GL01431

GeothermEx, Inc.
SUITE 201
5221 CENTRAL AVENUE
RICHMOND, CALIFORNIA 94804-5829

(510) 527-9876
CABLE ADDRESS GEOTHERMEX
TELEX 709152 STEAM UD
FAX (510) 527-8164

ASSESSMENT OF POWER POTENTIAL AND RECOMMENDATION FOR RESOURCE CONFIRMATION DRILLING AT THE SOUTH MEAGER GEOTHERMAL PROJECT, BRITISH COLUMBIA

for

COMMONWEALTH CONSTRUCTION COMPANY
Vancouver, British Columbia

by

GeothermEx, Inc.
Richmond, California

JANUARY 1992

GeothermEx, Inc.
SUITE 201
5221 CENTRAL AVENUE
RICHMOND, CALIFORNIA 94804-5829

(510) 527-9876
CABLE ADDRESS GEOTHERMEX
TELEX 709152 STEAM UD
FAX (510) 527-8164

CONTENTS

ILLUSTRATIONS

GeothermEx, Inc.
SUITE 201
5221 CENTRAL AVENUE
RICHMOND, CALIFORNIA 94804-5829

(510) 527-9876
CABLE ADDRESS GEOTHERMEX
TELEX 709152 STEAM UD
FAX (510) 527-8164

EXECUTIVE SUMMARY

GeothermEx, Inc. has been retained by Commonwealth Construction Company ("Commonwealth") to provide an independent review of the extensive data base collected during the exploration of the South Meager Geothermal Project, British Columbia, Canada. This area is considered to be the prime geothermal prospect in British Columbia. The exploration program, which included surface exploration and the drilling of a number of shallow and deep wells, was conducted by the British Columbia Hydro and Power Authority (B.C. Hydro) during the period 1973 to 1984. The Geological Survey of Canada (GSC) and its parent, Energy, Mines and Resources Canada also assisted in the exploration program by drilling several wells and providing financial assistance to B.C. Hydro. Between $30 and $35 million was spent by B.C. Hydro during the exploration phase.

The major purpose of the data review by GeothermEx is to develop a conceptual geological model of the geothermal resource, to estimate the available geothermal energy reserves and to provide a basis for the siting and design of confirmation holes which are to be drilled during the 1992 field season. Drilling of the confirmation holes is expected to complete the resource verification as well as early development phases of the project.

Exploration for geothermal resources in the vicinity of the Meager Mountain complex began in late 1973 and this initial work identified a near surface thermal anomaly along Meager Creek, referred to as the South Meager Geothermal Project. Surface exploration using geological, geophysical and geochemical techniques continued during the late 1970's. Sixteen slim holes were drilled within the South Meager geothermal project area to depths ranging from 60 m to 1,140 m. Five of the slim holes encountered temperatures of greater than 100°C, with a maximum temperature of 202°C being encountered in well M7 at a depth of 367 m.

Based on the encouraging results from the shallow, slim hole drilling program, three deep, deviated, full diameter wells were drilled during 1981-82. The first deep well, MC-1, was drilled to 2,500 m; wells MC-2 and MC-3 were both drilled to 3,500 m. Temperatures of up to 270°C were encountered in the deep wells, and well MC-1 was able to flow unassisted. This well was discharged at a maximum flow rate of 7.5 kg/s at 140 kPa wellhead pressure from November 1982 until the summer of 1984. During this period steam was provided intermittently to a 20 kW demonstration plant provided to B.C. Hydro by the Electric Power Research Institute (EPRI).

The inflow to well MC-1 is believed to occur at approximately 1,400 m at a temperature of 190° to 200°C. At these temperatures, it is common that self-flowing wells have a tendency to scale and in MC-1 a hard silicious-carbonate scale precipitated in the wellbore, requiring a number of well cleanouts. This scaling problem is overcome in producing geothermal fields by either using downhole pumps in the wells to prevent flashing or by injecting scale inhibitors downhole below the flash depth. Both methods have proven to be very effective.

During 1983, it was noted that the temperatures in well MC-3 were improving in the vicinity of the loss circulation zone at approximately 3,000 m. Therefore in November 1983, an attempt was made to discharge the well using airlifting. During the 20 hours of airlifting, it is reported that the well was able to flow unassisted for periods of up to 20 minutes, with wellhead pressures approaching 850 kPa. These results suggest that the well productivity index had improved since the initial testing was conducted in mid to late 1982.

Although only the southern margin of the South Meager geothermal system has been investigated with drill holes, the locations of the upflow and outflow components of the system can be inferred from the sub-surface temperature distribution defined by these holes. Steeply-dipping to vertical isothermal surfaces, with temperature increasing from 100°C beneath Meager Creek to over 260°C two kilometers to the north, indicates the upflow zone is beneath the volcanic vents of Pylon Peak. Shallower, sub-horizontal isothermal surfaces show the presence of an outflow zone, with temperatures in the range of 160° to 180°C at depths of only 400 m to 600 m, located just north of Meager Creek beneath easily accessible terrain.

The results of the exploratory work described above and our analysis thereof indicate that there is a very large amount of geothermal heat beneath the South Meager prospect. We have estimated a most likely reserves value of 250 MW for 30 years with a standard deviation of 87 MW; there is a very high probability that reserves exceed 140 MW. With the exception of the outflow zone, this heat underlies the terrain to the north of the valley; perhaps as far north as the ground beneath Pylon Peak. While exploratory drilling has established the presence of this large heat reservoir, confirmation well drilling is required to identify commercial permeability within this reservoir.

Highly productive wells have been drilled in granitic reservoirs similar to that at South Meager in a number of commercially developed geothermal fields: Coso, California; Steamboat, Nevada; Roosevelt, Utah; Zunil, Guatemala; and Palimpinon, the Philippines; the largest gross installed capacity being at Coso (258 MW).

At Coso, the temperature pattern, which reflects the permeability pattern, appears to be systematically distributed around the margin of a volcanic extrusion dome.

Applying the analogy of the Coso field geology and permeability to South Meager, it might be necessary to drill another 500 m or so north of the bottom hole location of MC-1 to find commercially permeable fractures in the upflow zone. This would require drilling wells with greater throws than the approximately 1,200 m to 1,600 m throws of the MC series wells.

An alternative resource confirmation strategy would be to develop only the relatively shallow outflow zone. This zone is readily accessible from the valley of Meager Creek and, if adequate permeability can be found, could be developed at far less cost than the upflow zone. Naturally, because of the restricted area of the outflow zone and its lower temperature, its maximum potential may be a few tens of megawatts compared to the estimated 250 MW of the upflow zone.

Highly deviated wells, designed for maximum throw, must be used to develop the upflow zone from drilling sites located in the valley of Meager Creek. The closest site on the valley floor to the upflow zone appears to be located about 300 m WNW of well M6. This site is just below the 914 m elevation contour. It is recommended that two holes be drilled, one to the NW and the other to the NNW from this location. The wells should be designed for throws of 1,500 m to 2,000 m. The amount of true vertical depth is not critical and should be the minimum required for the designed throws. We recommend drilling full diameter wells, rather than slim-holes, to be able to run additional casings in the event of hole problems, which are likely in a highly deviated well. The cost of such a well is estimated at US$1.5 to 2 million, excluding mobilization costs. If these holes find commercial permeability they can be retained as the first production wells for the project. Slim holes, on the other hand, can not be used for production even if they encounter good permeability.

An alternative to drilling two new large diameter wells would be to drill one such well and sidetrack the existing well MC-1 to reach a target located approximately 1,500 to 2,000 meters to the NW of the existing well pad, at an approximate depth of 1,000 m. This operation would require setting and orienting a deviation packer inside the 244 mm casing at a depth between 200 and 250m; milling out a window and following the deviation program presented in this report with a 216 mm bit diameter to reach the target. The cost of this workover operation is estimated at about US$500,000. However, an intermediate casing string may be required before reaching the target depending on the drilling conditions; this would increase the cost to about US$750,000.

Slim holes to explore the outflow zone should be sited between wells M7 and M10. These wells should have a maximum depth of 1,000 m, and a bottom hole diameter of 6-1/4 inches. Vertical holes will encounter temperatures of 160°C at sea level, and if higher temperatures are required, it will be necessary to deviate the wells to the north. The cost of these 1,000 m deep slim-holes is estimated at about US$200,000 to US$300,000 each, excluding mobilization costs. Drilling deviated wells would cost about an additional US$100,000.

The total cost of confirmation drilling for the upflow zone will be on the order of US$2 to 3 million, while that for the outflow zone will be about US$500,000 to US$1,000,000, including the cost of mobilization. While the hotter, upflow zone has the potential for a few hundred megawatts, the cooler, outflow zone has the potential for a few tens of megawatts. The outflow zone, because of its lower temperature, would yield a considerably lower MW capacity per well than will the upflow zone. While the confirmation of the outflow zone may be less expensive, these slim holes can not be used for production unlike the confirmation wells for the upflow zone. Therefore, confirmation of the upflow zone is much more attractive.

In summary, it can be stated that the exploration has already been successful at the South Meager Geothermal Project area in defining a large geothermal reserve base. The next logical step in this project should be the confirmation of commercial well productivity in the upflow zone. Considering that the reservoir developed at Coso is similar to the upflow zone at South Meager, the probability of developing a commercial geothermal project at South Meager is high.

GeothermEx, Inc.
SUITE 201
5221 CENTRAL AVENUE
RICHMOND, CALIFORNIA 94804-5829

(510) 527-9876
CABLE ADDRESS GEOTHERMEX
TELEX 709152 STEAM UD
FAX (510) 527-8164

1. INTRODUCTION

GeothermEx, Inc. has been retained by Commonwealth Construction Company ("Commonwealth") to provide an independent review of the extensive data base collected during the exploration of the South Meager Geothermal Project, British Columbia, Canada. This area is considered to be the prime geothermal prospect in British Columbia. The exploration program, which included extensive surface exploration and the drilling of a number of shallow and deep wells, was conducted by the British Columbia Hydro and Power Authority (B.C. Hydro) during the period 1973 to 1984. The Geological Survey of Canada (GSC) and its parent, Energy, Mines and Resources Canada also assisted in the exploration program by drilling several wells and providing financial assistance to B.C. Hydro. Between $30 and $35 million was spent by B.C. Hydro during the exploration phase.

Canadian Crew Energy Corporation (CCEC) acquired the development rights to the South Meager Geothermal Project after a geothermal lease was granted to the Meager Creek Development Corporation in December 1987 and is presently negotiating with B.C. Hydro for a long term power sales contract. Subject to these negotiations, work on the project is expected to recommence in the spring of 1992.

For the review of the database, CCEC have provided GeothermEx with a number of reports containing detailed information on the South Meager Geothermal Project. These reports were written by various subcontractors and consultants used by B.C. Hydro during the exploration project. A number of reports written for the Meager Creek Development Corporation were also provided. This data base has been augmented by a number of papers and reports available in the geothermal literature.

The major purpose of the data review by GeothermEx is to develop a conceptual geological model of the geothermal resource to provide a basis for the siting and design of several confirmation holes which are to be drilled during the 1992 field season. Drilling of the confirmation holes is expected to complete the resource evaluation and initial development phases of the project and the collected data will be combined with earlier data to confirm the commercial potential of the area and for design of the final field development plan. The available data have also been used to provide a probabilistic estimate of the megawatt capacity of the resource, using a volumetric approach.

1.1 Project Background and Drilling Results

The Meager Creek geothermal area is located approximately 160 km north of Vancouver (figure 1.1) in undeveloped mountainous country. Access is via highway 99 from Vancouver to Pemberton, followed by 25 km of sealed provincial highway through Pemberton Meadows. Final access to the South Meager site is via 36 km of secondary gravel logging roads and 18 km of existing gravel roads which require four-wheel drive vehicles during adverse weather conditions.

The Meager Creek area was initially identified as a potential geothermal resource by the occurrence of significant surface manifestations and favorable geological features in the vicinity of the Meager Mountain complex. The geological features include the occurrence of young volcanic rocks, the intersection of several major structural features and abundant hydrothermally altered rocks.

Exploration for geothermal resources in the vicinity of the Meager Mountain complex began with reconnaissance and exploration in late 1973 and this initial work identified a near surface thermal anomaly along Meager Creek, referred to as the South Meager Geothermal Project. A further area of interest was also identified to the north of the Meager Mountain complex but this area is outside the scope of this study.

Additional surface exploration using geological, geophysical and geochemical techniques continued during the late 1970's. A number of diamond drillholes were also drilled both to the north and south of the Meager Mountain complex; the most promising results were found to the south, where sixteen slim holes were drilled to depths ranging from 60 m to 1,140 m (figure 1.2). Five of the slim holes encountered temperatures of greater than 100°C, with a maximum temperature of 202°C being encountered in well M7 at a depth of 367 m.

Based on the encouraging results from the slim hole drilling program, drilling targets were selected to test the deeper geothermal system and three deep, deviated wells were drilled during 1981-82. The first deep well, MC-1, was drilled to 2,500 m; wells MC-2 and MC-3 were both drilled to 3,500 m (figure 1.2). Although temperatures of up to 270°C were encountered in the deep wells, insufficient permeability was encountered to allow the wells to flow unassisted. However, after continued stimulation by air and nitrogen lifting, the productivity index of well MC-1 was improved to the point that the well was able to flow unassisted. The ability of the well to flow was also due to artesian conditions being attained; this did not occur with wells MC-2 and MC-3.

Well MC-1 was initially able to maintain discharge at a flow rate of 6.5 kg/s and wellhead pressure of approximately 120 kPa. The well continued to discharge from November 1982 until the summer of 1984, including periods when steam was provided to a 20 kW demonstration plant provided to B.C. Hydro by the Electric Power Research Institute (EPRI). During the long term flow period, a maximum flow rate of 7.5 kg/s at 140 kPa was attained.

The inflow to well MC-1 is believed to occur at approximately 1,400 m at a temperature of 190 to 200°C. At these temperatures, it is common that self flowing wells have a tendency to scale and in MC-1 a hard silicious-carbonate scale precipitated in the wellbore, requiring a number of well cleanouts. This scaling problem is overcome in producing geothermal fields by either using downhole pumps in the wells to prevent flashing or by injecting scale inhibitors downhole below the flash depth. Both methods have proven to be very effective.

During 1983, it was noted that the temperatures in MC-3 were improving in the vicinity of the loss circulation zone at approximately 3,000 m. Therefore in November 1983, an attempt was made to discharge the well using airlifting with the tubing set as deep as 2,500 m. During the 20 hours of airlifting, it is reported that the well was able to flow unassisted for periods of up to 20 minutes, with wellhead pressures approaching 850 kPa. These results suggest that the well productivity index had improved since the initial testing which was conducted in mid to late 1982.

800?

Since the air-lifting of MC-3 and the completion of the long term flow test of MC-1, no further significant work has been conducted on the existing wells.

GeothermEx, Inc.
SUITE 201
5221 CENTRAL AVENUE
RICHMOND, CALIFORNIA 94804-5829

(510) 527-9876
CABLE ADDRESS GEOTHERMEX
TELEX 709152 STEAM UD
FAX (510) 527-8164

2. CONCEPTUAL GEOLOGIC MODEL

2.1 Geologic Setting

The South Meager geothermal prospect is located on the south flank of Meager Mountain, which is the northernmost of a long line of young volcanic centers extending from northern California through the states of Oregon and Washington into British Columbia.

The volcanic rocks of the Meager Mountain complex cover an elliptically shaped area about 12 km long by 8 km wide. The long axis of the complex is oriented N-S and is coincident with a north-trending series of about 7 extrusion centers (figure 2.1). The age of these centers decreases northward from 1.0 to 1.9 million years (m.y.) for the earliest and most southerly units of Pylon Peak to less than 0.9 m.y. for Capricorn Mountain and 0.1 m.y. for Plinth Peak (figure 2.1).

The Meager Mountain volcanic complex is bordered on the N and NE by the Lillooet River and on the S and SE by Meager Creek. There is about 2,000 m of topographic relief between the beds of those rivers, which are at an elevation of about 600 m msl and the high volcanic peaks at about 2,600 m msl. The base of the young volcanic sequence is exposed around the periphery of the complex. At South Meager, the elevation of this contact ranges from about 1,200 m to 1,400 m elevation. The volcanic rocks rest on crystalline basement mainly consisting of Cretaceous and/or Jurassic quartz dioite, with small inlayers of metamorphic rock including amphibolite, greenstone and phillite.

diorite?

Two structures have been mapped in the South Meager project area: the E-trending Meager Creek fault located in the bed of Meager Creek; and the N-trending No Good fault extending northward from Meager Creek between exploration holes M8 and M13 (figure 2.1). The Meager fault, which appears to have been located mainly on the basis of the morphology of the Meager Creek valley, is believed to be a type of "caldera boundary" fault dipping at about 50° to the N toward the Meager Creek volcanic complex. The geologic evidence for the presence of the No Good fault is not clear, and as this structure is variously referred to as a "fault", a "zone" and a "discontinuity", its geologic nature appears to be uncertain.

THIS INFO
IS AVAILABL

Prior to drilling, and the discovery of high temperatures at depth, the presence of a geothermal system beneath Meager Mountain was indicated by the occurrence of hot springs in the valleys of the Lillooet River and Meager Creek. Spring temperatures range from about 25°C to 60°C. The geochemistry of the spring water is described in section 2.4. Although not specifically mentioned in the literature reviewed for this evaluation, evidently no fumarole activity is associated with any of the Meager Mountain eruption centers. Hydrogen sulfide emanations are reported to be present beneath a glacier which lies on the north side of Mount Job (figure 2.1); the source of these has not been established.

2.2 Temperature Distribution

A series of horizontal sections have been prepared to show three-dimensional temperature distribution in the South Meager prospect. Temperatures from the shallow diamond-drill holes were used to construct sections at +700, +600 and +500 m msl (figure 2.2 through 2.4) and temperatures from the three deep exploration holes were used to construct sections at sea level, -500, -1,000 and -1,500 m msl (figures 2.5 through 2.8). Temperatures measured in diamond drill hole M9 were also used for the sea level and -500 m msl sections. Also, temperatures in holes M6 and M7 were projected downward to obtain values to construct the +500 m msl section. Projected temperatures are indicated by enclosing the temperature values in parentheses.

To further illustrate temperature distribution, figure 2.9 shows the 100°C isothermal surface at +500, +600 and +700 m msl, and figure 2.10 shows the 180°C isothermal surface at +500, 0, -1,000, -500, -1,000 and -1,500 m msl. Figure 2.11 shows temperature distribution along vertical section A-B. The location of section A-B is shown on the horizontal temperature sections.

Based on these figures, the following general observations can be made about the distribution of subsurface temperature at the south Meager project:

- Below +500 m msl isothermal surfaces are steep to vertical with temperatures increasing to the NNW. The horizontal temperature gradient at -500 m msl and below is 60° to 70° C/km.

- Because the locations of exploration holes are restricted to the valley of Meager Creek, due to the steepness of the slopes to the N, only the SW, S and SE boundaries of the temperature anomaly have been drilled.

- The steep, isothermal surfaces are concave to the NNW, indicating the presence of an upflow zone beneath the Pylon Peak extrusion centers. Temperatures in the upflow zone are in excess of 260°C.

- Isothermal surfaces are sub-horizontal above about +500 m msl reflecting horizontal outflow above this level. Outflow occurs to the S, between exploration holes M7 and M10, and discharge is into the thick alluvium of Meager Creek, giving rise to the hot springs along the creek bed.
- Outflow temperatures range from about 100°C at +700 m msl to about 180°C at +500 m msl.

