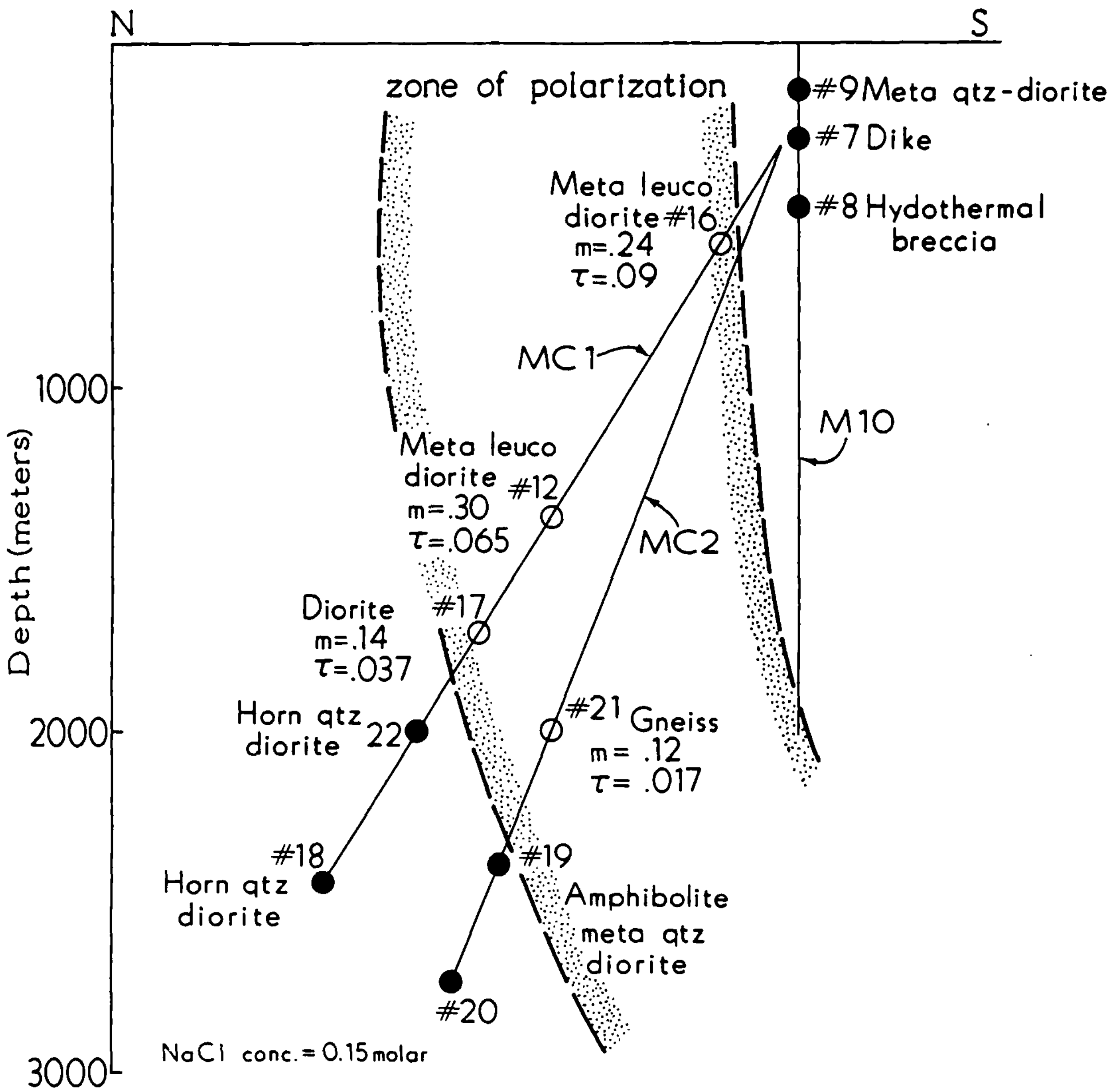
The rock parameters which contribute to chargeability and time constant are the grain size, volume percent of polarizable minerals and the mineralization texture. The functional relationships of each of these are shown in Figures 13 and 14 (Pelton et al., 1978). Both the time constant and the chargeability increase as the volume percent of polarizable minerals increase. The same plot demonstrates that increasing the grain size increases the time constant but has little effect on the chargeability. The texture of the mineralization has a strong influence on the chargeability in that the chargeability for disseminated textures ranges from 0.1 to 0.5 and for veinlet textures from 0.5 - 1.0. The time constants and chargeabilities for the textures of the Meager Creek samples show good agreement with the results of Pelton et al. (1978).

The chargeabilities plotted on the plan map (Figure 8) and cross-section (Figure 15) indicate that the zone of high chargeability is a hemispherical shell. Since high chargeability correlates to high pyrite and chalcopyrite volume percent, this hemispherical shell would correspond to the phyllic zone in the Lowell and Guilbert model of a porphyry system. Therefore, data from these samples indicate that at Meager Creek the top of the phyllic zone is at of depth of 500-1 000 m below drill hole MC-1 (see Figure 8).