2.3 Permeability Distribution

The South Meager geothermal system is contained in crystalline rocks consisting mainly of granodiorite with lesser amounts of metamorphic and volcanic dike rocks. Permeability, therefore, is related entirely to fractures.

Permeability encountered in drill holes is identified in three ways: by the loss of circulation of the drilling fluid; by water entries; or by interpretation of inflections in temperature profiles measured in the well after completion of drilling.

In drill hole M6, circulation was lost between +710 and +730 m msl and at +650 m msl. The +650 m msl loss corresponds to the depth of the highest temperature measured in the hole which is about 140°C. Temperatures decline below this depth to 131°C at the total depth (+580 m msl).

Drill hole M7 encountered the highest temperature found in the shallow exploration holes, 202°C at +532 m msl (total depth). No loss of circulation however occurred in this hole below +810 m msl.

Hole M9, which was drilled to +325 m msl, encountered no losses below +575 m msl.

Hole M10 encountered 5 points of lost circulation, the deepest near the bottom of the hole at +670 m msl.

In summary, of the 4 shallow holes drilled near the S margin of the South Meager temperature anomaly, all encountered permeability in the outflow zone at levels ranging between +575 m to +670 m msl, except the hottest well, M7, which encountered no permeability below +810 m msl. Hole M6 encountered the highest temperature which is also accompanied by permeability, 140°C at +650 m msl, which corresponds to a depth of 250m.

In the three deep exploratory wells partial losses of circulation were noted between -600 m and -1100 m msl in MC-1, between -750 m and -1,100 m msl in MC-2 and between -1,700 m and -2,200 m msl (total depth) in MC-3. A particularly large loss was noted in MC-3 at an elevation of about 1,850 m.

Apparently, none of these losses were cased-off or cemented-off before drilling deeper, and therefore, it is possible that only the shallowest loss is actually associated with a permeable zone. For example, a major temperature inflection was measured in MC-1 at -600 m msl (1,400 m vertical depth) suggesting that the losses noted down to -1,100 m msl may all have been related to permeability at -600 m msl. As noted in section 1.2, well MC-1 was the only deep well with sufficient permeability to sustain continuous production, and, for the above reason, it is probable that fluid was produced from the -600 m msl level.

The main temperature inflection in well MC-2 is at -1,600 m msl, rather than at the top of the loss of circulation zone at -750 m msl. It is uncertain, therefore, from what depth fluid was produced during airlift operations. Permeability was too low to support sustained flow.

Although no losses were reported in well MC-3 at -800 m msl, temperature inflections during heat-up indicate some permeability at this level. The main temperature inflection in MC-3, however, is at -1,900 m msl, which is within the zone of loss of circulation noted above. As with MC-2, permeability in MC-3 was insufficient to sustain continuous fluid production.

In summary, partial loss zones and/or inflections of the temperature profile during heat-up, indicate the presence of permeability in the depth interval between -600 m and -800 m msl in all three deep exploration wells. In addition, a particulary large loss was noted at an elevation of -1,850 m in MC-3. Only in well MC-1, however, was this permeability sufficient to support sustained flow. There are no geologic features observed either on the surface or in the wells to which this permeability can be specifically ascribed. Because of the massive nature of the reservoir rock, it is not possible to determine if the permeable zones encountered in each well are, in fact, related to one or more through-going structural features or are merely randomly distributed throughout the otherwise massive granodiorite. Indeed, it is doubtful even if pressure interference or tracer tests could resolve the exact geometry of permeability distribution at South Meager without drilling additional wells.

2.4 Geochemistry

Deep reservoir waters

The deep exploration holes MC-1, MC-2 and MC-3 have all produced a high temperature, sodium chloride geothermal water type, sampled by the self-sustained flow of MC-1, and air-lift and nitrogen-lift of the other two wells. All three wells showed strong effects of drilling fluid clean-out during initial production. The chemistries of MC-2 and MC-3 never stabilized completely during the test periods, but probably came close to representing natural formation fluids, and indicate production zones more dilute than at MC-1 by 25% to 35%.

Well MC-1 flowed long enough to be clearly purged of drilling fluids and stabilize. Production came from a zone or zones between 1,200 and 1,700 m depth, where flowing down-hole logging surveys indicate a temperature of 194°C. The composition is in essence a typical example of deep, high temperature fluid from hot volcanic or intrusive rocks as shown in Table 1.

The average quartz solubility temperature of nine samples from MC-1 was 196°C, and the average sodium-potassium-calcium empirical geothermometer temperature (aka cation temperature) was 194°C. These temperatures are in good agreement with the measured temperatures at the production zone.

Samples obtained from well MC-2 are less clearly interpretable. The single sample which must be closest to uncontaminated thermal reservoir water was obtained at the end of airlift tests in October, 1982: this had 1,490 ppm chloride, 49 ppm calcium, 0.6 ppm magnesium, a quartz solubility temperature of 221°C, and a cation temperature of

203°C. This fluid was obtained when the well was lifted from 0 to 2,100 m, and probably came from a zone or zones between 1,600 m and 1,800 m depth. During subsequent lifting below 2,100 m the well produced water distinguished by much higher chloride, higher calcium and magnesium, and very low silica. The chemistry of the "deeper" samples are consistent with strongly decreasing temperature, whereas temperature surveys indicate a strong increase with depth. Therefore, we doubt that these "deep" samples are unaltered formation water from below 2,100 m.

The water chemistry from well MC-3 had nearly stabilized by the end of the air and nitrogen lifting, at 1,270 to 1,370 ppm chloride, 13 to 35 ppm calcium, 0.8 to 1.9 ppm magnesium, and pH 8.8 to 9.0. The quartz solubility temperature was 180 - 200°C, and cation temperature 190 - 200°C.

Other water groups

Combined with the deep thermal waters, there are a total of four hydrochemical groups found in the South Meager area. Distinguishing the waters above as group (a), the other three types are:

(b) surface waters and shallow groundwaters of meteoric origin;

(c) cool high chloride-sulfate-bicarbonate waters;

(d) moderate-chloride warm springs.

The group (b) waters are unremarkable examples of their type: dissolved solids contents are low and calcium and bicarbonate are the most concentrated species. Indicators of geothermal heating, such as low magnesium and high silica are absent. Sources include the various creeks which drain the southern slopes of Pylon Peak, Meager Creek, shallow well M2, and a shallow, cool zone in well M7.

The cool group (c) waters are characterized by well M12, just east of South Fork Creek to the south of Meager Creek, and by several seeps along the creek near that well (figure 1.2). These have a chloride concentration as high as 4,200 mg/l in well M12, but the well was only warm (maximum 45°C), the associated surface seeps are cold, and chemical indicators of heating such as high silica, low magnesium and low sodium/potassium ratios are absent. The origin of these waters is uncertain: one possibility is that they are former thermal waters which have cooled and reacted with rocks during a slow ascent to the surface; another is that they are pore waters from sedimentary rocks in the area.

The moderate-chloride warm spring waters (group (c)) include Meager Creek and Placid Hot Springs, No Good Springs, and waters from numerous shallow drillholes in Meager Creek valley. These are all mixtures of the group (a), group (b), and (c) waters, with chlorides ranging from several hundred to several thousand ppm. The maximum measured temperatures of these waters are 60°C.

2.5 Definition of the Geothermal System

The steeply-dipping isothermal surfaces illustrated in figures 2.9 through 2.11 strongly indicate the presence of a thermal fluid upflow zone to the NNW of the wellhead locations of the MC wells. These surfaces are concave to the NNW (figure 2.10) and temperatures increase in that direction (figure 2.11). Indeed, the increase in temperature with drilled depth in the deep exploration wells is due more to their horizontal throw to the north than to increased depth (figure 2.11).

The general lack of permeability in the deep holes, as well as the regular spacing and simple geometry of the isothermal surfaces, indicates that horizontal conduction is the main mechanism of heat transfer in the drilled area below +500 m msl. Upward convecting thermal fluid, at a temperature somewhat higher than 260°C, must be the source of the heat being horizontally conducted to the south.

The upflow zone should be located to the north of the bottom hole location of well MC-1. The resistivity boundary of the field, shown in relation to the exploration well traces and the 180°C isothermal surface in figure 2.12, may mark the E, N and W boundary of the upflow zone. (South ?) However, because of the large topographic relief above the northern part of the resistivity anomaly and because of the comparatively limited depth of penetration of resistivity surveys, the relevance of the resistivity boundary to deep geothermal-related features is questionable. It is more probable that the upflow zone is located beneath the volcanic vent of Pylon Peak.

Figure 2.11 shows that outflow from the geothermal system occurs above an elevation of +500 m msl. The temperature contours at +700 m, +600 m and +500 msl, and the 100°C isothermal surface shown in figure 2.9, show what is known about the location of the outflow zone. From these figures, it is apparent that outflow is to the SSW in a relatively narrow channel between wells M-7 and M-10. The outflow discharges into the deep alluvium of Meager Creek and first appears in No Good springs where it is mixed with near-surface groundwater.

3. ESTIMATION OF POWER CAPACITY

3.1 Methodology

We have used, with some modifications, the volumetric reserve estimation introduced by the U.S. Geological Survey. We have further improved this approach, to account for uncertainties in some parameters, by using a probabilistic basis (Monte Carlo simulation).

In our method, the maximum sustainable power plant capacity (E) is given by:

$$E = VC_v(T-T_o)\cdot R/F/L \qquad (1)$$

where V = volume of the reservoir,
C_v = volumetric specific heat of the reservoir,
T = average temperature of the reservoir,
T_o = rejection temperature (equivalent to the average annual ambient temperature),
R = overall recovery efficiency (the fraction of thermal energy in-place in the reservoir that is converted to electrical energy at the power plant),
F = power plant capacity factor (the fraction of time the plant produces power on an annual basis), and
L = power plant life.

The parameter R can be determined as follows:

$$R = \frac{W \cdot r \cdot e}{C_f \cdot (T - T_o)} \qquad (2)$$

where r = recovery factor (the fraction of thermal energy in-place that is recoverable as thermal energy),
C_f = specific heat of reservoir fluid,
W = maximum available work from the produced fluid, and
e = utilization factor to account for mechanical and other losses that occur in a real power cycle.

The parameter C_v in (1) is given by:

$$C_v = \rho_r\, C_r\, (1-\phi) + \rho_f C_f\, \phi \qquad (3)$$

where ρ_r = density of rock matrix,
C_r = specific heat of rock matrix,
ρ_f = density of reservoir fluid, and
ϕ = reservoir porosity.

The parameter W in (2) is derived from the First and Second Laws of Thermodynamics as follows:

$$dW = dq\,(1 - T_o/T), \text{ and} \qquad (4)$$

$$dq = C_f dT \qquad (5)$$

where q represents thermal energy.

3.2 Parameter Estimation

For the purposes of reserve estimation, the minimum acceptable fluid temperature was assumed to be 180°C. The following parameters could be estimated for the South Meager reservoir without significant uncertainty:

$\rho_r C_r$ = 2,430 kJ/m^3/°C (based on representative rock types at South Meager),
T_o = 10°C (average ambient temperature at South Meager),
e = 0.50 (typical for modern geothermal plants),
F = 0.90 (typical for modern geothermal plants), and
L = 30 years (typical amortization period for a power plant).

The value of V, reservoir volume, is estimated by combining estimates of its area and thickness.

The minimum area of the reservoir is estimated to be about 4.5 km^2 which corresponds to the area enclosed by the 180°C isothermal surface on the S and SE and by the boundary of the resistivity anomaly on the W, NW, N and NE (figure 2.12). The maximum area of the reservoir is estimated to be about 10.2 km^2, which includes the minimum area described above plus the volcanic vent areas of Pylon Peak.

Because temperature profile A-B (figure 2.11) shows that the deep isothermal surfaces are essentially vertical, the only limit to the thickness of the reservoir is the economic drilling depth, which is estimated to be 3 km.

The minimum average temperature (T) of this volume of rock is estimated to be 220°C; whereas the maximum average temperature is estimated at 240°C.

The porosity value was assumed to be uncertain, being in the range of 3% to 7%. The recovery factor was considered the most uncertain parameter and, therefore, was conservatively estimated to be in the range of 10% to 20%.

Estimates of C_f and ρ_f were assumed to have the values for pure water corresponding to the average reservoir temperature; therefore, these parameters were also uncertain.

3.3 Results

Figure 3.1 presents the results of Monte Carlo simulation (1,000 trials) as a probability distribution of the calculated MW capacity. The most-likely MW capacity for this project is 250 MW, the standard deviation being 87 MW. Figure 3.2 presents the same results in terms of the cumulative probability distribution. This figure shows that there is an extremely high probability that at least 140 MW of reserves exist.

4. ADDITIONAL WORK REQUIRED FOR RESERVOIR CONFIRMATION

4.1 Drilling Strategy

It is clear from the results of the exploratory work described above that there is a very large amount of geothermal heat beneath the South Meager prospect. With the exception of the outflow zone, this heat is not under the easily accessible valley of Meager Creek, but underlies the rugged and high-relief terrain to the north of the valley; perhaps as far north as the ground beneath Pylon Peak. Drilling has established the presence of this large heat reservoir, but has not proven the presence of sufficient permeability for economic resource extraction. No additional data reviews, surface surveys, well workovers or well tests will be helpful in locating permeability. Permeability can only be found by additional test drilling.

Highly productive wells have been drilled in granitic reservoirs similar to that at South Meager in a number of geothermal fields: Coso, California; Steamboat, Nevada; Roosevelt, Utah; and Palimpinon, the Philippines. Although a few wells in each of these fields are believed to produce from a single recognizable fault, the majority of wells produce from fractures that have no obvious relationship to one single fault or fault zone. Indeed, in most cases it is not certain if the fracture distribution and, therefore, the permeability distribution, is related to a regional stress field, a local stress field, a combination of both, or are merely randomly distributed.

At Coso, where the largest number of wells have been drilled, the temperature pattern, which reflects the permeability pattern, appears to be systematically distributed around the margin of a volcanic extrusion dome. Wells drilled within about 1.5 km of the dome have found permeability, while holes drilled beyond that distance, although hot, have encountered insufficient fracturing for economic production. It can be inferred, therefore, that implacement of the volcanic "neck" caused the fracturing responsible for high permeability and that the fracturing is limited to a distance of about 1.5 km from the volcanic feature. At the present time, the Coso field supports an installed capacity of 258 MW with average well outputs of 4 to 5 MW.

Applying the analogy of the Coso field to South Meager, it might be necessary to drill another 500 m or so north of the bottom hole location of MC-1 to find permeable fractures in the upflow zone. This would require drilling wells with even greater throws than the approximately 1,200 m to 1,600 m throws of the MC series wells.

An alternative resource confirmation strategy would be to develop only the relatively shallow outflow zone. This zone is readily accessible from the valley of Meager Creek and, if adequate permeability can be found, could be developed at far less cost than the upflow zone. Naturally, because of the restricted area of the outflow zone and its lower temperature, its maximum potential may be a few tens of megawatts compared to the estimated 250 MW of the upflow zone.

4.2 Drilling Targets and Preliminary Well Design

Highly deviated wells, designed for maximum throw, must be used to develop the upflow zone from drilling sites located in the valley of Meager Creek. The closest site on the valley floor to the upflow zone appears to be located about 300 m WNW of well M6. This site is just below the 914 m elevation contour. It is recommended that two holes be drilled, one to the NW and the other to the NNW from this location. The wells should be designed for throws of 1,500 m to 2,000 m. The amount of true vertical depth is not critical and should be the minimum required for the designed throws.

A tabulation of measured depth, inclination, vertical depth and throw for such a highly deviated well is given in Table 2. This well design was developed by Eastman Christensen, a company specializing in the design and drilling of deviated wells. We recommend drilling a full diameter, rather than a slim-hole, to be able to run additional casings in the event of hole problems, which are likely in a highly deviated well. The cost of such a well is estimated at US$ 1.5 million, excluding mobilization costs.

An alternative to drilling two new large diameter wells would be to drill one such well and sidetrack the existing well MC-1 to reach a target located approximately 1,500 to 2,000 meters to the NW of the existing well pad, at an approximate depth of 1,000 m. This operation would require setting and orienting a deviation packer inside the 244 mm casing at a depth between 200 and 250m; milling out a window and following the deviation program presented in this report with a 216 mm bit diameter to reach the target. The cost of this workover operation is estimated at about US$500,000. However, an intermediate casing string may be required before reaching the target depending on the drilling conditions; this would increase the cost to about US$750,000.

Slim holes to explore the outflow zone should be sited between wells M7 and M10. These wells should have a maximum depth of 1,000 m, and a bottom hole diameter of 6-1/4 inches. Vertical holes will encounter temperatures of 160°C at sea level (figure 2.5), and if higher temperatures are required, it will be necessary to deviate the wells to the north. The cost of these 1,000 m deep slim-holes is estimated at about US$200,000 to US$300,000 each, excluding mobilization costs. Drilling deviated wells would cost about an additional US$100,000.

5. CONCLUSIONS

1. Below +500 msl isothermal surfaces are steep to vertical with temperatures increasing to the NW from Meager Creek.

2. The configuration of these surfaces, and the magnitude of the temperature gradient they reveal, indicate the presence of an upflow zone beneath the Pylon Peak extrusion centers. Temperatures in the upflow zone are in excess of 260°C.

3. Isothermal surfaces are sub-horizontal above +500 m msl reflecting horizontal outflow from the upflow zone above this level. Outflow is to the south, between exploration hole M7 and M10. Outflow temperatures range from 100°C at +700 m msl to 180°C at +500 m msl.

4. Most of the shallow holes drilled in the outflow zone encountered permeablility between +575 m and +670 m msl. The hottest well drilled in the outflow zone, M7, reached 202°C at a bottom hole elevation of +532 m msl (367 m total depth).

5. All three deep exploration wells found permeability in the elevation interval between -600 m and -800 m msl (about 1,400 m to 1,600 m vertical depth), but these zones do not have sufficient permeability for commerical production.

6. The chemical composition of fluids produced from the three deep tests indicate reservoir fluid temperatures ranging from 196°C to 200° C, which is compatable with downhole temperatures measured in the depth range of 1,200 m to 1,800 m. The

chemical composition of fluids produced from wells MC2 and MC3 show dilution of 25% to 35% compared to the fluid produced from well MC1.

7. Based on the downhole temperature data, as well as surface geologic and geophysical data, the probable minimum and maximum areas underlain by the South Meager reservoir are 4.5 km^2 and 10.2 km^2, respectively.

8. The thickness of the reservoir is clearly in excess of the maximum economic drilling depth of about 3 km.

9. Monte Carlo simulation based on our best estimates of maximum and minimum values of reservoir volume, temperature, permeability and recovery factor, indicates the most likely MW reserves of the South Meager reservoir is 250 MW, with a standard deviation of 87 MW. There is a very high probability that at least 140 MW of reserves exist.

10. Although drilling has established the presence of a very large energy reserve at South Meager, it has yet to prove the presence of sufficient permeability for economic resource extraction.

11. Highly productive geothermal wells have been drilled in granite reservoirs similar to that found at South Meager. Of the granite reservoirs under production, the closest geological analogy to Meager is the Coso reservoir in California which presently supports an installed capacity of 258 MW.

12. Permeability at Coso appears to be related to fracturing out to a distance of about 1.5 km from the margin of the volcanic extrusion center with which the field is associated. Applying this analogy to South Meager, it is possible that sufficient permeability could be found by drilling deviated wells from the valley of Meager Creek with horizontal throws of 1,600 m to 2,000 m. Such long throws are needed because the upflow zone is located beneath steep, rugged and generally inaccessible terrain north of Meager Creek. These wells would cost in the range of US$ 1.5 to 2 million.

13. Alternatively, the outflow zone can be developed by relatively shallow wells located within the easily accessible valley of Meager Creek. Because of the restricted area of the outflow zone, and relatively low fluid temperatures, the potential of such a project would be limited to a few tens of megawatts. Slim holes to confirm production from the outflow zone would cost in the range of US$ 200,000.

GeothermEx, Inc.
SUITE 201
5221 CENTRAL AVENUE
RICHMOND, CALIFORNIA 94804-5829

(510) 527-9876
CABLE ADDRESS GEOTHERMEX
TELEX 709152 STEAM UD
FAX (510) 527-8164

TABLES

GeothermEx, Inc.

SUITE 201
5221 CENTRAL AVENUE
RICHMOND, CALIFORNIA 94804-5829

(510) 527-9876
CABLE ADDRESS GEOTHERMEX
TELEX 709152 STEAM UD
FAX (510) 527-8164

Table 1. Chemical Composition of Thermal Fluid from Well MC-1

A. FLUID AFTER BOILING TO THE ATMOSPHERE, SAMPLE COLLECTED OCT. 23, 1982

T°C	100.	
pH	8.3	
Na	1,260.	ppm-wt
K	97.	
Ca	40.	
Mg	0.8	
Li	3.3	
HCO_3	72.	
SO_4	120.	
Cl	1,990.	
SiO_2	370.	
B	12.8	
F	2.1	

B. TOTAL DISCHARGE CONCENTRATIONS, FROM STEAM SAMPLES COLLECTED VARIOUS DATES, SEPT.-NOV. 1982

CO_2	1,600.	ppm-wt
H_2S	7.4	

Note: Samples collected from well MC-1 in November and December, 1982 showed some evidence of contamination by cool ground water entering through a casing leak at about 200m depth.

Table 2. Measured Depth, Inclination, Vertical Depth and Throw for Proposed Deviated Well

GEOTHERMEX
BRITISH COLUMBIA,WELL 1
BRITISH COLUMBIA,BRITISH COLUMBIA

PROPOSAL LISTING Page 1
Your ref : WELL 1
Last revised : 21-Jan-92

Measured Depth	Inclin. Degrees	Azimuth Degrees	True Vert. Depth	RECTANGULAR COORDINATES		Dogleg Deg/100Ft	Vert Sect
0.00	0.00	0.00	0.00	0.00 N	0.00 E	0.00	0.00
500.00	0.00	0.00	500.00	0.00 N	0.00 E	0.00	0.00
650.00	0.00	0.00	650.00	0.00 N	0.00 E	0.00	0.00
750.00	4.00	0.00	749.92	3.49 N	0.00 E	4.00	3.49
850.00	8.00	0.00	849.35	13.94 N	0.00 E	4.00	13.94
950.00	12.00	0.00	947.81	31.30 N	0.00 E	4.00	31.30
1050.00	16.00	0.00	1044.82	55.49 N	0.00 E	4.00	55.49
1150.00	20.00	0.00	1139.91	86.38 N	0.00 E	4.00	86.38
1250.00	24.00	0.00	1232.61	123.84 N	0.00 E	4.00	123.84
1350.00	28.00	0.00	1322.47	167.66 N	0.00 E	4.00	167.66
1450.00	32.00	0.00	1409.05	217.66 N	0.00 E	4.00	217.66
1550.00	36.00	0.00	1491.94	273.56 N	0.00 E	4.00	273.56
1650.00	40.00	0.00	1570.72	335.12 N	0.00 E	4.00	335.12
1750.00	44.00	0.00	1645.02	402.02 N	0.00 E	4.00	402.02
1850.00	48.00	0.00	1714.48	473.94 N	0.00 E	4.00	473.94
1950.00	52.00	0.00	1778.74	550.52 N	0.00 E	4.00	550.52
2050.00	56.00	0.00	1837.51	631.41 N	0.00 E	4.00	631.41
2150.00	60.00	0.00	1590.49	716.20 N	0.00 E	4.00	716.20
2250.00	64.00	0.00	1937.43	804.47 N	0.00 E	4.00	804.47
2350.00	68.00	0.00	1978.09	895.81 N	0.00 E	4.00	895.81
2450.00	72.00	0.00	2012.29	989.76 N	0.00 E	4.00	989.76
2550.00	76.00	0.00	2039.85	1085.87 N	0.00 E	4.00	1085.87
2555.43	76.22	0.00	2041.15	1091.14 N	0.00 E	4.00	1091.14
3000.00	76.22	0.00	2147.06	1522.91 N	0.00 E	0.00	1522.91
3500.00	76.22	0.00	2266.18	2008.51 N	0.00 E	0.00	2008.51
4000.00	76.22	0.00	2385.30	2494.11 N	0.00 E	0.00	2494.11
4500.00	76.22	0.00	2504.42	2979.72 N	0.00 E	0.00	2979.72
5000.00	76.22	0.00	2623.54	3465.32 N	0.00 E	0.00	3465.32
5500.00	76.22	0.00	2742.66	3950.92 N	0.00 E	0.00	3950.92
6000.00	76.22	0.00	2861.78	4436.53 N	0.00 E	0.00	4436.53
6500.00	76.22	0.00	2980.90	4922.13 N	0.00 E	0.00	4922.13
6580.18	76.22	0.00	3000.00	5000.00 N	0.00 E	0.00	5000.00

GeothermEx, Inc.
SUITE 201
5221 CENTRAL AVENUE
RICHMOND, CALIFORNIA 94804-5829

(510) 527-9876
CABLE ADDRESS GEOTHERMEX
TELEX 709152 STEAM UD
FAX (510) 527-8164

FIGURES

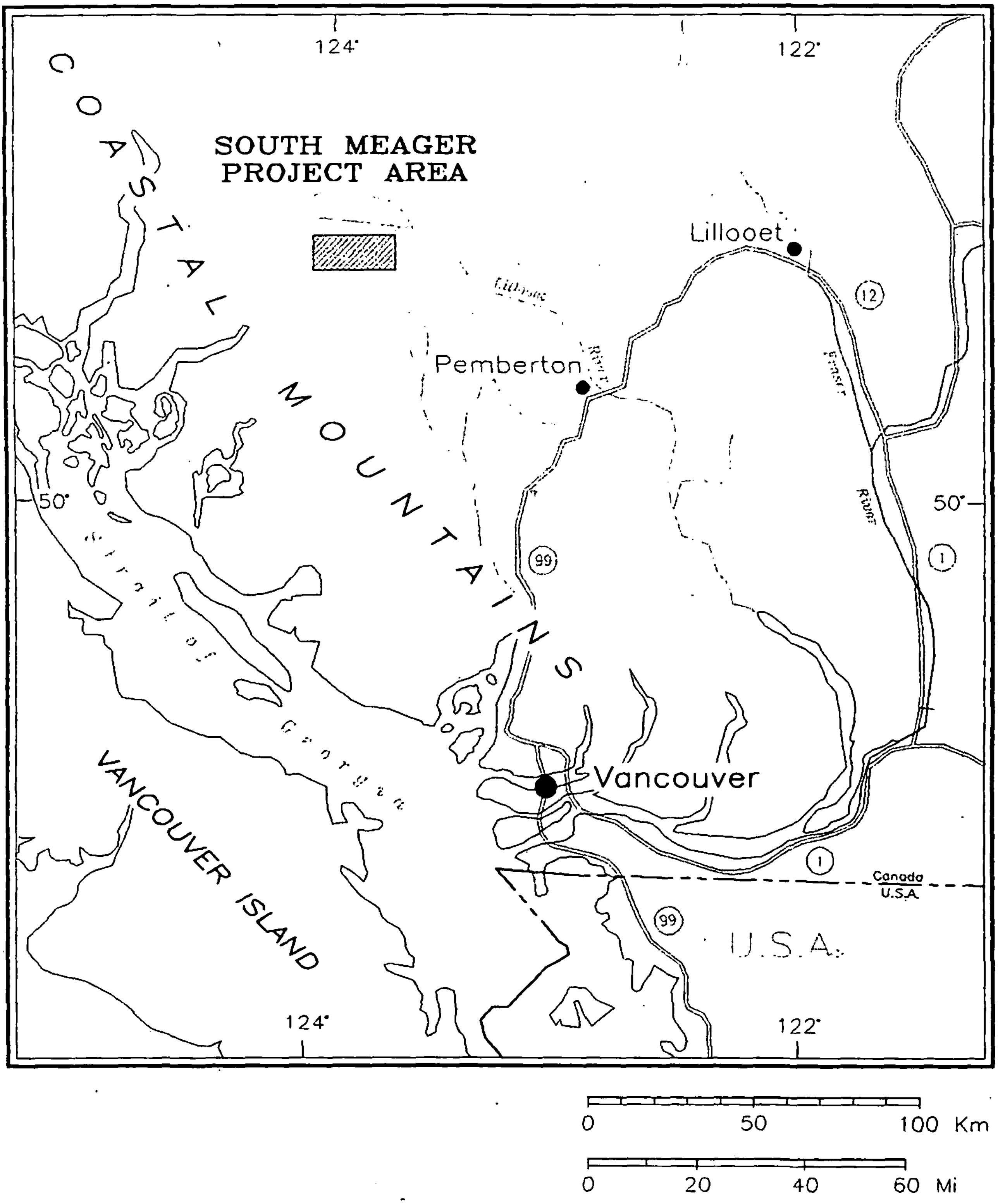


Figure 1.1 Project location map

1992, GeothermEx, Inc.