PORPHYRY
Chargeability
Log Time Constant
INCREASING VOL. %
VOL. %
MINERAL
NOMINAL VALUE
RANGE
10 7 - 15
5 3 - 7
2 1.5 - 3
1.0 .7 - 1.5
.5 .3 - .7
.2 15 - .3


PORPHYRY
Chargeability
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
INCREASING GRAIN SIZE
PYRITE
COPPER MINERALIZATION
VEINLET
DISSEMINATED
-5 -4 -3 -2 -1 0 1 2 3 4 5 6
Log Time Constant


N
S
zone of polarization
#9 Meta qtz-diorite
#7 Dike
#8 Hydothermal breccia
Meta leuco diorite #16
m=.24
τ=.09
MC 1
M10
1000
Meta leuco diorite
#12
m=.30
τ=.065
MC2
Depth (meters)
Diorite
#17
m=.14
τ=.037
Horn qtz diorite
22
#21 Gneiss
m= .12
τ= .017
2000
#18
Horn qtz diorite
#19
Amphibolite meta qtz diorite
#20
NaCl conc. = 0.15 molar
3000

DISCUSSION

While the limited sampling by drilling is grossly imperfect, one may conclude from Figure 8 that all high values of chargeabilities are contained within an arcuate zone extending from just southeast of the deeper regions encountered by MC-1 and MC-2, and thence southeastward to span the collar of M-12. There is no obvious order of the time constants within this zone, indicating that grain size is variable.

The chargeability and time constant data for borehole MC-1 and MC-2 were projected onto a north-south cross-section through the collar of borehole MC-1. Figure 15 reveals that the values of high chargeability are concentrated in a north-south zone which appears to dip steeply to the south.

CONCLUSIONS

While the knowledge of the distribution of values of IP chargeabilities suffers from insufficient sampling, there is reasonable evidence to suggest that IP has mapped an arcuate zone of IP chargeability that could be related to a fossil convective hydrothermal system. This zone dips to the south, suggesting that the center of the fossil hydrothermal system is to the south of most of the manifestations of the present-day hydrothermal system.

An extensive surface IP survey appears totally warranted as a means of establishing the nature, size and location of the fossil hydrothermal system which the current hydrothermal system pervades.

ACKNOWLEDGMENTS

Funding for this study was derived from Contract No. DE-AC03-84SF12196 with the U.S. Department of Energy. Patrick Daubner was responsible for assembling the illustrations while Joan Pingree typed the manuscript; we are grateful to them both.

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FIGURE CAPTIONS

Fig. 1. Geologic map of Meager Mountain, British Columbia, Canada.

Fig. 2. Locations of boreholes at Meager Creek geothermal prospect, British Columbia, Canada.

Fig. 3. Distribution of K in quartz diorite, Meager Creek geothermal prospect, British Columbia, Canada.

Fig. 4. Distribution of Cu in metaquartz diorite, Meager Creek geothermal prospect, British Columbia, Canada.

Fig. 5. The Lowell and Guilbert (1970) model of a porphyry copper system.

Fig. 6. Plan view of the first-separation, induced-polarization chargeability at Poison Mountain porphyry copper deposit, British Columbia, Canada (after Seraphim and Rainboth, 1976).

Fig. 7. Plan view of the first-separation, induced-polarization percent frequency effect at the Dungate Creek porphyry molybdenum prospect in British Columbia, Canada (after Ward, 1972).

Fig. 8. Plan view of zone of high chargeability at Meager Creek geothermal system, British Columbia, Canada (NaCl concentration, 0.15 molar).

Fig. 9. Typical amplitude and phase spectra fitted to a Cole-Cole model. Data from Meager Creek geothermal prospect, British Columbia, Canada.

Fig. 10. Measured data (dots), best-fit single Cole-Cole model (dashed line), and Cole-Cole model multiplied by asymptotic phase expression (solid line). Data from Meager Creek geothermal prospect, British Columbia, Canada.

Fig. 11. Chargeability versus NaCl concentration for core samples from Meager Creek geothermal prospect, British Columbia, Canada.

Fig. 12. Time constant versus NaCl concentration for core samples from Meager Creek geothermal prospect, British Columbia, Canada.

Fig. 13. Data from porphyry deposits plotted in chargeability-time constant space. The larger dots indicate high sulfide concentration. Superimposed on the plot is an arrow which indicates the trend due to increasing volume percent sulfides in artificial rocks (after Pelton et al., 1978).

Fig. 14. Data from porphyry deposits plotted in chargeability-time constant space. There is a grouping of veinlet mineralization (open symbols) veruss discretely disseminated mineralization (closed symbols) but there is no distinct grouping of pyrite mineralization (triangles) versus copper mineralization (circles). Superimposed on the plot is an arrow which indicates the trend due to increasing grain size in artificial rocks (after Pelton et al., 1978).

Fig. 15. Section view of zone of high chargeability at Meager Creek geothermal prospect, British Columbia, Canada (NaCl concentration, 0.15 molar).

TABLE CAPTION

Table 1. Sample Locations, Descriptions, Hydrothermal Mineralogy, Parameters and IP.

The sample numbers in parentheses refer to the well number and the depth in meters. Abbreviations: dike = dike of Mount Meager Volcanic Complex; m.q.d. = metaquartz diorite; h.b. = hydrothermal breccia; q. diorite = quartz diorite. (W) weak, (M) moderate, and (S) strong refer to the intensity of hydrothermal alteration.

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FEB 09 1981

February 3, 1981

Mr. P. Michael Wright
Earth Science Laboratory
University of Utah Research Institute
Research Park
420 Chipeta Way
Suite 120
Salt Lake City, Utah 84108

Dear Mike:

Enclosed is the copy of my talk. Some drawings have been added subsequently for purposes of clarity and information.

I have informed my partners of your invitation to speak to the Utah section of the GRC. I will look forward to doing that at some future time, however it is impossible to plan for that at the present time. However we will stay in touch about it.

Very truly yours,

NEVIN SADLIER-BROWN GOODBRAND LTD.

Andrew E. Nevin

AEN/pm
Enclosure

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The Meager Creek Geothermal Project in British Columbia and its Implications for Washington and Oregon.