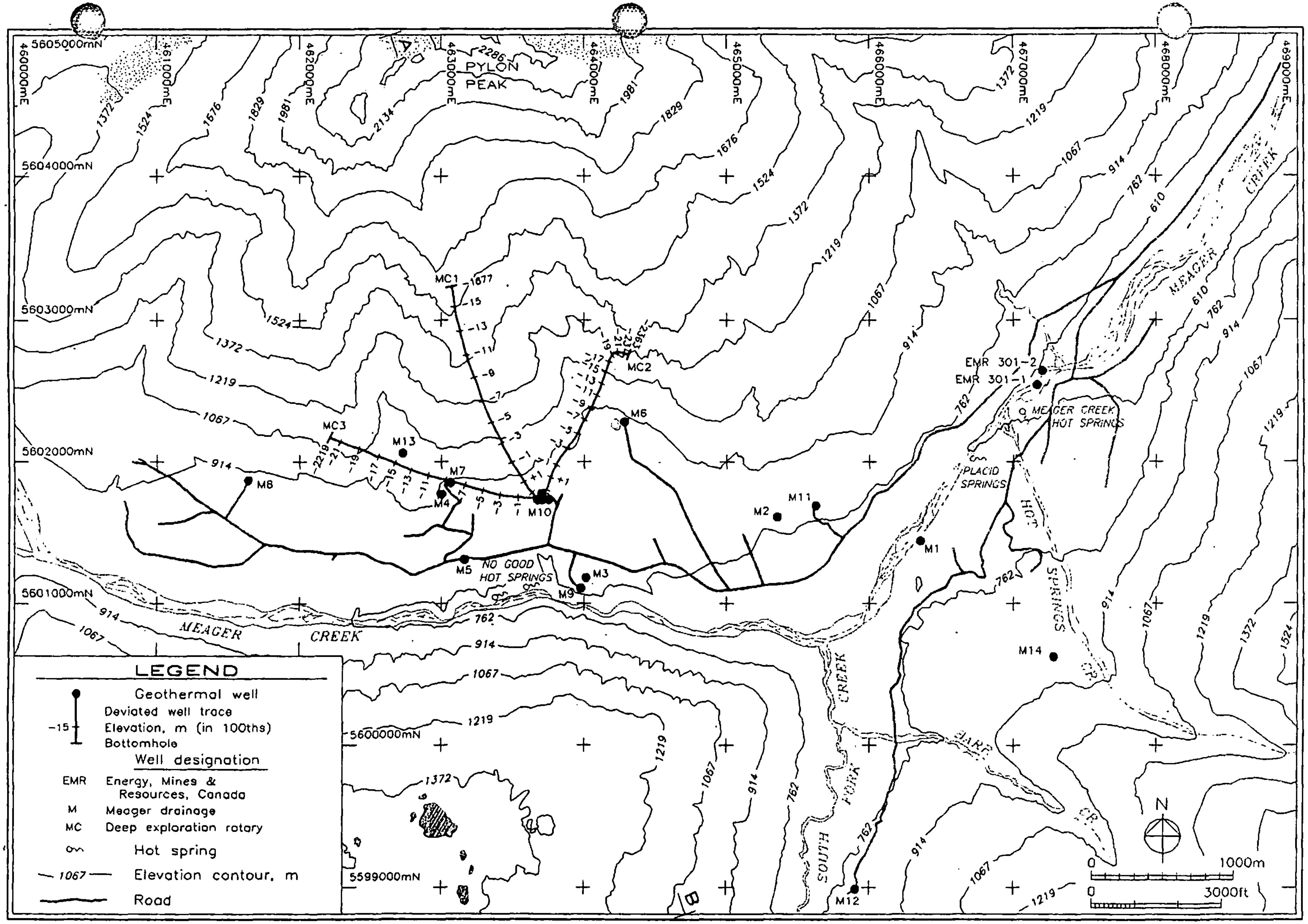


Figure 1.2: Well location map

1992, GeothermEx, Inc. CCMLOCAL/012392/H583/EMMN1=35.1/MEAGER.JP

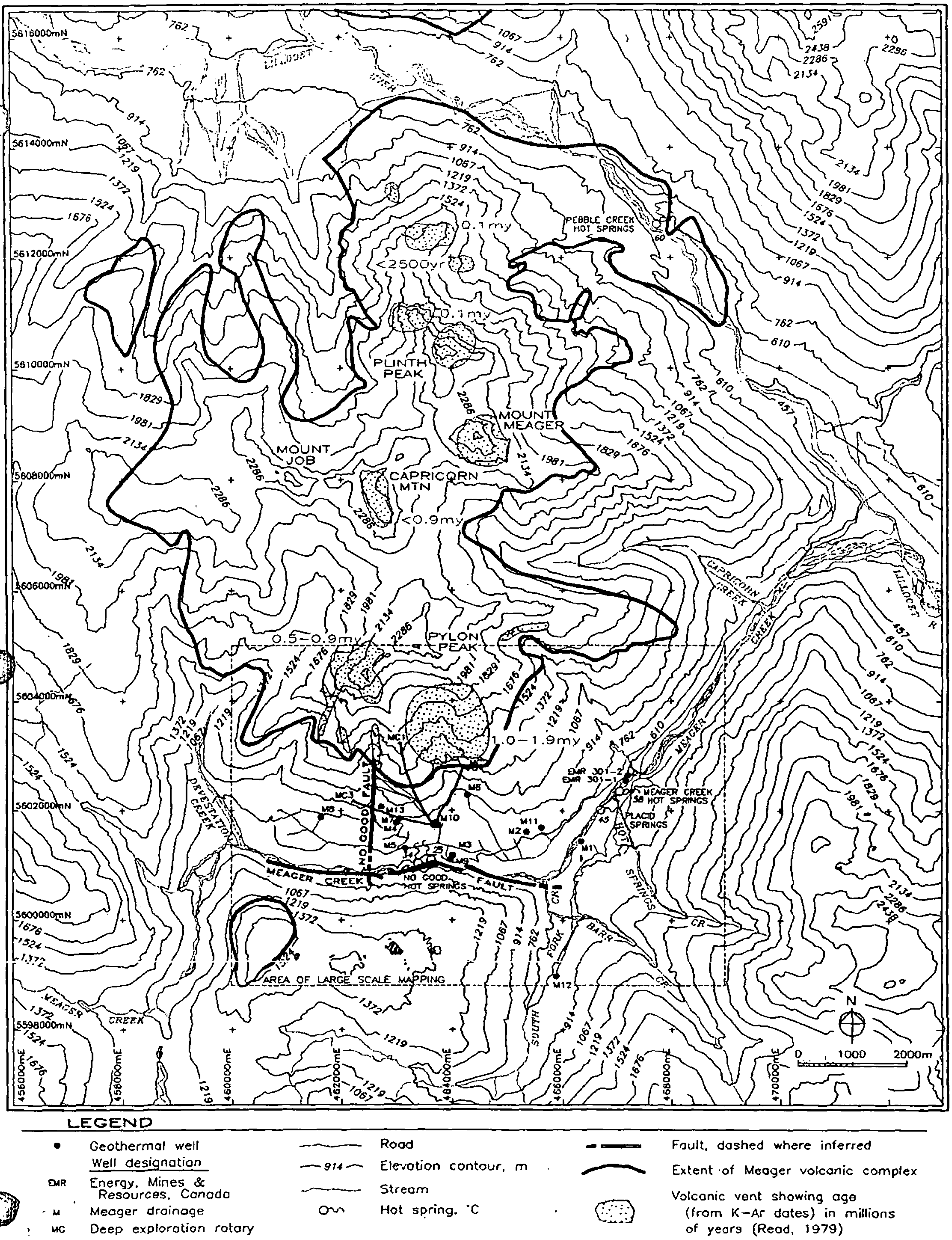


Figure 2.1: Geologic setting of the South Meager Prospect

1992, GeothermEx, Inc. COMINTBS/013092/H3966/EMMY1=91/MEAGER.JP

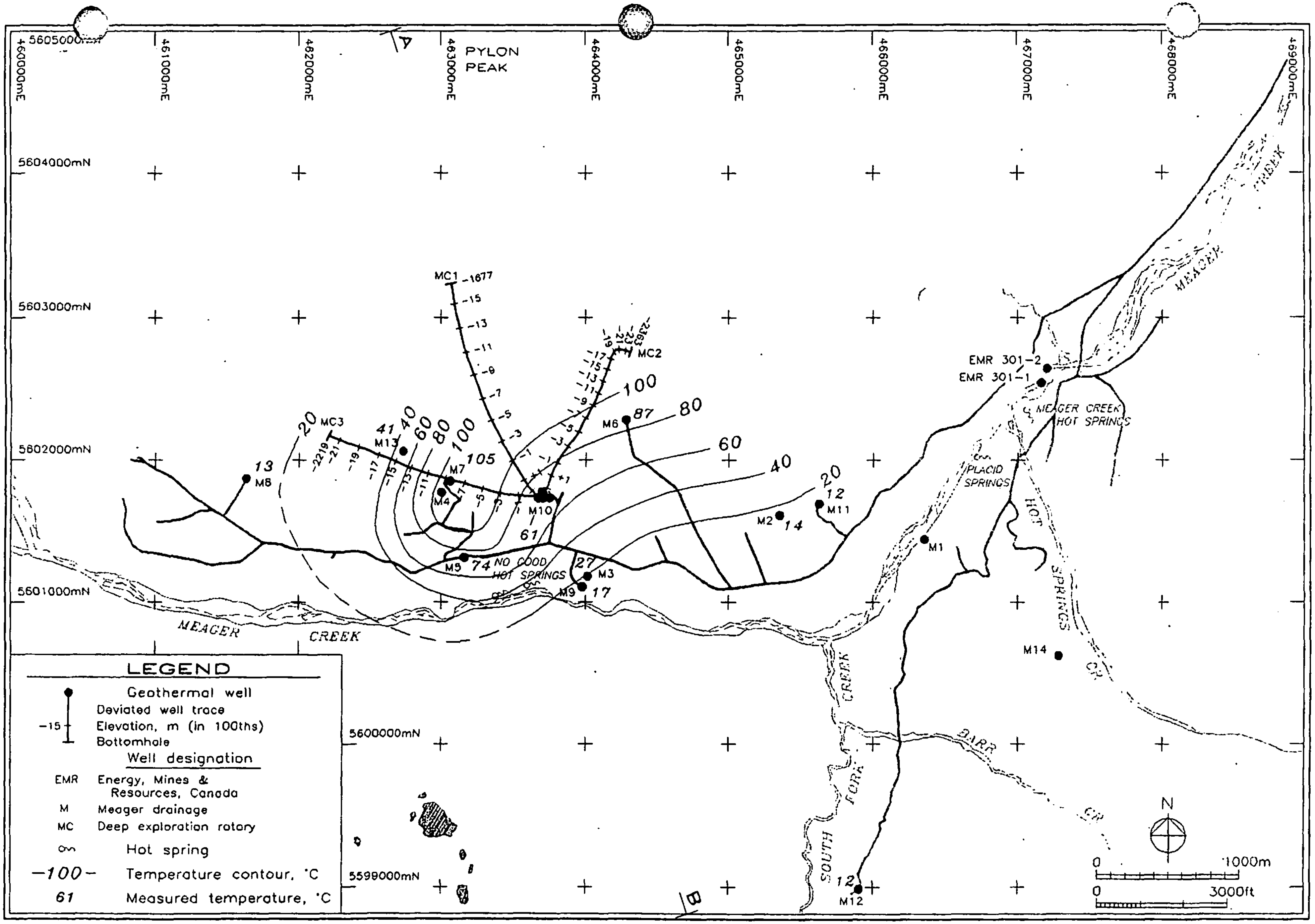


Figure 2.2: Temperature distribution at +700 m msl, South Meager Prospect

1992, GeothermEx, Inc. CCMTP7/012392/H3891/EMMN1=35.1/MEAGER.JP

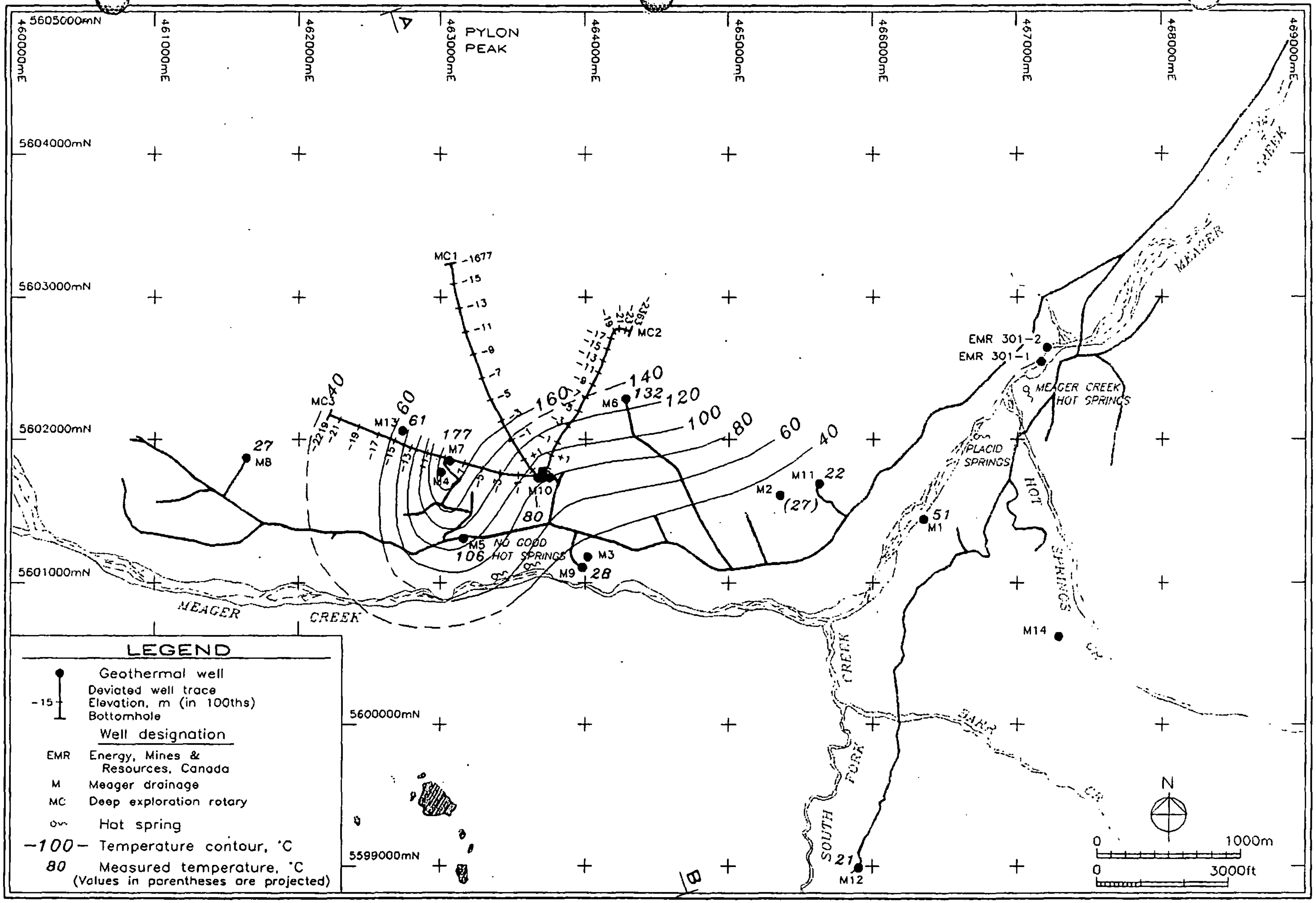


Figure 2.3: Temperature distribution at +600 m msl, South Meager Prospect

1992, GeothermEx, Inc. CCMTP6/012392/H3891/EMMN1=35.1/MEAGER.JP

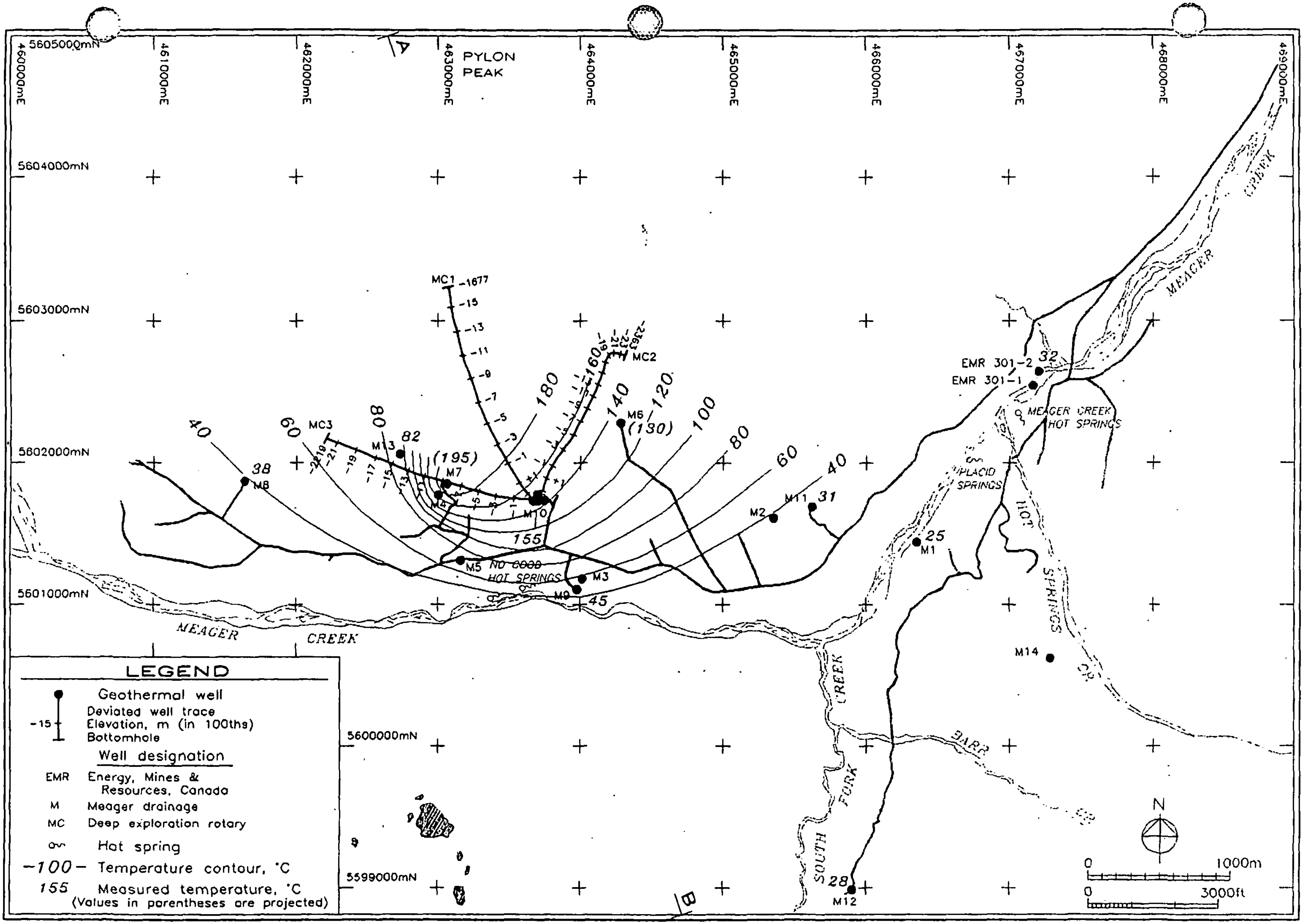


Figure 2.4: Temperature distribution at +500 m msl, South Meager Prospect

1992, GeothermEx, Inc. CCMTP5/012392/H3891/EMMN1=35.1/MEAGER.JP

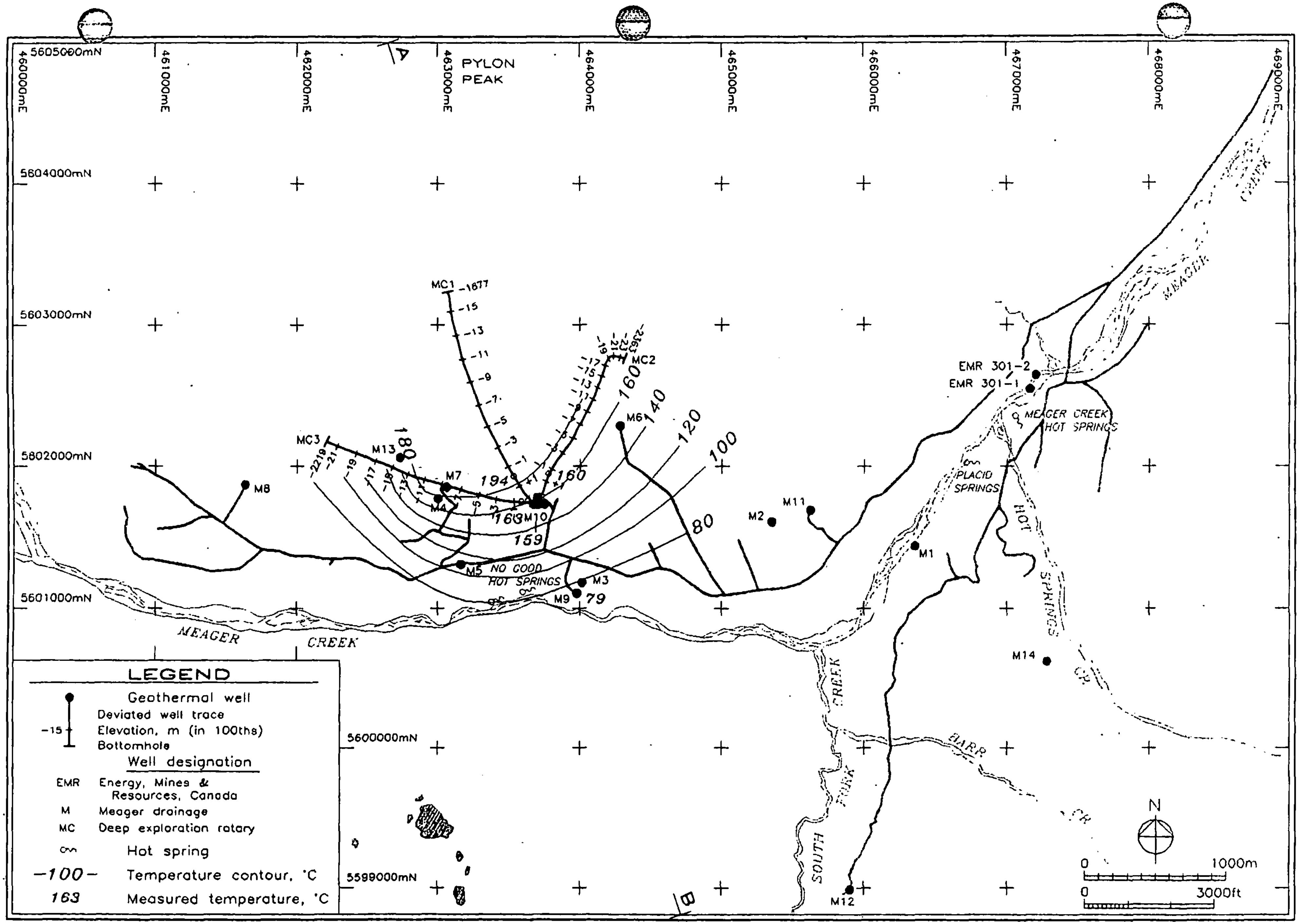


Figure 2.5: Temperature distribution at sea level, South Meager Prospect

1992, GeothermEx, Inc. CCMTSEA/012392/H3891/EMMN1=35.1/MEAGER.JP

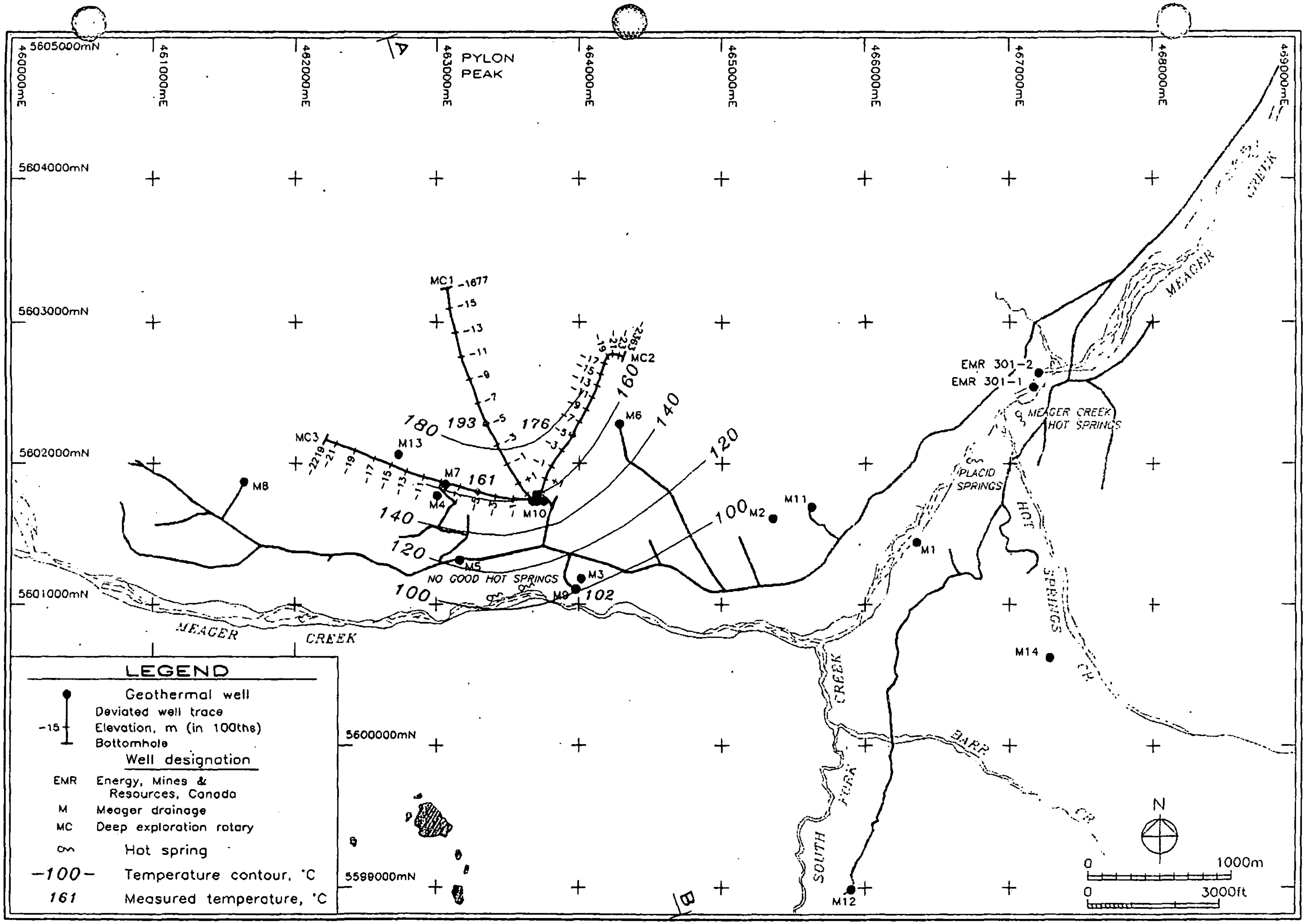


Figure 2.6: Temperature distribution at −500 m msl, South Meager Prospect

1992, GeothermEx, Inc. CCMTM5/012392/H3891/EMMN1=35.1/MEAGER.JP

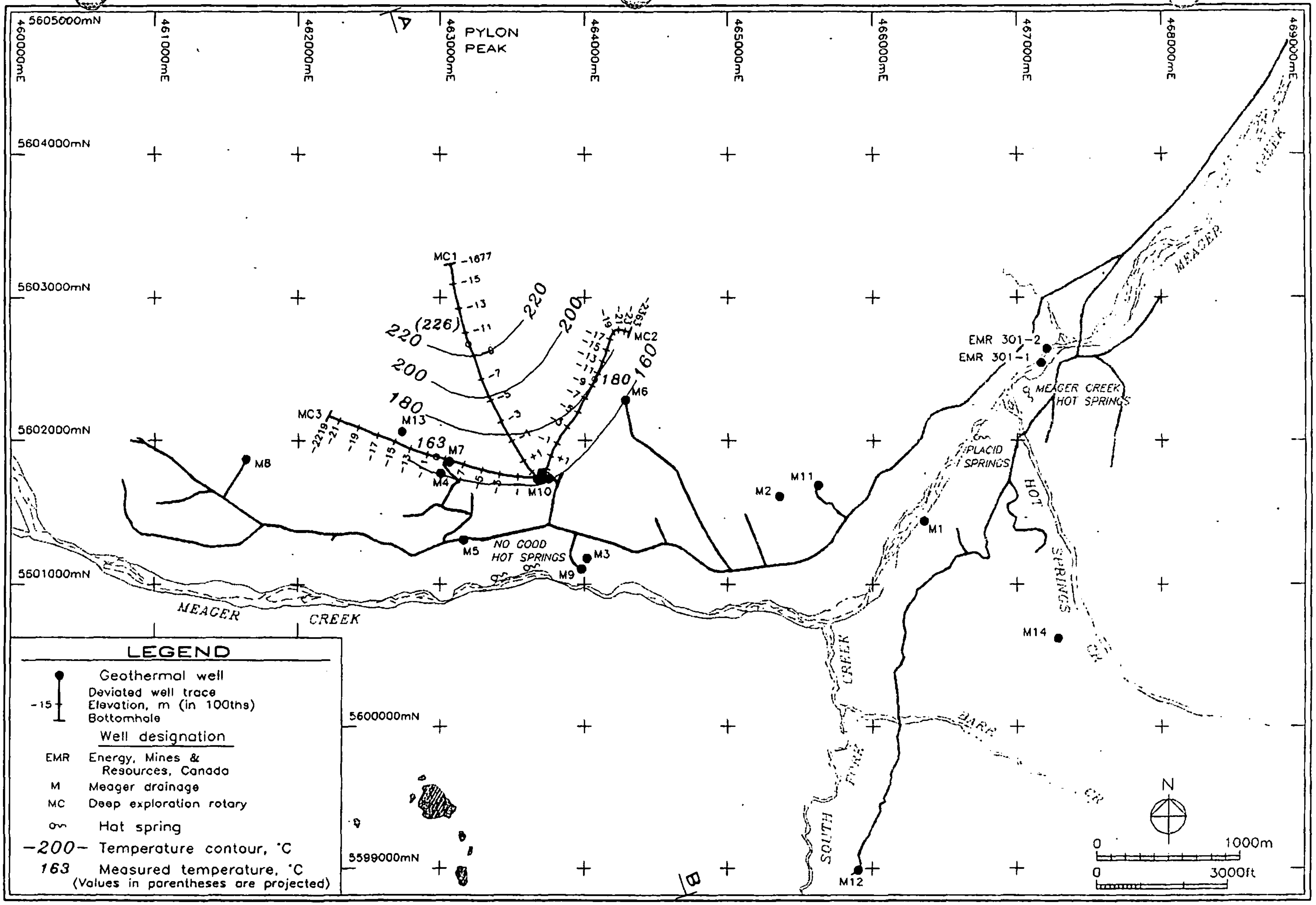


Figure 2.7: Temperature distribution at −1,000 m msl, South Meager Prospect