Text of Luncheon Address by Andrew E. Nevin, at Federal-State Geothermal Conference, Seattle, Washington, January 28, 1981, Sponsored by U.S. Department of Energy.

Introduction

Thank you, Roald. Ladies and gentlemen: I am pleased to have the opportunity to speak to a group of geothermal experts. I have talked about the Meager Creek Project many times in the past, generally to groups of people outside the geothermal community. Today, for the first time, I can get highly technical with respect to thermodynamics. I intend to base several aspects of my talk around that thermodynamic law which states: "there is no such thing as a free lunch".

To illustrate this law: you have to listen to me for the next 30 minutes. For my part, I accepted this invitation knowing that I was the Nth choice of speaker, where N is equal to or greater than 3.

Outline

My talk today is broken down into three parts:

1. First I would like to summarize the present and future status of the Meager Creek Project.

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2. Then I would like to backtrack and give you a case history of the exploration leading up to the present. This part will necessarily cover the legal fabric of geothermal exploration and development as it exists in western Canada at the present time.

3. I am sure that you will draw your own conclusions from the case history of Meager Creek; however I have the temerity to make some suggestions for geothermal exploration and development in the northwestern states, particularly in the Cascades.

Please note that my comments are made solely by me. I do not speak for the British Columbia Hydro and Power Authority, nor for the other funding agencies: the Ministry of Energy, Mines and Petroleum Resources of B.C., nor the Department of Energy, Mines and Resources of Canada. In fact, my own Board of Directors does not entirely agree with my comments.

My firm is a group of geologists, geophysicists and engineers whose principal concern is mineral exploration, with particular emphasis on metallic minerals and geothermal resources. We provide consulting services and project management. We have been and are the principal scientists, engineers and managers of B.C. Hydro's geothermal exploration endeavors since 1973.

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Present Status at Meager Creek

The Meager Creek system lies about 150 kilometers north of Vancouver. The system is controlled by a central volcano belonging to what is called the Garibaldi Group north of the border, and the Cascade Volcanics south of the border. It is one of about one-half dozen such eruptive centers or clusters in the Garibaldi chain.

The volcanic rocks are a series of dacite and andesite lavas and pyroclastics which erupted from several vents. The volcanics crop out in an area about 15 kilometers in diameter. The relief in the area is about 2000 meters from the Lillooet River valley to the highest peaks, and the volcanic edifice extends over the greater part of this relief. Eruptions systematically progressed from the south, starting 1.9 million years ago, to the north, where the second to last event is dated at 2400 years.

Underlying basement rock is quartz diorite of Cretaceous age and some pre-Cretaceous pendants of metavolcanics and metasediments.

The volcanic edifice is very much like any of the Cascade Mountains such as Mt. Baker or Mt. St. Helens except for the fact that it lies within the jagged granitic peaks of the Coast Range,

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and that the ramp of lava flows and pyroclastic deposits which characteristically surrounds many isolated Cascade volcanos has been deeply dissected by erosion.

There are two geothermal reservoirs flanking the north and south sides of the mountain. Each has a 60°C hot spring system which is displaced 2 to 5 kilometers down drainage from its inferred escapement point. Both are dilute brines--about 2000 ppm tds; one is NaCI-dominated and the other $NaHCO_3$. Water geochemistry is re-equilibrated withan observed low temperature mineral assemblage (at 80°C). This was established by Hammerstrom and Brown of U.B.C.; summarized by my paper in the GRC Hilo proceedings.

Total drilling, in both reservoirs is about 7000 m.

The South Reservoir has been penetrated by fourteen diamond drill holes ranging from about 30 meters to 1150 meters in depth, with a median at about 300 meters. We now feel that we are not assured of meaningful thermal information until a hole reaches about 600 meters in depth. More on this later. However, the highest temperature measured in the South Reservoir is 202°C at 365 meters, the total depth of the well.

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The best information available at present suggests that the South Reservoir is at least 5 kilometers in its east-west dimension and is at least 2 and perhaps as much as 5 in its north-south dimension.

Nearly all of the reservoir rock in the South is quartz diorite, and the underlying high temperature reservoir--which is presumed at present to exist--occupies faults and fractures within that generally impermeable rock. There are several postulated geologic controls on the reservoir, one of which is a breccia pipe inferred to exist in the subcrop--a large and probably circular feeder which supplied the first volcanic ejecta 1.9 million years ago.

The South Reservoir was tracked up-drainage by resistivity and drilling from the hot spring.(Recall the hot spring is displaced down-drainage). In most cases water stands in the wells some tens of meters below the collar.(Some wells have artesian flow). The 200°C well was blown in 1980 and puffed a little steam to the atmosphere, but the rock is impermeable and flow was not sustained. Fractures are plugged with mineral veinlets. More on the fractures later.

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The North Reservoir is not as well known. Three diamond drill holes have been put down, two to depths of about 600 meters and one to a depth of about 250. The highest recorded temperature is 100°C, at the t.d. of 600 meters in one well, and the bottom-hole gradient is 210°C per kilometer. The area of the North Reservoir is not known, however evidence suggests an east-west dimension of at least 8 kilometers and a north-south dimension of at least 6 kilometers.

This evidence includes the drill holes, a thermal spring which is displaced down-drainage, two hydrogen-sulfide gas vents, a very large and potent resistivity anomaly, an extraordinary self potential anomaly--about one volt over a distance of a few kilometers, hydrothermal alteration, and finally, the manner in which all of these aspects fit with the stratigraphy, structure and chronology.

The North Reservoir is the only place where the ramp of recent flows and ash extends down slope and fills the valley floor. We have drilled through 250 meters of layered flows and fragmental rocks.

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That is a summary of the present status of knowledge gathered so far on the Meager Creek system. I believe you can appreciate that we are excited about the project. We are also rather proud to have played a role in work to date.

The exploration cost so far is on the order of $4.0 million Canadian. We started in 1973 with an expenditure of $75,000 Canadian, and annual expenditures have grown to about $1.8-million in 1980. Perhaps we could integrate this in light of inflation and currency exchange and say that the project cost to date in current US dollars is about $3.7-million. This excludes any land acquisition costs, which I will discuss; also excluded are environmental base-line studies.

In mid-1980 Hydro announced plans to accelerate the program. Currently our firm and Bechtel have been engaged to prepare a pre-conceptual study for a 50-100 MW pilot plant. We are also designing a drilling program for one or more 2000 meter rotary wells--to be spudded in 1981--and intend to continue diamond drilling with 6 or more holes. Various surveys will be continued, and geologic mapping is continually being refined.

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The program beyond 1981 is contingent upon this year's results. But let me point out that the Meager Creek system is very large, and that it is apparently not unique in B.C. It happens to be the first candidate chosen. The geothermal potential of the province is unknown.

History

In late 1971 Tim Sadlier-Brown and I each had one-man consulting practices in metal exploration. Our colleague Gene Ciancanelli, who now runs Cascadia Exploration in Escondido, convinced us of the wisdom of pursuing geothermal energy for fun and profit. (There's the free lunch, again).

During the ensuing two years we scouted volcanos and hot springs in British Columbia and the Yukon, and attempted to obtain a client for systematic work. We published three papers on geothermal potential in B.C. during that period.

After several rebuffs the British Columbia Hydro and Power Authority accepted our proposal to conduct reconnaissance on the

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lower mainland of the province in 1973. Concurrently the Geological Survey of Canada, under the leadership of Jack Souther, a well known volcanic geologist, initiated a reconnaissance program aimed at determining the chemistry of some hot springs, and continued their usual high quality of geologic mapping, including mapping late Cenozoic volcanos. In early 1974 Energy, Mines and Resources Canada dumped some surplus budget money--desperately before the end of a fiscal year--into two very short diamond drill holes right at Meager Creek hot spring and, at the very least, in our thermodynamic terms, turned money into work into energy into momentum.

Our reconnaissance identified five or six target areas worth additional investigation, with the recommendation that we start at Meager Creek. B.C. Hydro budgeted about $150,000 and on September 1, 1974 we began a program, renewed unevenly from year to year, of electrical resistivity and diamond drilling.

One hole was drilled to a depth of 350 meters on a resistivity anomaly in 1974-5 and reached a peak of 70°C before reversing and assuming a normal gradient. Three diamond drill holes went down in 1975 to depths of about 90 meters. Temperatures were low, as you would imagine, but bottom hole gradients approached or exceeded 300°C per kilometer.

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In 1975 we learned a tough lesson on geologic hazards. On a hot July day 15-million tons of fragmental volcanics and a few million tons of ice-cap broke loose from the head of a cirque and roared 8 kilometers down a valley, coming to rest against a facing hill. The slide, riding on an air cushion, had a velocity estimated at 150 km/hour. Four men were cutting geophysical lines in the path of the slide and lost their lives.

Electrical resistivity up to this point was done using a dipole-dipole array such as is commonly used in Canada and in the United States for metal exploration with the induced polarization method. Electrode spacings ranged from 100 to 500 meters. Entire arrays could reach 3 kilometers in length and surveys were limited to valley floors.

There is no such thing as a free lunch. In 1976 B.C. Hydro lost interest and the geothermal exploration budget was slashed to $20,000 for the year. This would be the end of the story, if Joe Stauder, one of Hydro's engineers, had not become a believer and if we had not made a pact with the devil.

Now here's an important point: Up through 1976 the nearest road was 15 miles away. Our total annual exploration budgets would not have supported one mile of road building. So our Canadian heritage led to operation from small helicopter-supported tent camps.

The geophysical gear, diamond drills, rods, water pumps, hose, tents, food, supplies and spares were all transported by light helicopter. Geophysicists, drillers, geologists, and

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linecutters worked on foot in the valleys and on the mountain. The crew sizes ranged from a minimum of six or seven people to a maximum of about twelve or fourteen. The cook was the most important. No time off. No overtime. Work through weekends and holidays; and we managed to convince an enthusiastic crew that there was such a thing as a free lunch.

Communications with the outside world were by 10-watt single-banded radio.

The helicopter would make supply trips once or twice a week, and camp would call for spares or emergency supplies when needed. hen needed the helicopter would base at camp for a few days to move a drill or to ferry geophysical crews or geologists to remote places.

Virtually all of the light helicopters were used at different times--particularly the Hiller 12E, Bell 206B, and Hughes 500C. Effective payloads were 500 to 1000 pounds. (Our particular favourite at the present time is the Hughes 500D. It is the best available light machine for bush work).

Now this is nothing unusual. Every summer, about 200 mining companies or exploration contractors operate--let's say--500 such camps in northern and western Canada.

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We were back in business in 1977 when B.C. Hydro's concerns about the environmental lobby convinced them to work a little harder. Two items changed.

One of the logging companies extended a road to the base of the mountain. This had the adverse effect of allowing the men and women on the crew to go to town on Saturday night. But it also meant that we could use heavier equipment economically.

Secondly, our geophysical contractor, Greg Shore, developed a pole-pole resistivity array which allowed us to place electrodes and obtain data high on the mountain slopes, and to process these data (from uneven X,Y,Z coordinates) immediately on a computer based in camp. This is described in his paper in the GRC Proceedings from the Hilo meeting.