1992, GeothermEx, Inc. CCMTM10/012392/H3891/EMMN1=35.1/MEAGER.JP

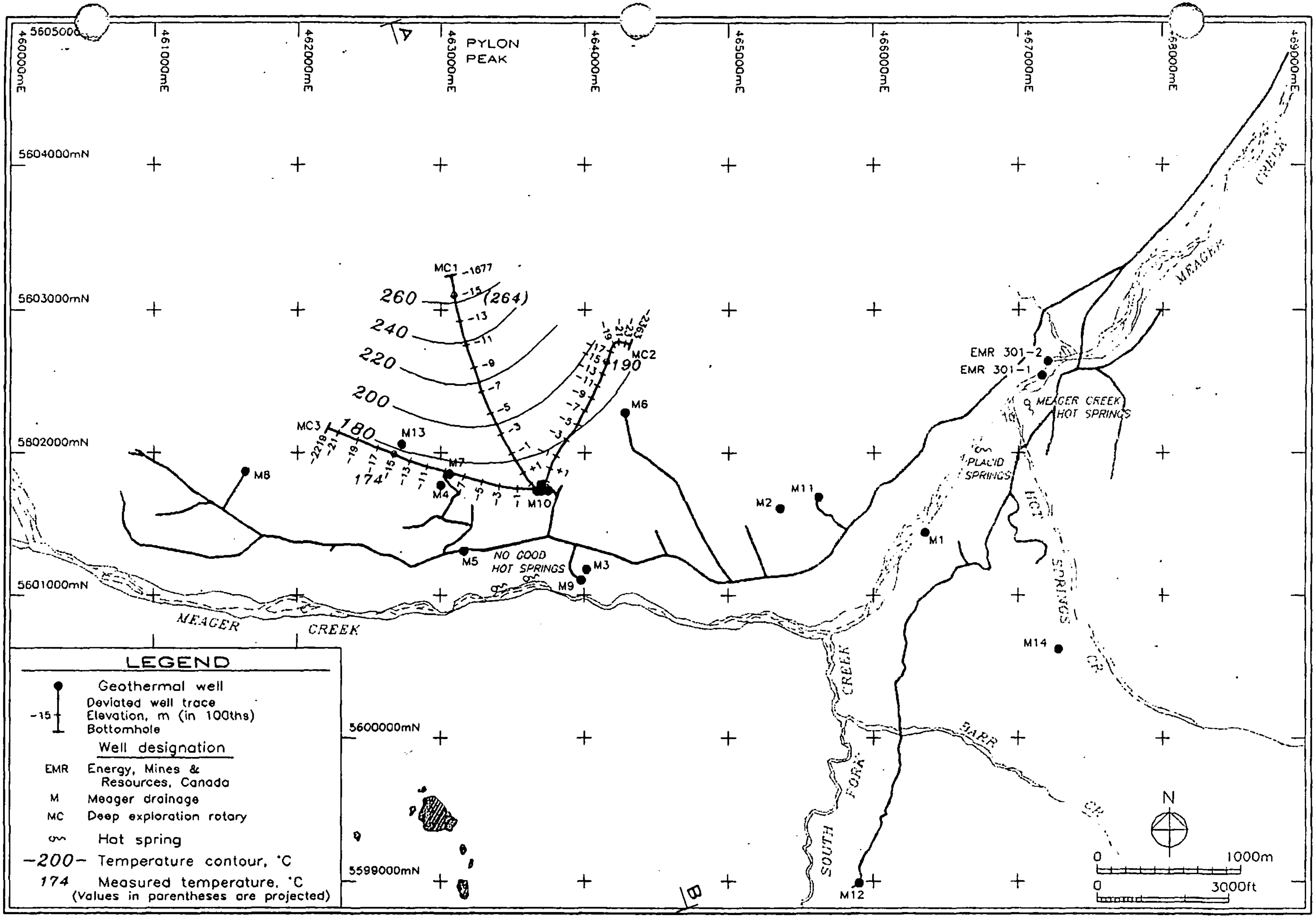


Figure 2.8: Temperature distribution at −1,500 m msl, South Meager Prospect

1992, GeothermEx, Inc. CCMTM15/012392/H3891/EMMN1=35.1/MEAGER.JP

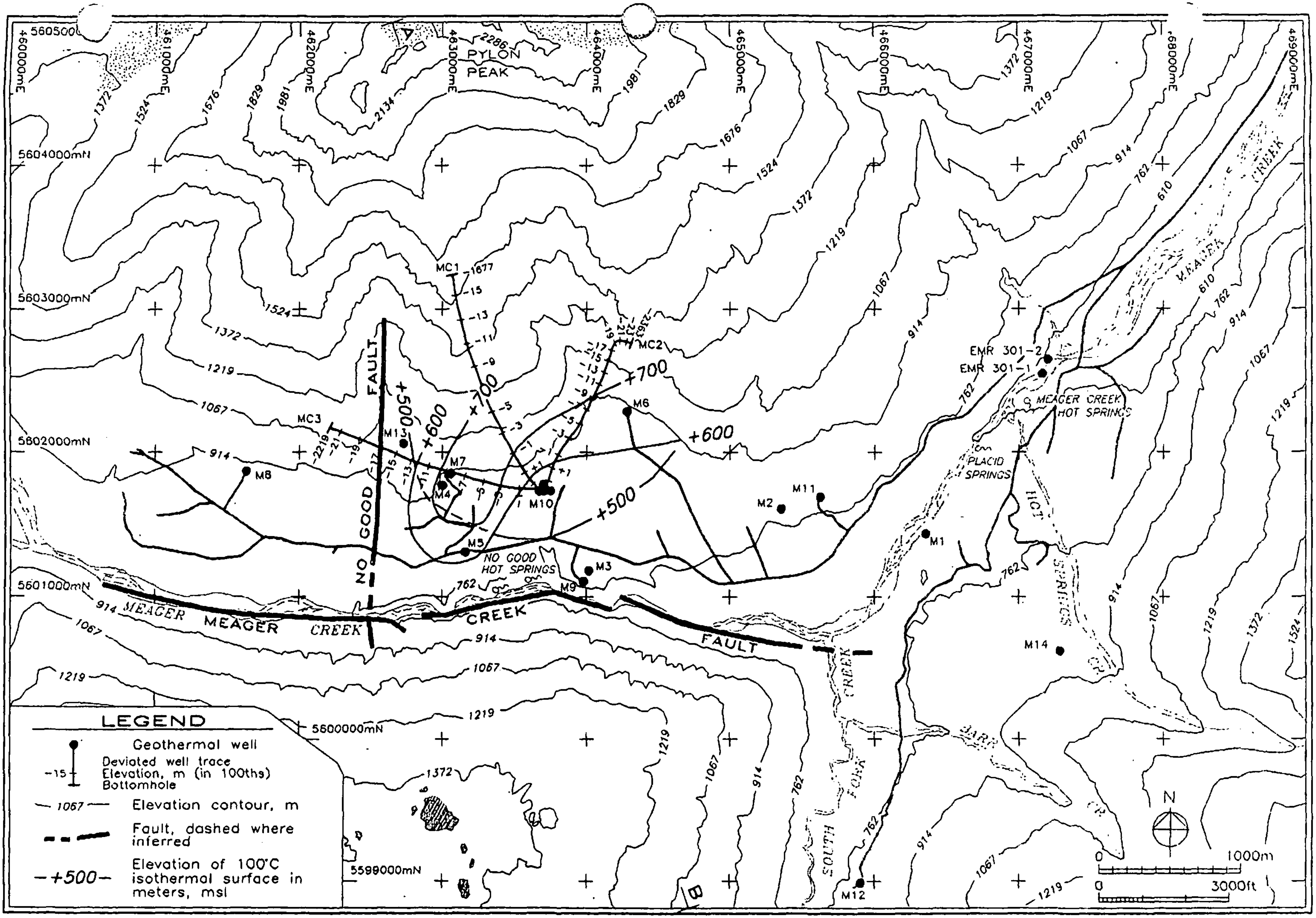


Figure 2.9: 100°C isothermal surface, South Meager Prospect

1992, GeothermEx, Inc. CCMIS010/012392/H3896/EMMN1=35.1/MEAGER.JP

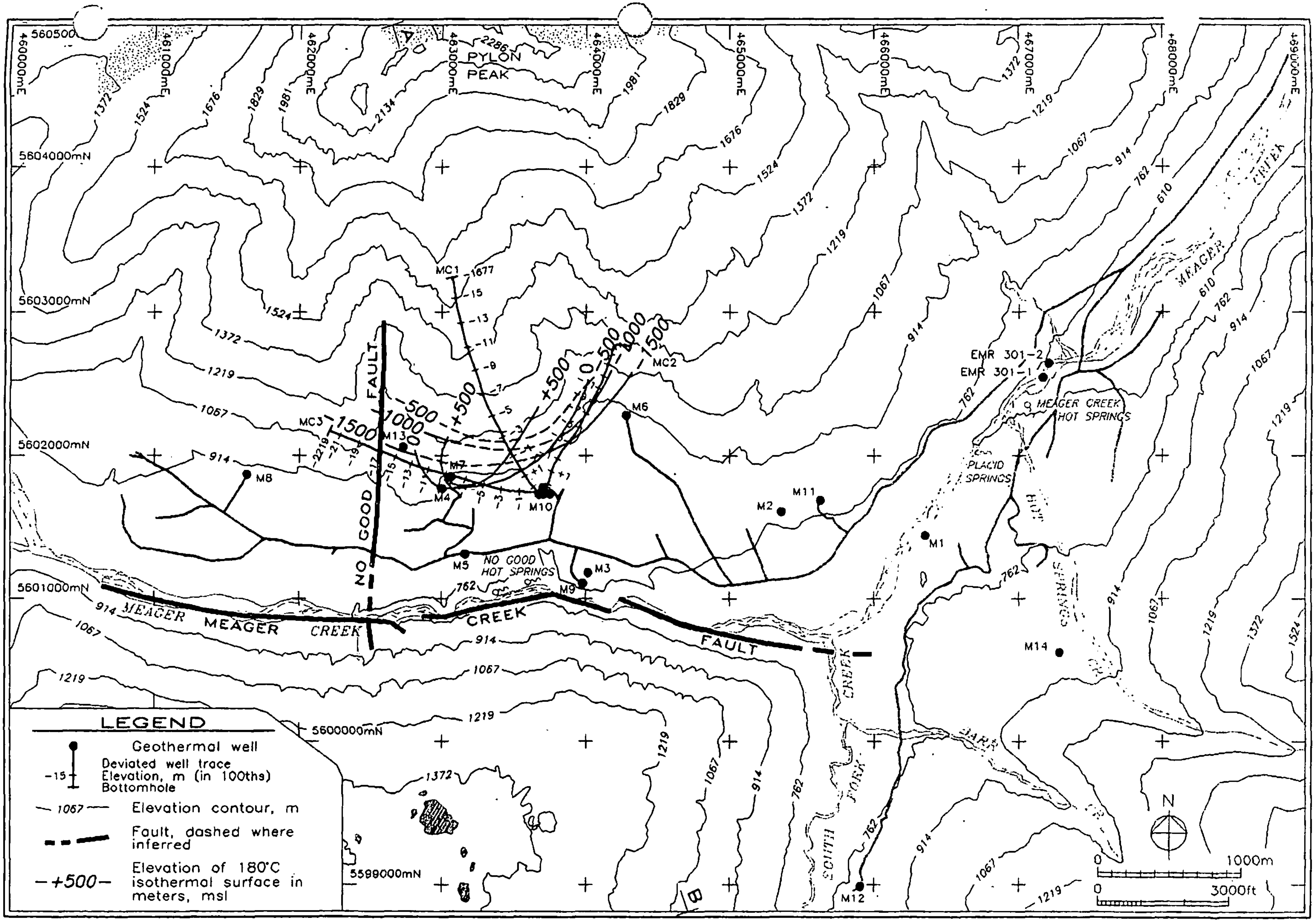


Figure 2.10: 180°C isothermal surface, South Meager Prospect

1992, GeothermEx, Inc. CCMIS018/012392/H3896/EMMN1=35.1/MEAGER.JP

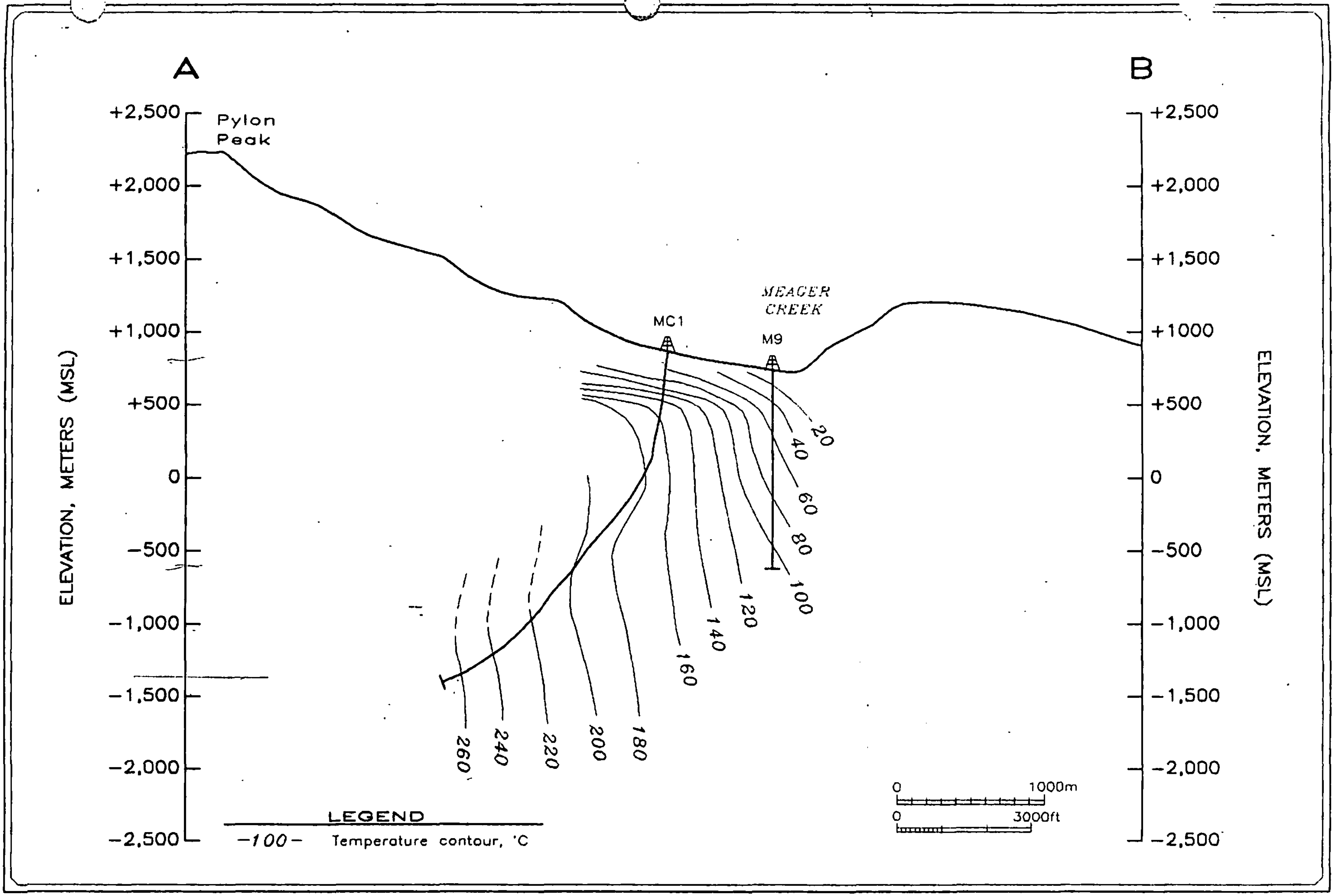


Figure 2.11: Temperature cross section A–B, South Meager Prospect

1992, GeothermEx, Inc. CCMXTAB/012392/H3891/EMMN1=35.1/MEAGER.JF

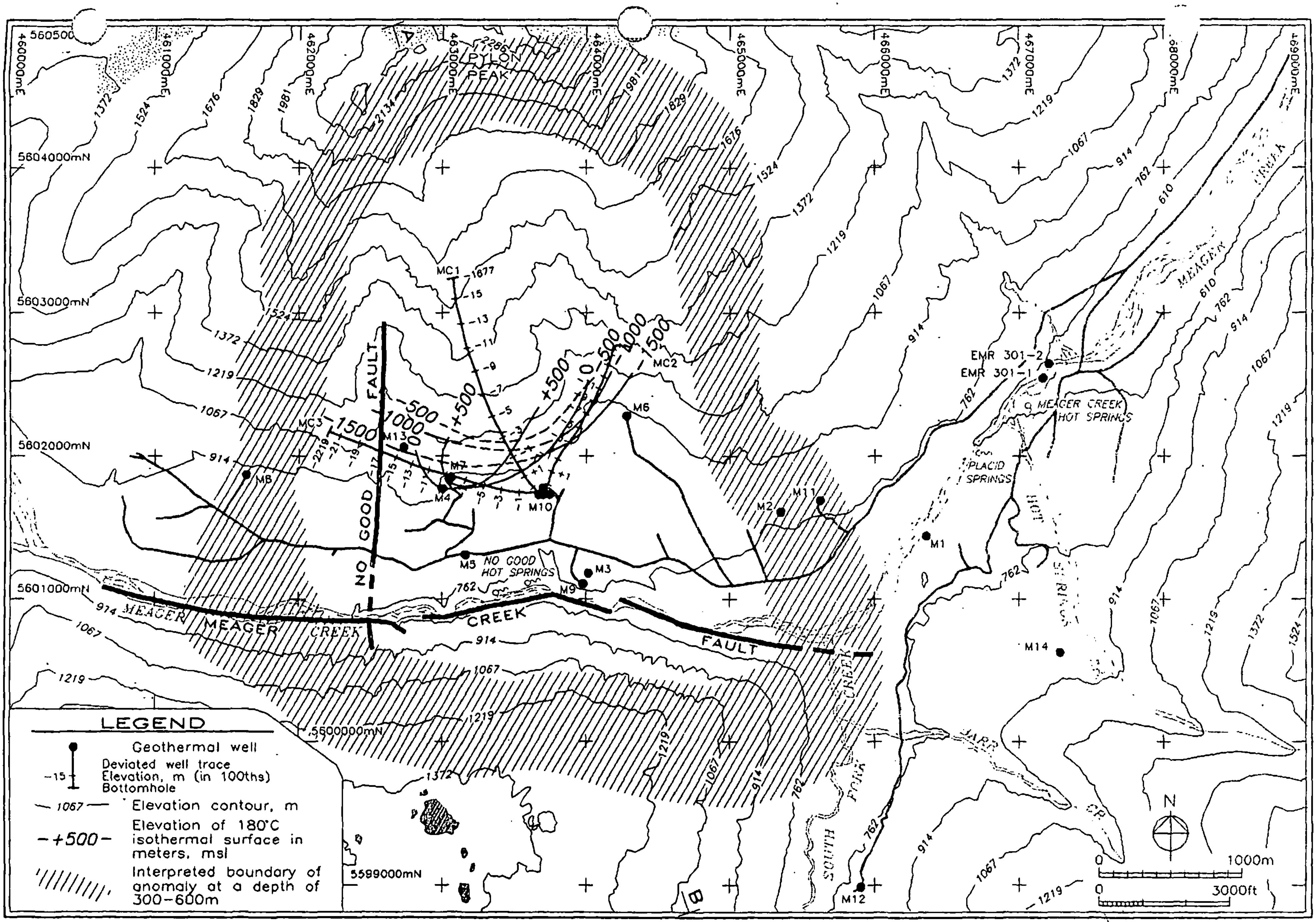
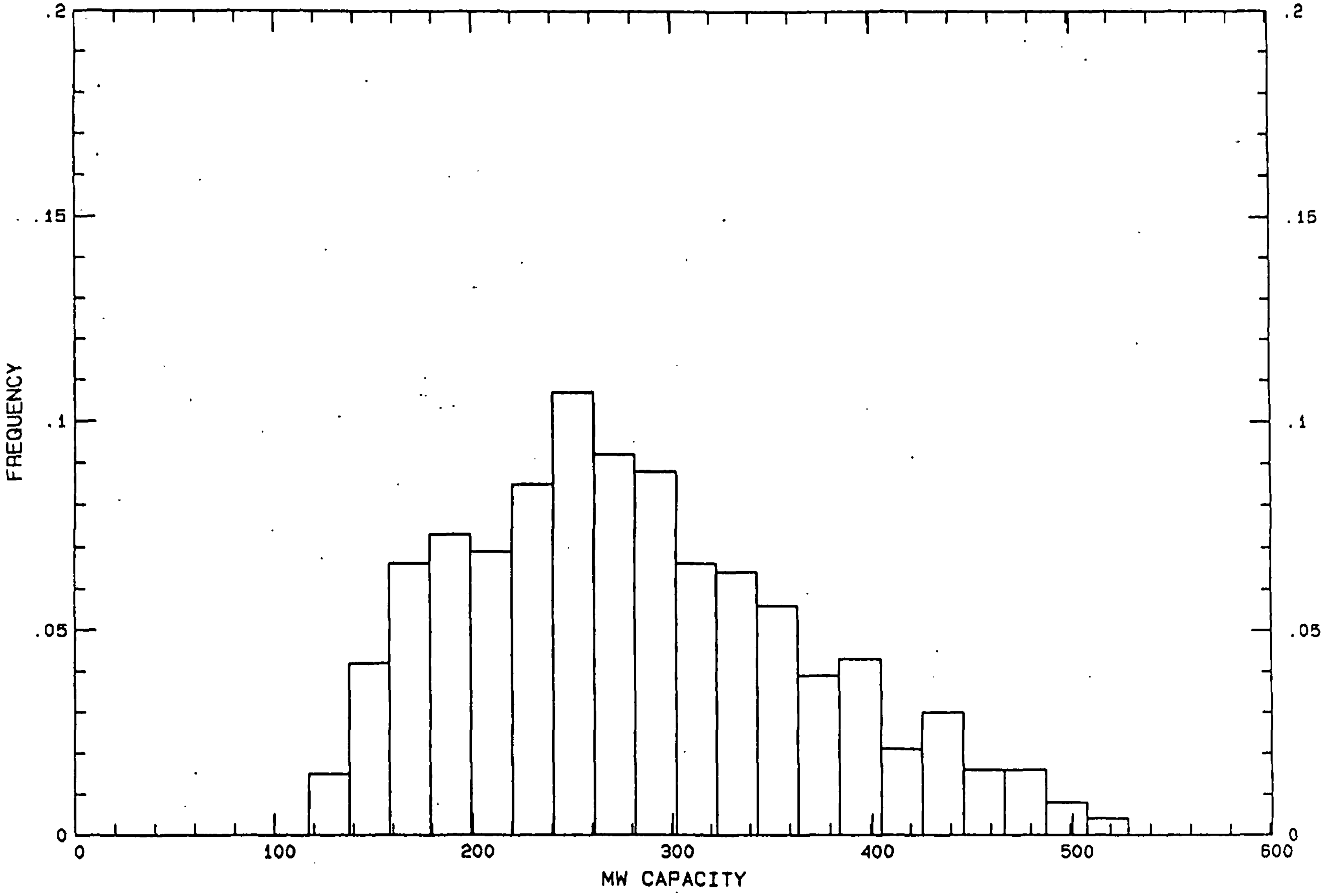


Figure 2.12: Resistivity boundary and 180°C isothermal surface, South Meager Prospect

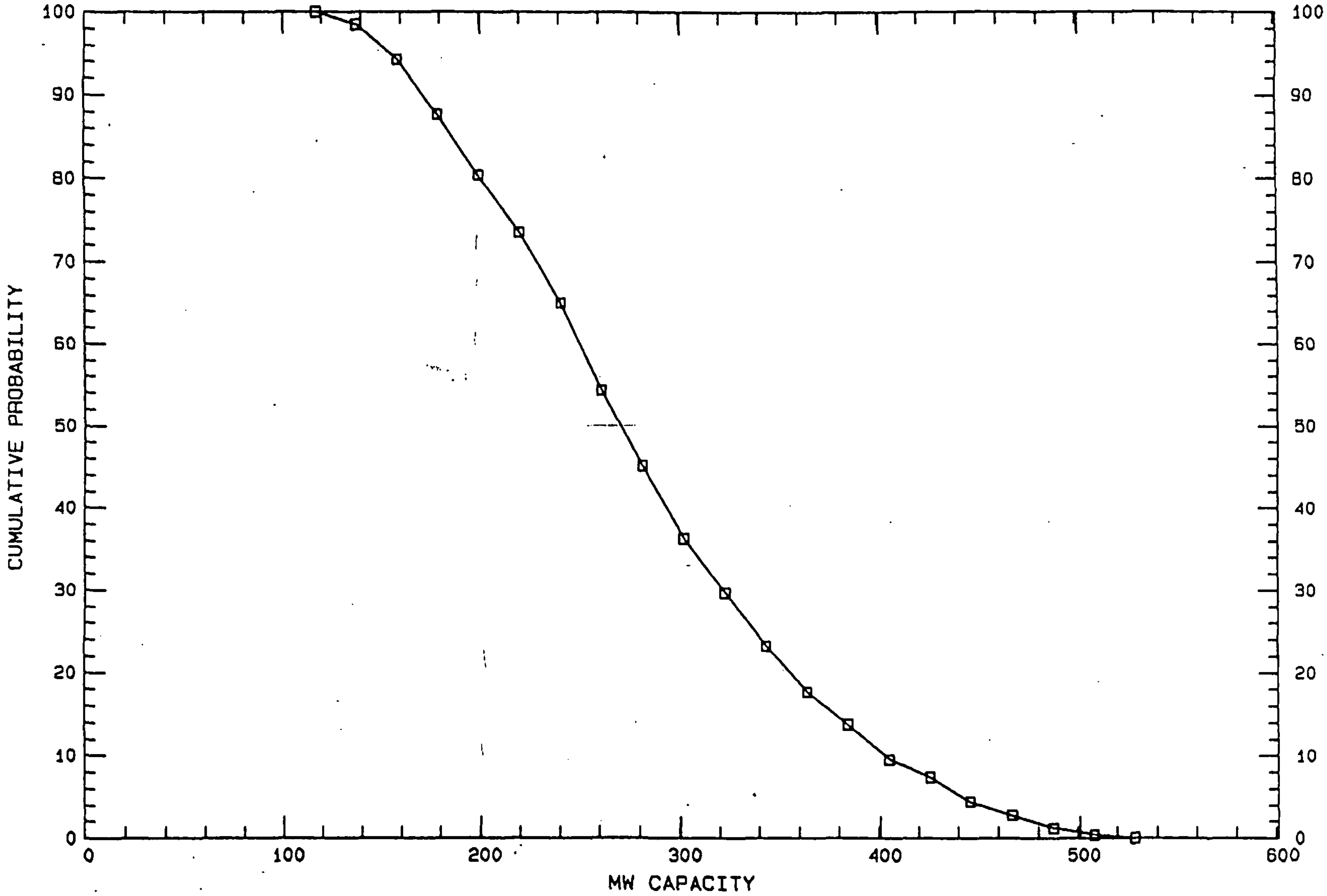
1992, GeothermEx, Inc. CCMRESIS/012492/H583/EMMN1=35.1/MEAGER.JP

FIGURE 3.1: HISTOGRAM OF MW CAPACITY, SOUTH MEAGER PROSPECT



GeothermEx, Inc.
01-22-1992 MEGR5HIS.PLT

FIGURE 3.2: CUMULATIVE PROBABILITY OF MW CAPACITY, SOUTH MEAGER PROSPECT



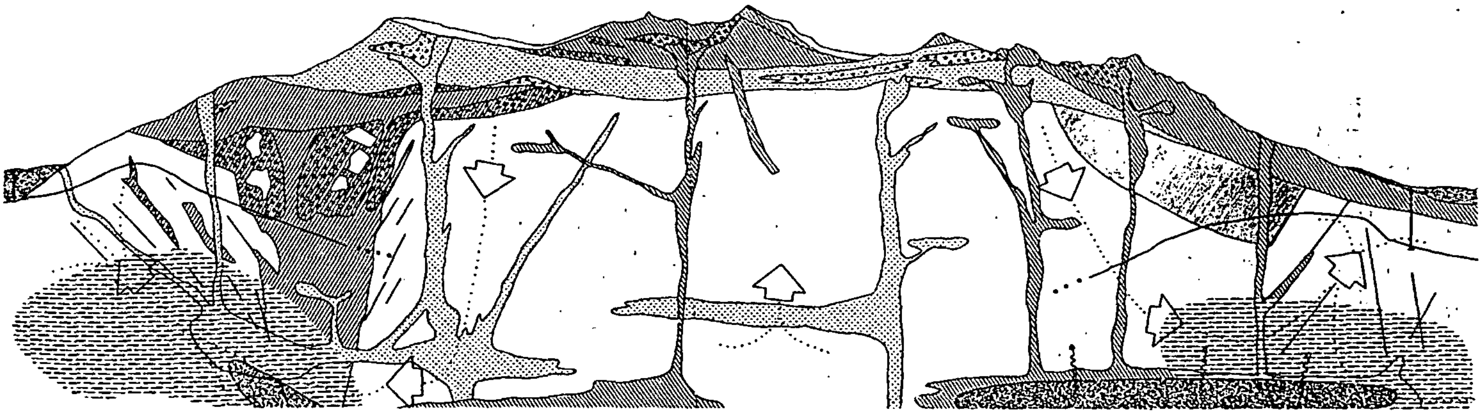
GeothermEx, Inc.
01-22-1992 MEGA6CMP.PLT

HPR

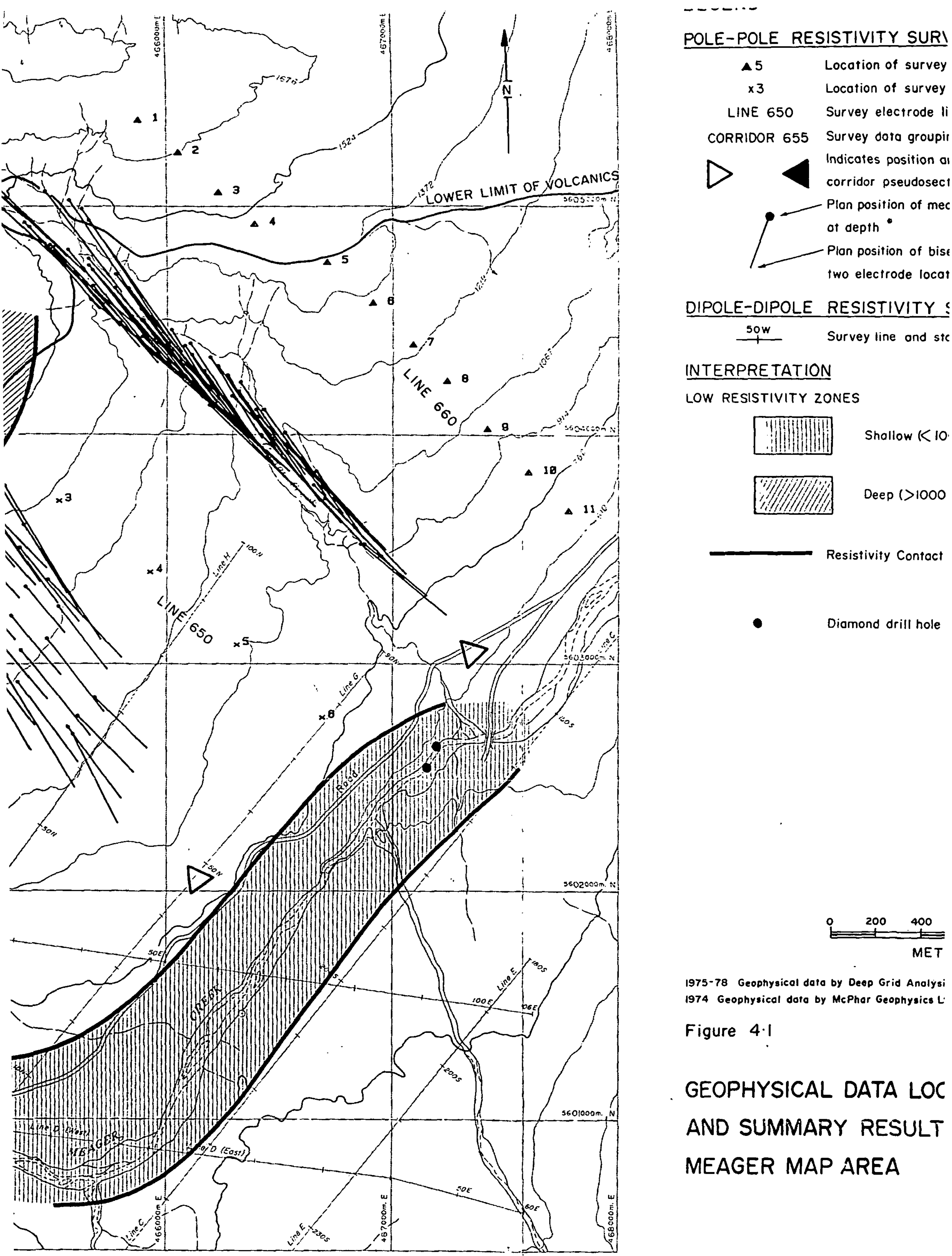