Up through 1977 Energy, Mines and Resources (through its two agencies, the Geological Survey of Canada and the Earth Physics Branch) ran independent surveys, but co-ordinated with Hydro's. In 1978 EMR began to jointly fund Hydro's work, and at the present the Provincial government has joined funding.

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It was in 1977 that Dr. Peter B. Read, under contract from the GSC, produced the excellent 1:10 000 geologic map in use at present.

The pole-pole work continued into 1978 and we also drilled two holes, one in the North and one in the South. We used a Longyear Super 38, skid-mounted. Set-ups were beyond the road-head and the drill was moved in and out with Bell 204 and 212 helicopters. Those two wells were the first to exceed 100°C. Four people; drillers, a geologist and cook lived in tent camps at the drill, of course.

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I have mentioned the tentative nature of our client. Geothermal exploration was in competition with windmills, cheap southern hydro-electric projects, expensive northern hydro-electric projects, power line maintenance, replacement transformers, and the like. Those two 100°C temperatures, coupled with the 200°C bottom-hole gradients, sparked some enthusiasm and initiative on the part of our client.

Up until 1979 the project had been managed and run by Nevin Sadlier-Brown Goodbrand Ltd. on a turn-key basis. Camps were small and under canvas. With our blessing B.C. Hydro took over camp supply, catering, and part of the drilling in 1979. Pre-fabricated wood and metal buildings were hauled in for the camp. Living accommodations and field procedures were adjusted to union standards--T.V., pool table, etc.

In preparation for the 1979 field season B.C. Hydro's Drilling Division ordered a Boyles 56A diamond drill--a large machine for a diamond drill, but fairly small in comparison to a workover rotary drill, and they designed and built a super-structure and a sub-structure.

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During the two seasons 1979 and 1980 nine more wells were drilled bringing the project up to the point where I started this talk. Four drills were active during the last season. Over the two-year period an extensive road and bridge network was put in.

Legal Fabric

Prior to late 1973 there was no act recognizing geothermal resources in any Canadian jurisdiction. In late 1973 the Legislative Assembly of the Province of British Columbia passed a geothermal resources act. This defined geothermal resources as sub-surface fluids in excess of 250°F (121°C) and reserved all rights to such resources to the Crown.

Unlike the situation in the United States, Canadian public lands are administered by provincial governments. In the Yukon and the Northwest Territories, lands are administered by the federal government, in consultation with the Territorial governments.

Provincial administration of Crown land has its advantages and disadvantages as you can imagine. An advantage is that law makers and administrators are close to home, rather than being off in a remote hinterland such as Ottawa or Washington. The

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disadvantage, of course, is that provincial governments are charged with many responsibilities, some with high priority, and their resources of time and money are limited. Therefore a low priority item which requires considerable technical expertise tends to fall between the chairs. The 1973 act was essentially a caretaker act put into place while the government decided on a course of action.

The British Columbia Hydro and Power Authority is a Crown corporation--it is owned by the government of the Province of British Columbia. Hydro's primary charge is to generate, transport, distribute, and sell electrical energy. They are also charged with anticipating load growth in the province and having the necessary facilities in place when needed.

Energy demand is currently running at about 38,000 gigawatt-hours per year and is projected to reach about 55,000 by 1990. Hydro's system is dominated by hydro-electric power. It is a system which is long on capacity and critical for energy.

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There are two other major electrical facilities in British Columbia: The West Kootenay Power and Light Company, owned by the Canadian Pacific group, in southeastern B.C., which is a public utility; and the Aluminum Company of Canada reduction works at Kitimat, which consumes most of its energy, sells surplus to Hydro, and has recently applied for license to dam another river.

To those of you in the western US our hydro-electric system and potential sounds very rich indeed. Many people in British Columbia, however, point out that there are two competing resource uses which are largely excluded by hydro-electric projects: 1) we have a shortage of flat valley bottom land suitable for agriculture, and 2) the salmon fishery is an extraordinarily resource--about the fourth largest industry in British Columbia--and many dams take a toll of spawning grounds.

Returning to geothermal energy, B.C. Hydro is apparently operating under the assumption that rights to the energy in the sub-surface at Meager Creek would or could be conveyed to the utility of following a discovery.

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It is our understanding that at the present time the Ministry of Energy, Mines and Petroleum Resources in Victoria is working on a geothermal leasing act. Our feeling is that before the private sector can enter geothermal exploration and development in British Columbia two additional elements must drop into place. Revenue Canada, our equivalent to the IRS, must provide for write-offs of exploration expense and investment tax credits. In addition, a developer in the private sector must be assured of the marketability of his product from a practical standpoint. This means that legislation must provide for compelling Hydro to buy geothermal energy, or for the developer to generate, transport, sell or export energy.

As you may know at the present time Canadian energy matters are a source of controversy between certain provincial governments and the federal government. Any further discussion would stray too far from the geothermal field.

Environmental standards for geothermal work in British Columbia and the Yukon are quite high and demand consideration of effects on flora, fauna, water, air, surface stability, social and economic dislocation, competing resource uses and so forth.

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They are applied,however,without the bureacracy which has grown up in the United States, and with more sensitivity toward reason adn economic health.

You have just heard how we have found the Meager Creek reservoirs while working for a government monopoly; and my temerity enters because I am about to suggest to you that you might have too much government and too many conflicting governmental interests.

Suggestions for Exploration

With special reference to the Cascades, let me give you my assessment of the various exploration methods. But first let's talk about putting the cart before the horse. As an observer of your activities I submit to you that all of the planning, all of the conceptual designs, all of the research studies done by the Department of Energy, US Geological Survey, and the various state agencies will not provide 1 kilojoule or 1 kilowatt of marketable geothermal energy unless the private sector is allowed to proceed with geothermal exploration.

DOE's "confirmation drilling loan program" is terrific. The performance of your Forest Service is terrible.

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You--the DOE and state workers--must resist the temptation to design plants and processes for exploiting resources which are not yet discovered (recall Pat Muffler's McKelvey diagram in U.S.G.S. circular 790), and turn your energies into springing leases from the Forest Service.

Now on technology:

Geologic Mapping. Geologic mapping is the single most important item! It is also the most frequently overlooked or poorly done element. All of us have seen prospects where geophysics and drilling have been extensive, but where the geology has been copied from a 1:500 000 scale county map and blown up. Geology must be mapped at a scale of 1:10 000 or 1:20 000 before undertaking anything else. The geology is about the cheapest item one could possibly do on a prospect.

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Resistivity. In our rain-forest environment, with its abundant clear groundwater, we have found the electric resistivity is one of the best tools for determining the lateral extent of geothermal waters within the 1000 or 2000 meter depth range. It works well where the basement rocks are non-conductive. It does not work well in piles of andesite or andesite tuff.

Shallow Drilling. Temperature gradient holes or heat flow holes are commonly acknowledged to be the first and the principal method for acquiring direct thermal information. There is no argument against the value of shallow wells in exploration.

Our preferred 600 meter depth, incidentally, derives from experience. Our heavy rainfall and permanent ice pack results in a thick, moving blanket of cold ground water. We have to drill beneath its effects.

We used diamond drills for several reasons. They are easily portable by light helicopters. Small drills, such as a Longyear 34 or a BBS1, mounted on skids can be broken down into about three pieces which lie within 600 or 700 pound load limit.

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We are a metal exploration province and we have a cultural propensity to use diamond drills. There are dozens of contractors and hundreds of drillers. With only two men to a shift, delays and time-dependent costs are low. Rods and all the ancillary gear are generally lightweight and can be packed by hand. The drill site required is much smaller than most suburban back yards. Most of our drill setups were cleared by two men using chain saws, axes or brush hooks in less than 3 or 4 hours. And lastly the continuous core is extremely valuable to the geologist in the early stages of exploration. Recall that we know mineralogy, structure, stratigraphy and fracture density of all our wells.

Lastly, temperature logging is easier and better information accrues. Our procedure is to drill one shift per day (8-10 hours), pull up off bottom for the night--whatever distance the driller determines, and remove the core barrel with the wireline. The bottom hole temperature (BHT) re-equilibrates overnight. At 4am, before the start of the next shift the thermistor probe or Kuster tool is lowered through the rods and bit and a BHT is recorded. The continuous BHT log shows all the peaks, hollows and reversals in gradient--far better information in our wet country than a post-drilling traverse provides.

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What the diamond drill does not do well is to cut through extensive overburden containing abundant large fragmental material. However it can be done by starting with large diameter casing and casing shoes, and a lot of skill on the part of the crew. We have found that refraction seismic profiles are necessary for planning in thick overburden. Also, for your information, the diamond drill generally uses clear water and grease as the medium. Lost circulation is often handled by drilling blind until the driller feels he is in competent rock, then running a string of casing and reducing to smaller size.

An optimum program, if you have road access, would be to do use the procedures from the porphyry copper patch in Arizona: Drill through the overburden with a small rotary rig such as a Failing 1500. Case the hole with 3½" pipe. Then move on a diamond drill and continue with NQ core. You still have two sizes to reduce to.

Here are cost figures for two wells drilled in the North Reservoir in 1980, one to a depth of 250 meters, the other to 600 meters. Drilling was done by a contractor, Connors Drilling Company, and site preparation, management and geology were done

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by our firm. Two drills were used and the wells were put down concurrently. I will give you the costs in Canadian dollars per meter and then the arithmetic conversion to US dollars per foot. The contractor's per footage rates were C $130/m or US $34/ft. The cost of mobilization, demobilization, casing left, chemicals, room and board, transportation, standby, fishing, and all other items billed by the contractor were on an item-by-item basis, but when set against the depth were Canadian $75/m or US $19/ft. Note that a longer program would reduce this cost slightly. Geology and temperature logging at the site cost about C $20/m or US $5/ft. The grand totals are Canadian $225/m or US $58/ft. Not included in those charges is the relatively minor cost of head office overhead, and reporting and drafting after completion of the entire project.

Perhaps you see my suggestion: the US Forest Service is dragging its feet in setting environmental standards for exploratory work in the Cascades. I am suggesting to the geothermal industry that use of light diamond drills and small camps would allow "in-and-out" exploration assessment, leaving no significant environmental scars; and that proposals to do so might bring the Forest Service around to our way of thinking.

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Other Methods. Other exploration methods tried on a tentative basis at Meager Creek are magneto-telluric surveys, radon surveys, mercury surveys, airborne infra-red photography, and a pilot survey for micro-earthquakes. Expenditures on all of these were low. Each contributed some tiny increment of information; however most have not proven to be leading methods.

Support Your Local Consulting Geologist. Last Sunday many of us watched Coach Tom Flores in the final step of managing a small group of motivated people in a difficult endeavor. Can you imagine the outcome if Tom Flores had been a committee of five? A committee of ten? A committee of twenty? What happens when the committee exceeds the number of players, in this case about 45? Do I make my point? Some geothermal jobs have six people in the field, but stacked on top of the field crew is a management committee of a dozen or more, and stacked on top of that is a planning committee of a dozen or more, and most of these people are from different agencies of government or contractors or specialized contractors, all with divergent points of view.