B.C. Hydro and Power Authority
and **Energy, Mines and Resources Canada**
1978 Joint Venture

Report on **1978 Field Work**
Meager Creek Geothermal Area
Upper Lillooet River, British Columbia

MARCH 15, 1979



NEVIN | SADLIER-BROWN | GOODBRAND | LTD



1975-78 Geophysical data by Deep Grid Analysi
1974 Geophysical data by McPhar Geophysics L

Figure 4·1

GEOPHYSICAL DATA LOC
AND SUMMARY RESULT
MEAGER MAP AREA

4.0 RESISTIVITY

4.1 Introduction

4.1.1 Objectives

The 1978 resistivity program was designed to initiate or complete investigations in the South Reservoir area, in the Lower Lillooet River valley (Lillooet Valley resistivity anomaly); and on the north flank of Meager Mountain (Possible North Reservoir). These areas are shown on Figure 1.1 and the surveys are detailed in the following paragraphs.

Dipole-dipole array surveys undertaken in 1974 and 1975 defined a large resistivity anomaly in the Meager Creek valley on the south flank of the complex. The 1978 pole-pole survey work was designed to explore the higher elevations beyond the reach of dipole-dipole survey and to trace any extensions of the valley resistivity anomaly northward within the basement rocks and possibly continuing beneath the cap of volcanic rocks. The possibility of eastward or westward extensions of the resistivity anomaly on the slope was also investigated.