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We feel that exploration, like sports, like the fine arts, and like bio-chemistry, is an activity best performed by a very small group of individuals who are superbly motivated (by money in particular, or by some other yardstick of achievement).

The most fruitful exploration programs in any commodity transpire when a funding group hires a geologist or other prime mover and says: "Go to it! I want to hear from you infrequently! And I will fire you if I think you are wrong!"

Now part of my instructions in the preparation of this talk were to acquaint you with what you call the "slim hole" and what we call the "diamond drill hole". I would be happy to provide more detailed information. I would be happy to send you more performance costs including mistakes, fishing, lost circulation and the like. But I suggest another course of action. The western United States is just as rich in metal exploration heritage as is western and northern Canada. There

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are hundreds of diamond drilling contractors distributed throughout Nevada, Arizona, Colorado, Utah, etc.

As well there are hundreds of consulting exploration geologists--Bob Grant in Seattle, Moe Kaufman in Spokane, Shrimp Clark in Yoncalla, Sharky Bell in Reno, Gene Ciacanelli in Escondido, Fred Johnson in Durango, Ted Eyde and Al Perry in Tucson, and many more. I suggest that if the idea of a slim hole interests you, you contact a consultant--your state geologists will know them all--and hire him to drill some holes, and not bother him while he's working!

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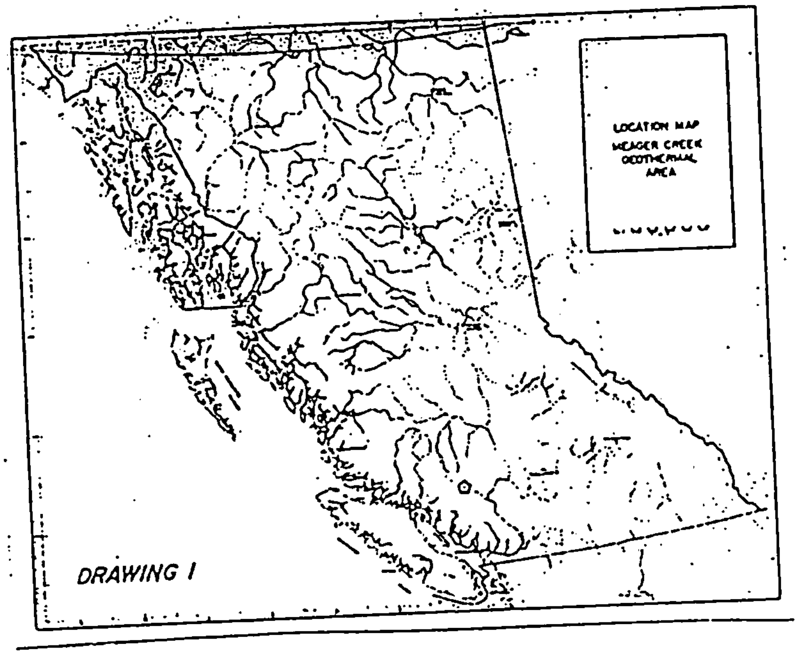
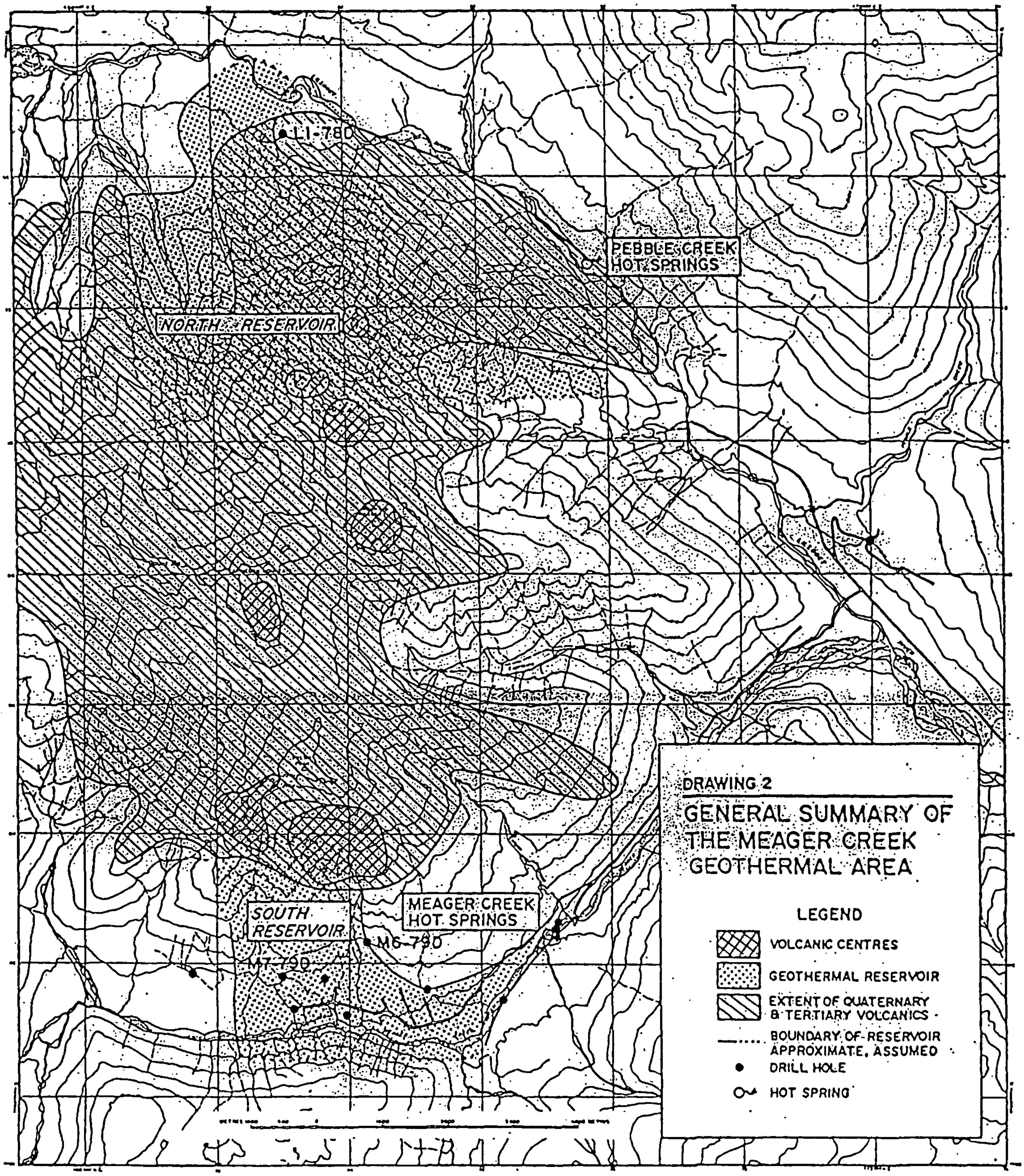
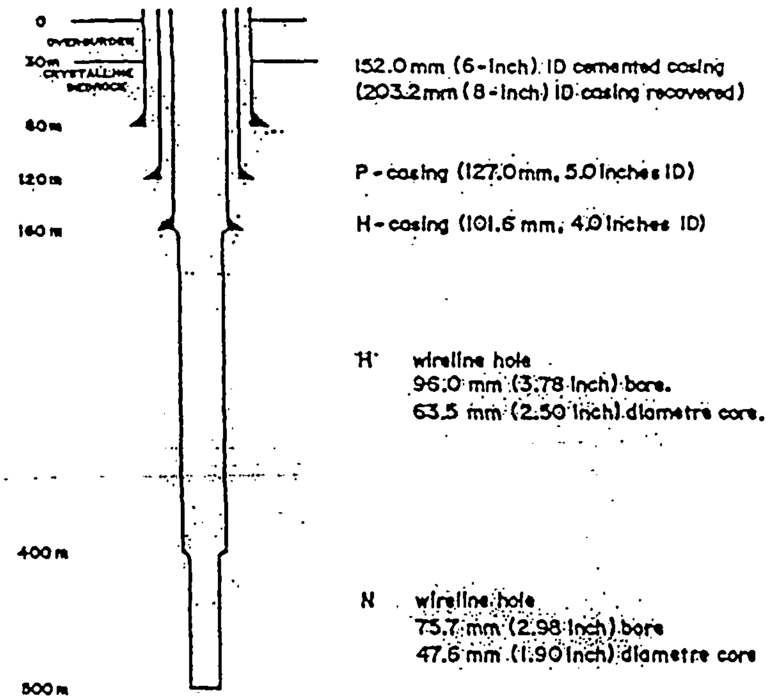
Attached are drawings added following the talk.