A dipole-dipole resistivity survey along the south-west side of the Lillooet Valley in 1974, and self-potential (SP) and resistivity sounding in 1976, led to the application of pole-pole array survey in 1977. The 1977 survey located anomalous low resistivities in the lower valley, downstream from Pebble Creek. The 1978 survey was designed to

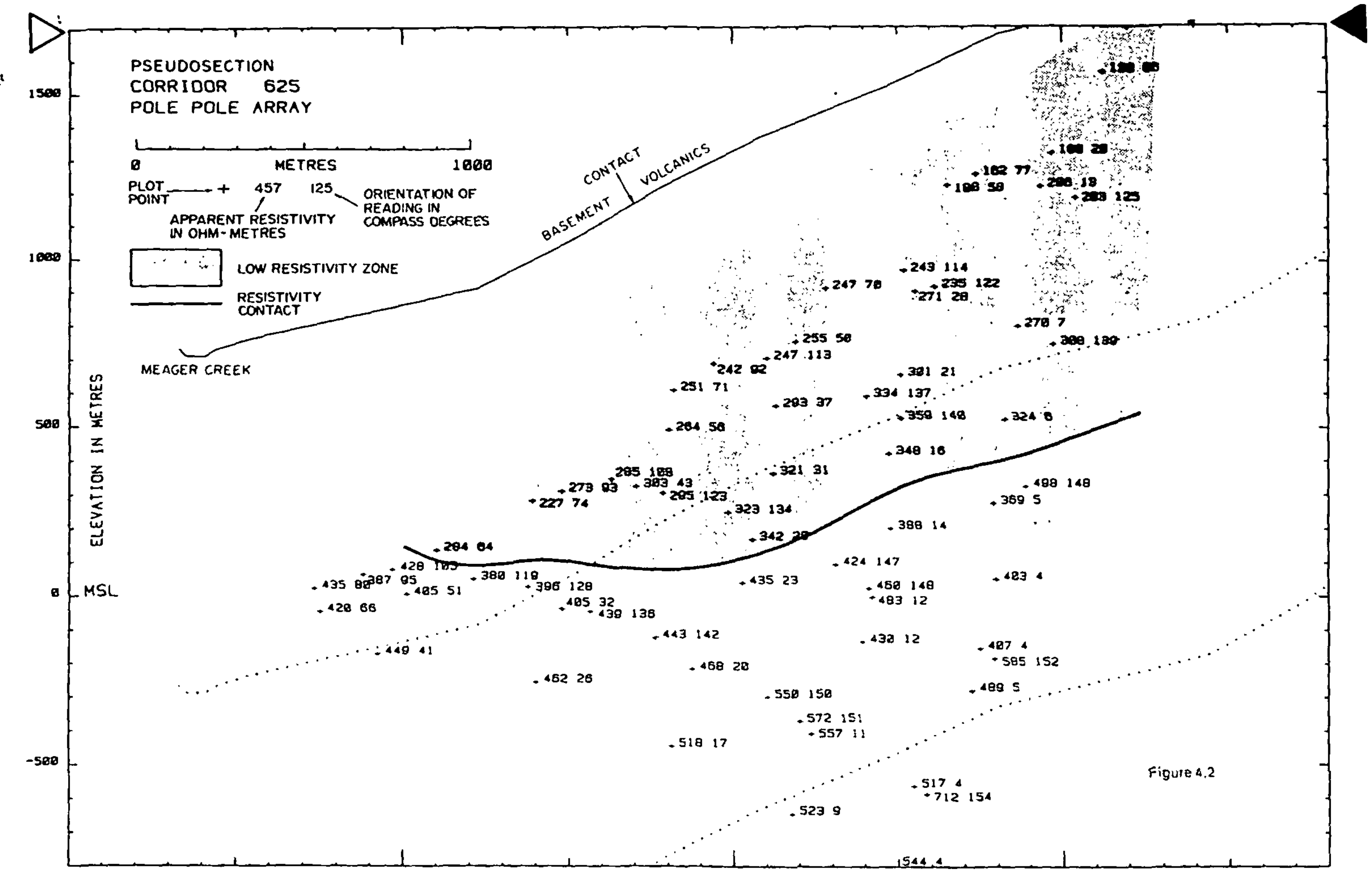


Figure 4.2

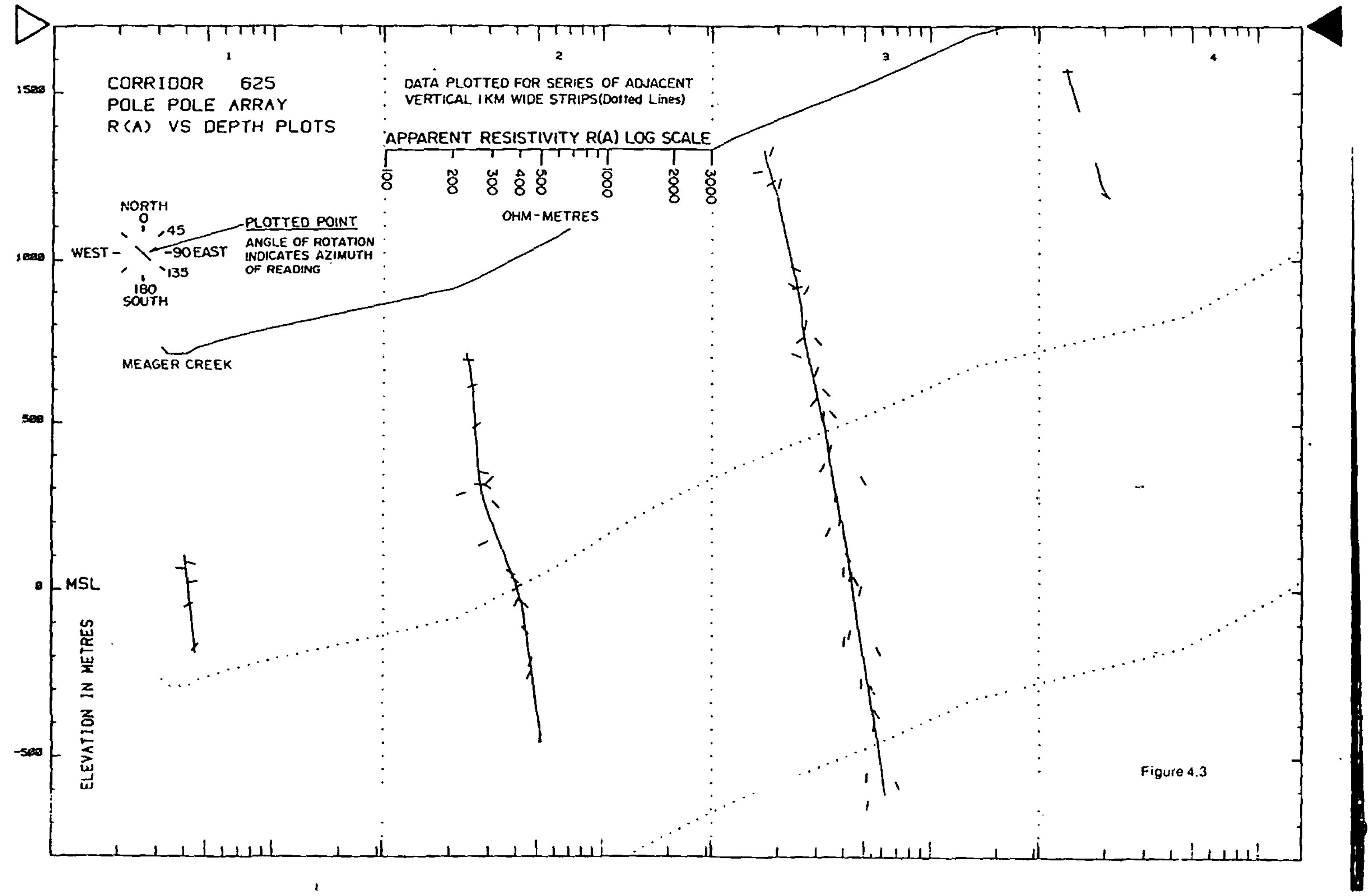


Figure 4.3

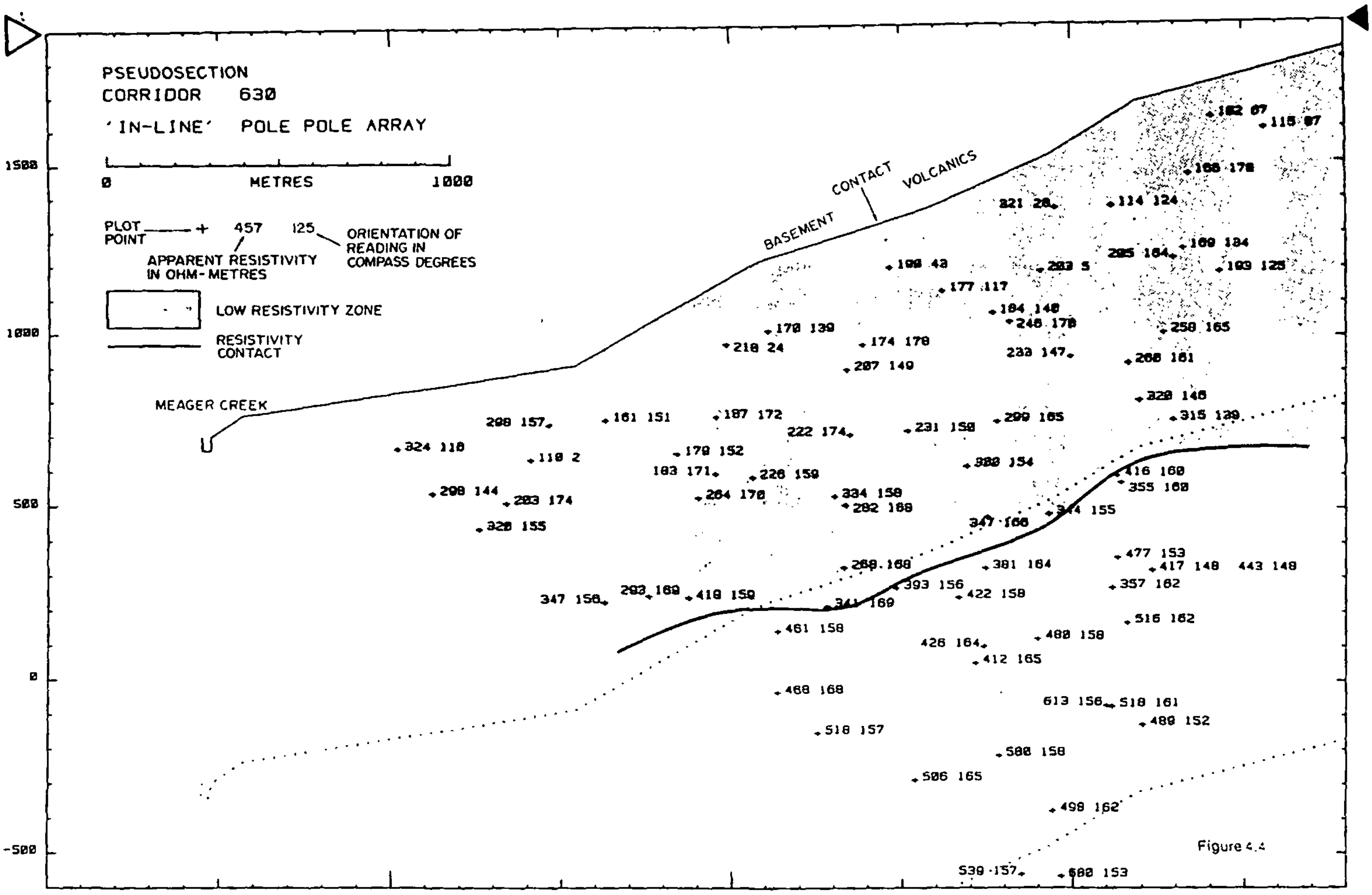


Figure 4.4

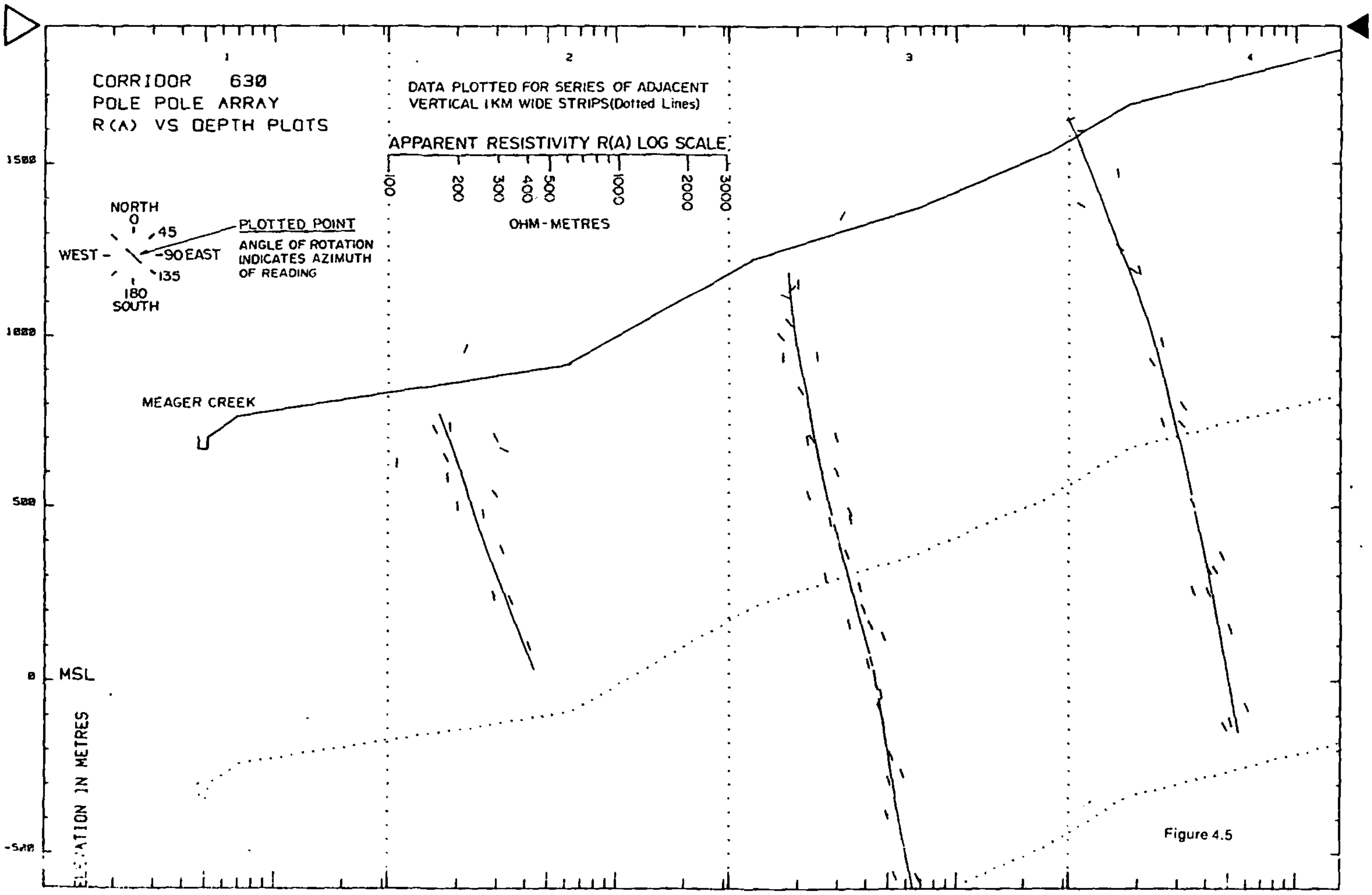


Figure 4.5

APPENDIX B-1

DATA PRINT OUTS

The print outs contain apparent resistivity (R(A)) data for each corridor, listed in ascending order of magnitude to facilitate cross-reference from the pseudosection plots. Each R(A) value is listed with the plot location co-ordinates, measurement direction, and electrode numbers, providing all of the information used for the construction of the pseudosections and R(A) vs. depth plots.

The corridor number is the principal identification for the body of data. The P Line number and C Line number are numbers assigned to the potential electrode line and the current electrode line, respectively. These lines are plotted in Figure 4.1 (Meager Map Area) and Figure 4.6 (Lillooet Map Area).

The columns of data provided are:

R(A): Apparent resistivity in ohm-metres.

Dir: Direction of reading; compass orientation of a line between the potential and current electrodes. North = 0.

C#: Number assigned to the current electrode responsible for the reading.

P#: Number assigned to the potential electrode responsible for the reading.

Ze: Effective depth of penetration or search, after Edwards (1977), in metres.

Xd: X coordinate (northing) of plot point at depth Ze below the estimated surface plane (Universal Transverse Mercator Grid)

Yd: Y coordinate (easting) of plot point; as above.

Zd: Z coordinate of the plot point; metres of elevation above (below) mean sea level.

Vhor: Relative horizontal distance in metres of the plot point Xd, Yd, Zd along the data corridor (This value is used with Zd to plot pseudo - sections).

POLE-POLE RESISTIVITY DATA: 1978
CORRIDOR 605 P LINE 600 C LINE 610
MEAGER CREEK MAP AREA

✓

R(a)	Dir	C#	P#	Ze	Xd	Yd	Zd	Vhor
220	59	2	1	202	462038	5603400	1500	2512
✓232	37	8	1	1384	461689	5603380	120	2458
262	49	4	1	595.	461936	5603340	1040	2442
270	52	3	1	404	462001	5603370	1262	2478
272	48	5	1	813	461817	5603440	797	2526
✓285	53	9	3	908	461587	5602520	236	1589
✓288	32	9	1	1527	461728	5603250	-57	2326
✓288	37	9	2	1252	461696	5602950	114	2023
289	58	6	2	786	461715	5603170	693	2242
✓295	27	24	1	1762	461767	5603070	-329	2150
295	101	3	2	252	461907	5603140	1316	2238
✓299	52	7	2	974	461684	5603150	464	2227
✓306	43	7	1	1220	461726	5603430	314	2510
✓308	45	6	1	1022	461753	5603440	554	2522
309	103	5	3	525	461727	5602910	320	1988
✓309	30	24	2	1478	461727	5602770	-148	1845
→ 313	32	25	2	1402	461632	5602870	-51	1945
314	3	1	2	321	462092	5603340	1361	2466
✓317	44	25	3	1033	461549	5602420	94	1489
323	63	8	3	811	461590	5602670	372	1742
328	44	8	2	1120	461666	5603090	232	2159
✓329	28	25	1	1684	461614	5603200	-222	2266
331	66	5	2	593	461768	5603180	926	2262
331	169	2	3	633	462015	5603190	874	2306
345	1	1	3	773	462116	5603340	807	2471
✓345	41	24	3	1100	461589	5602330	7	1396
347	78	7	3	732	461607	5602780	499	1854
348	90	6	3	611	461651	5602920	669	1897
383	77	4	2	397	461814	5603180	1166	2259

R(a)	Dir	W C#	E P#	Ze	Xd	Yd	Zd	Vhor
391	149	2	2	209	461986	5603220	1408	2325
398	151	3	3	528	461919	5603070	923	2169
⊙398	173	2	4	1050	462028	5603150	370	2264
✓401	131	7	5	959	461528	5602130	-9	1198
410	110	9	5	753	461531	5601830	131	898
✓410	168	3	5	1336	461937	5602830	-53	1938
413	129	4	3	493	461805	5602990	926	2075
⊙419	121	8	5	834	461540	5601950	63	1017
⊙435	95	25	5	709	461503	5601610	146	684
⊙438	141	7	6	1309	461606	5601900	-387	973
⊙443	88	24	5	705	461505	5601550	143	626
⊙450	1	1	4	1194	462117	5603300	301	2434
⊙464	163	3	4	923	461947	5603010	436	2113
⊙470	151	5	5	1124	461689	5602510	1	1588
⊙473	162	4	6	1616	462142	5602550	-363	1720
⊙481	168	3	6	1722	462405	5602670	-381	1933
⊙482	142	6	5	1029	461637	5602350	22	1427
⊙489	160	4	5	1229	461831	5602710	8	1798
⊙496	128	9	6	1031	461544	5601500	-136	572
⊙500	175	2	5	1469	462012	5602980	-121	2099
⊙505	155	5	6	1508	461807	5602310	-411	1401
⊙507	135	8	6	1154	461654	5601750	-277	824
⊙516	148	6	6	1400	461811	5602180	-362	1272
⊙518	130	1	5	1613	462062	5603140	-189	2266
⊙541	119	25	6	923	461556	5601370	-94	438
⊙542	173	2	6	1850	462625	5602790	-415	2139
⊙553	114	24	6	881	461561	5601300	-60	375
⊙582	177	1	6	1936	463342	5602810	-158	2584