LOCATION MAP
MEAGER CREEK
GEOTHERMAL
AREA
DRAWING I

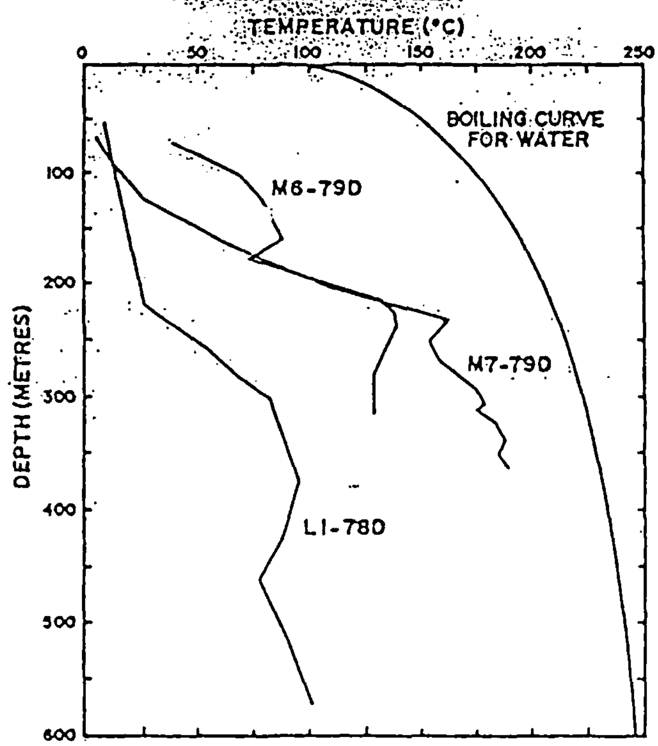

L1-78D
PEBBLE CREEK
HOT SPRINGS
NORTH RESERVOIR
SOUTH
RESERVOIR
MEAGER CREEK
HOT SPRINGS
M6-78D
M7-79D
DRAWING 2
GENERAL SUMMARY OF
THE MEAGER CREEK
GEOTHERMAL AREA
LEGEND
VOLCANIC CENTRES
GEOTHERMAL RESERVOIR
EXTENT OF QUATERNARY
& TERTIARY VOLCANICS
BOUNDARY OF RESERVOIR
APPROXIMATE, ASSUMED
DRILL HOLE
HOT SPRING



DRAWING 3

HYPOTHETICAL PROFILE FOR 500-METRE DRILL HOLE REQUIRING BLOW OUT PREVENTION EQUIPMENT

TYPICAL DRILL HOLE TEMPERATURE GRADIENTS AT MEAGER CREEK



DRAWING 4