Cond 16
res 1
not 22
plotted
ttl. 59 59

POLE-POLE RESISTIVITY DATA: 1978
CORRIDOR 615 P LINE 620 C LINE 610
MEAGER CREEK MAP AREA

✓

R(a)	Dir	E C#	W P#	Ze	Xd	Yd	Zd	Vhor
245	75	1	1	676	462457	5603310	1163	2854
263	81	2	2	785	462465	5603430	965	2474
270	88	3	2	806	462486	5603470	873	2520
281	156	10	1	1917	462415	5603010	-501	2063
282	57	1	2	344	462418	5603680	925	2731
283	101	2	1	752	462499	5503610	979	2651
288	97	5	3	810	462543	5602830	507	1877
304	67	7	5	855	462544	5601890	54	939
311	92	11	6	656	462540	5601140	123	184
318	96	7	4	800	462534	5602270	218	1320
338	107	3	1	809	462520	5603570	902	2611
339	58	6	5	952	462536	5602030	45	1130
340	74	10	6	676	462559	5501210	126	250
342	71	5	4	861	462549	5602630	336	1675
345	91	9	5	750	462534	5601570	104	612
350	129	10	4	985	462546	5601880	-56	923
352	110	8	4	842	462557	5602130	142	1172
355	129	8	3	1061	462537	5602510	97	1556
356	40	1	3	1160	462441	5603610	493	2660
356	84	4	3	809	462542	5603020	612	2062
362	60	4	4	960	462554	5602800	321	1850
365	110	4	2	872	462509	5603250	698	2300
365	119	9	4	973	462560	5602020	95	1069
373	105	10	5	775	462517	5601460	53	507
382	57	2	3	961	462487	5603320	574	2371
384	119	11	5	859	462501	5601360	-67	410
388	42	4	5	1235	462586	5602530	-58	1573
390	63	3	3	931	462515	5603260	592	2304
396	137	11	4	1136	462551	5601780	-242	827
403	136	9	3	1134	462553	5602430	12	1475
404	142	10	3	1286	462525	5602300	-183	1342
409	141	6	1	1303	462616	5503410	278	2453
410	121	5	2	979	462506	5603190	537	2231

R(a)	Dir	E C#	W P#	Ze	Xd	Yd	Zd	Vhor
⊙415	110	6	3	863	462550	5602730	399	1771
423	30	1	4	1516	462439	5603540	46	2589
⊙424	84	6	4	810	462559	5602490	330	1539
428	146	7	1	1462	462602	5603380	71	2421
⊙430	53	8	6	957	462584	5601460	-11	506
430	147	11	3	1467	462544	5602210	-394	1259
442	130	6	2	1111	462513	5603120	358	2163
⊙455	119	7	3	944	462534	5602660	262	1709
469	31	2	5	1501	462500	5603009	-253	2048
472	41	2	4	1254	462483	5603220	181	2268
⊙475	60	9	6	757	462568	5601360	77	404
476	46	3	4	1196	462514	5603140	211	2135
⊙479	38	6	6	1144	462622	5601830	-181	878
⊙496	81	8	5	790	462541	5601750	91	796
⊙502	44	7	6	1000	462569	5601650	-119	692
⊙517	22	2	6	1901	462495	5602770	-594	1815
⊙522	33	5	6	1311	462572	5602080	-263	1121
⊙523	136	7	2	1249	462496	5603090	172	2125
⊙525	135	5	1	1140	462583	5603450	479	2499
⊙529	23	1	5	1895	462468	5603340	-413	2399
⊙546	154	11	2	1862	462416	5602650	-578	1706
⊙557	16	1	6	2218	462456	5603120	-774	2168
⊙562	159	11	1	2118	462471	5602950	-729	1999
⊙563	29	4	6	1494	462615	5602280	-358	1328
⊙581	150	8	1	1633	462534	5603230	-155	2276
⊙582	154	9	1	1737	462611	5603180	-260	2229
⊙588	49	5	5	1080	462558	5602330	8	1373
⊙588	143	8	2	1404	462466	5602940	-31	1937
⊙596	147	9	2	1497	462483	5602870	-138	1916
⊙608	33	3	5	1528	462525	5602910	-211	1958
⊙629	151	10	2	1668	462400	5602730	-353	1782
⊙695	24	3	6	1818	462519	5602680	-541	1722

POLE-POLE RESISTIVITY DATA: 1978

CORRIDOR 625 P LINE 620 C LINE 630
MEAGER CREEK MAP AREA

R(a)	Dir	W C#	E P#	Ze	Xd	Yd	Zd	Vhor
136	86	1	1	214	462998	5603720	1567	2924
162	77	2	2	303	463119	5603350	1263	2535
188	20	2	1	368	462991	5603560	1327	2767
188	58	3	2	304	463137	5603260	1231	2451
203	125	1	2	505	462996	5603630	1194	2837
206	13	3	1	457	462965	5603520	1228	2733
227	74	8	5	627	463301	5602010	284	1190
235	122	2	3	563	463165	5603230	923	2410
242	92	5	4	499	463318	5602570	692	1740
243	114	3	3	484	463196	5603140	973	2317
247	70	4	3	435	463212	5602900	919	2080
247	113	4	4	567	463289	5602730	708	1903
251	71	6	4	518	463323	5602450	613	1619
255	50	5	3	526	463219	5602310	757	1989
264	56	7	4	607	463300	5602430	493	1604
270	7	4	1	808	462913	5603430	804	2663
271	28	4	2	559	463072	5603150	910	2352
273	93	7	5	604	463349	5602110	313	1280
284	64	9	5	701	463331	5601730	137	904
285	109	6	5	655	463316	5602260	349	1431
293	37	6	3	673	463195	5602750	566	1931
295	123	5	5	765	463271	5602410	307	1586
301	21	5	2	748	463072	5603110	659	2309
303	43	8	4	749	463238	5602320	326	1506
308	139	1	3	878	463042	5603570	751	2770
321	31	7	3	834	463161	5602730	366	1921
323	134	4	5	919	463207	5602600	252	1784
324	6	5	1	1019	462995	5603410	525	2622
334	137	3	4	797	463243	5603030	595	2206
342	25	8	3	1020	463070	5602640	172	1359
348	16	6	2	944	463042	5603060	424	2272
359	140	2	4	894	463218	5603130	529	2309
359	5	6	1	1225	462975	5603370	278	2587
380	119	7	6	941	463515	5601860	51	1015
387	95	9	6	770	463454	5601530	64	684
388	14	7	2	1129	462986	5603050	205	2278
396	128	6	6	946	463464	5602020	28	1179
403	4	7	1	1418	462908	5603360	53	2596
405	32	10	4	1038	463245	5602090	-36	1280
405	51	10	5	806	463331	5601630	6	813
407	4	8	1	1620	462764	5603270	-153	2547
420	66	11	6	836	463448	5601390	-45	551
424	147	3	5	1206	463101	5602910	96	2111
428	105	8	6	766	463473	5601620	79	771
430	12	9	2	1467	462791	5602910	-133	2193
435	23	9	3	1155	462985	5602580	41	1827
435	80	10	6	779	463472	5601380	23	535
439	136	5	6	1091	463427	5602210	-44	1366
443	142	4	6	1260	463356	5602400	-122	1562
449	41	11	5	947	463335	5601540	-171	726
460	148	2	5	1307	463066	5603010	26	2213
462	26	11	4	1225	463223	5602010	-255	1203
468	20	10	3	1343	463071	5602450	-216	1675
483	12	9	2	1330	462882	5602970	-1	2222
489	5	9	1	1754	462646	5603200	-278	2523
498	148	1	4	1240	463134	5603500	328	2687
517	4	10	1	1951	462931	5603110	-561	2347
518	17	11	3	1545	463026	5602370	-445	1613
523	9	11	2	1974	462899	5602720	-644	1978
544	4	11	1	2165	462874	5603030	-801	2289
550	150	3	6	1564	463288	5602730	-298	1903
557	11	10	2	1662	462947	5602790	-407	2037
572	151	2	6	1566	463253	5602830	-370	2002
585	152	1	5	1663	462930	5603360	-183	2591
712	154	1	6	2024	463168	5603200	-584	2386

POLE-POLE RESISTIVITY DATA: 1978

CORRIDOR 630 P LINE 630 C LINE 630
MEAGER CREEK MAP AREA

R(a)	Dir	C#	P#	Ze	Xd	Yd	Zd	Vhor
102	67	2	1	89	463130	5603660	1630	2706
110	2	11	5	168	463770	5601770	635	707
114	124	3	2	175	463264	5603400	1377	2414
115	87	1	1	221	463004	5603780	1596	2863
161	151	9	5	154	463689	5601970	751	927
166	170	3	1	207	463155	5603600	1467	2639
169	134	2	2	378	463141	5603580	1254	2622
170	139	7	4	135	463607	5602460	1014	1408
174	178	7	3	273	463497	5602710	973	1687
177	117	5	3	204	463416	5602930	1130	1918
179	152	8	5	357	463523	5602130	655	1138
183	171	10	4	416	463642	5602300	596	1253
184	140	4	3	344	463302	5603050	1066	2066
187	172	9	4	288	463618	5602300	762	1253
190	43	6	3	119	463480	5602790	1198	1764
193	125	1	2	513	462992	5603630	1186	2729
203	5	5	2	263	463308	5603200	1198	2206
203	174	12	5	320	463699	5601650	511	639
205	164	4	1	423	463087	5603530	1226	2593
207	149	6	4	367	463422	5502630	903	1640
218	24	8	4	111	463548	5602340	975	1285
222	174	8	3	482	463505	5602680	712	1649
226	159	7	5	563	463339	5602280	588	1362
231	150	5	4	551	463407	5602820	723	1817
233	147	3	3	558	463170	5603240	939	2293
246	170	6	2	435	463218	5603060	1040	2115
258	165	5	1	594	463136	5603510	1009	2564
260	161	6	1	776	462860	5603270	922	2461
264	170	11	4	584	463372	5602110	528	1203
268	168	10	3	802	463463	5602640	326	1632
282	168	9	3	674	463395	5602620	507	1636
293	169	12	4	730	463721	5602120	242	1057
298	144	11	6	247	463923	5601520	539	420
298	157	9	6	527	463405	5501530	737	761
299	165	7	2	661	463212	5603020	751	2077
300	154	4	4	716	463334	5502980	621	1990
315	139	1	3	884	462879	5603430	756	2591
320	146	2	3	765	463016	5603390	813	2493
320	155	10	6	413	463718	5601570	436	559
321	28	4	2	111	463334	5603250	1371	2248
324	116	12	6	117	463952	5601420	665	315
334	158	6	5	798	463080	5602400	532	1605
341	169	11	3	971	463229	5602470	215	1581
344	155	3	4	935	463391	5603250	482	2230
347	156	8	6	722	463820	5602020	225	925
347	166	8	2	872	463263	5603010	473	2050
355	160	7	1	1009	462947	5603300	574	2441
357	162	8	1	1218	463183	5603380	268	2417
381	164	9	2	1070	463004	5602880	325	2044
393	156	5	5	978	463121	5602640	267	1784
412	165	11	2	1366	462821	5602710	51	2013
416	160	9	1	1419	462257	5602760	595	2430
417	148	1	4	1246	462973	5603410	319	2531
419	159	7	6	928	463259	5601990	239	1174
422	158	4	5	1146	462891	5602710	240	1966
426	164	10	2	1197	463149	5602950	99	2039
443	148	1	4	1246	462973	5603410	319	2531
461	158	6	6	1159	463050	5602150	143	1435
468	168	12	3	1118	463587	5602480	-35	1434
477	153	2	4	1139	463213	5603400	356	2432
480	158	3	5	1365	462724	5602870	121	2197
489	152	1	5	1669	462617	5603170	-129	2502
498	162	12	1	1858	463946	5603360	-378	2241
506	165	12	2	1512	463418	5602840	-289	1837
516	162	11	1	1713	462138	5602730	168	2459
518	157	5	6	1346	463219	5602430	-152	1552
518	161	10	1	1545	462874	5603230	-75	2415
539	157	2	6	1933	463321	5603140	-561	2151
580	158	3	6	1732	464259	5603190	-218	2082
613	156	2	5	1568	462704	5603110	-71	2399
680	153	1	6	2030	462848	5603040	-567	2267
680	153	1	6	2030	462848	5603040	-567	2267

POLE-POLE RESISTIVITY DATA: 1978
CORRIDOR 635 P LINE 640 C LINE 630
MEAGER CREEK MAP AREA

E N E W

R(a)	Dir	C#	P#	Ze	Xd	Yd	Zd	Vhor	R(a)	Dir	C#	P#	Ze	Xd	Yd	Zd	Vhor
287	67	1	1	857	463631	5604300	1035	3103	472	107	6	1	1505	464015	5603960	124	2690
306	50	3	3	975	464031	5603640	526	2370	474	127	11	3	1259	464168	5602760	-141	1486
313	82	4	2	997	464028	5603770	569	2500	484	42	4	4	1156	464167	5603350	220	2057
342	46	1	2	907	463750	5604120	962	2904	484	70	7	4	1157	464328	5603150	122	1843
343	80	2	1	936	463714	5604220	886	3006	495	64	8	5	1103	464488	5602650	-62	1337
345	60	2	2	891	463840	5603990	793	2755	487	114	8	2	1454	464247	5603490	-48	2189
345	73	3	2	915	463942	5603840	687	2586	487	121	9	2	1454	464230	5603380	-67	2076
368	114	11	4	977	464230	5602420	34	1133	489	103	7	2	1373	464215	5603610	69	2308
369	93	9	4	980	464363	5602700	165	1393	504	129	10	2	1504	464188	5603280	-159	1983
379	52	10	6	848	464588	5601780	35	470	506	45	8	6	1209	464794	5602040	-253	781
380	27	1	3	1136	463837	5603970	533	2731	512	61	4	3	979	464109	5603570	493	2285
389	104	10	4	929	464314	5602560	166	1258	513	111	7	1	1635	464059	5603920	-39	2642
390	90	3	1	1036	463797	5604170	746	2936	518	22	3	5	1546	464217	5603370	-240	2076
391	80	10	5	823	464496	5602070	69	753	519	47	9	6	1034	464711	5601930	-95	642
391	101	5	1	1336	463956	5604070	357	2809	529	37	5	5	1403	464390	5603110	-213	1798
394	70	5	3	1047	464207	5603460	354	2166	535	70	9	5	958	464612	5602150	-16	841
395	88	7	3	1178	464329	5603300	138	1990	543	134	11	2	1621	464031	5603130	-366	1871
398	61	11	6	732	464473	5601630	71	318	556	46	6	5	1329	464449	5602980	-190	1651
402	89	5	2	1130	464097	5603760	400	2473	562	53	7	5	1278	464499	5602850	-191	1537
403	97	4	1	1169	463883	5604080	560	2831	565	16	2	5	1688	464153	5603550	-309	2260
404	84	8	4	1073	464380	5602980	112	1569	573	37	7	6	1441	464549	5602540	-393	1222
412	38	2	3	1037	463955	5603780	527	2521	577	18	4	6	1724	464104	5602960	-501	1647
429	25	2	4	1322	464000	5603620	166	2360	578	13	3	6	1841	464245	5603120	-562	1824
441	91	11	5	780	464388	5602030	43	725	605	120	8	1	1753	464136	5603870	-168	2576
448	17	1	4	1460	463875	5603830	134	2585	608	29	4	5	1453	464309	5603240	-195	1928
443	102	8	3	1189	464351	5603160	87	1844	608	32	6	6	1529	464522	5602670	-430	1349
450	97	6	2	1265	464172	5603660	212	2365	615	132	10	1	1838	464165	5603720	-278	2430
450	110	9	3	1151	464329	5603020	99	1708	667	126	9	1	1771	464163	5603800	-185	2501
455	120	10	3	1165	464283	5602900	40	1599	688	25	5	6	1644	464435	5602840	-483	1524
456	33	3	4	1210	464076	5603460	209	2186	724	10	1	5	1853	464030	5603770	-364	2496
458	62	6	4	1151	464337	5603110	108	1803	733	3	2	6	2001	464216	5603300	-652	2004
461	52	5	4	1159	464260	5603240	152	1935	791	4	1	6	2178	464042	5603520	-721	2255
466	81	6	3	1114	464286	5603370	240	2062	1234	137	11	1	1964	463778	5603400	-568	2203

POLE-POLE RESISTIVITY DATA: 1978
CORRIDOR 645 P LINE 640 C LINE 650
MEAGER CREEK MAP AREA

W E W E

R(a)	Dir	C#	P#	Ze	Xd	Yd	Zd	Vhor	R(a)	Dir	C#	P#	Ze	Xd	Yd	Zd	Vhor
249	35	2	1	595	464549	5604350	1167	2674	471	41	8	4	899	465317	5603210	238	1309
272	74	2	2	618	464709	5604150	1051	2421	472	6	9	2	1408	461801	5603610	14	1917
273	21	5	2	653	464915	5603900	335	2103	482	68	10	6	1438	465568	5602720	-491	756
277	37	4	2	603	464834	5603960	984	2197	493	63	9	5	992	465475	5603110	127	1145
281	71	4	3	640	464961	5603730	830	1975	500	80	9	6	1194	465637	5602850	-198	332
294	55	3	2	585	464802	5604030	1022	2270	503	93	5	5	1104	465356	5603510	143	1567
311	8	4	1	826	464595	5604220	873	2540	509	103	4	5	1280	465225	5603670	46	1761
321	56	1	1	575	464435	5604430	1263	2803	513	116	1	5	1338	464839	5604140	-299	2350
324	20	3	1	705	464613	5604280	1008	2581	525	9	11	2	1792	464725	5603570	-449	1932
324	85	3	3	737	464879	5603900	774	2124	536	176	9	1	1747	464532	5603900	-203	2311
327	55	5	3	559	465073	5603670	851	1330	538	9	10	2	1605	464713	5603580	-207	1943
328	83	5	4	783	465241	5603550	537	1648	539	179	10	1	1932	464465	5603870	-417	2327
339	100	3	4	1075	465015	5603850	367	2016	543	109	4	6	1637	465374	5603610	-367	1649
341	2	7	2	958	464981	5603770	502	1957	565	49	11	5	1420	465298	5602950	-409	1033
360	179	5	1	955	464655	5604180	701	2474	572	39	9	4	1079	465213	5603160	106	1311
364	97	2	3	869	464774	5604050	709	2307	579	19	9	3	1152	464995	5603320	126	1568
364	112	1	4	1449	464725	5604160	156	2421	605	63	11	6	1521	465589	5602690	-634	717
365	2	8	2	1245	464901	5603670	182	1913	608	106	5	5	1451	465479	5603370	-269	1395
379	54	7	4	697	465381	5603340	530	1392	610	112	2	5	1619	465015	5603980	-176	2131
391	92	4	4	933	465108	5603710	463	1349	618	119	1	5	2215	464927	5603990	-743	2177
398	0	1	2	750	464561	5604300	1013	2626	621	0	11	1	2119	464528	5603880	-656	2294
414	170	7	1	1319	464709	5604070	263	2349	630	33	11	4	1432	465121	5603100	-330	1313
416	106	1	3	1064	464604	5604200	606	2515	633	58	9	5	1134	465361	5603060	-19	1155
416	112	3	6	1807	465291	5603780	-482	1342	642	19	11	3	1534	464903	5603270	-337	1589
422	109	3	5	1441	465129	5603810	-63	1933	643	20	10	3	1355	464900	5603290	-100	1502
424	23	7	3	698	465181	5603480	616	1604	659	74	9	6	1311	465612	5602770	-326	786
427	17	8	3	973	465099	5603330	308	1557	676	37	10	4	1274	465112	5603130	-103	1347
435	172	8	1	1599	464632	5603970	-51	2307	639	53	10	5	1299	465349	5602920	-260	1040
464	79	7	5	886	465524	5603250	264	1265	709	116	2	6	1992	465171	5603940	-599	2032
467	107	2	4	1239	464903	5604010	273	2210	834	116	2	6	1992	465171	5603940	-599	2032

POLE-POLE RESISTIVITY DATA: 1978
CORRIDOR 655 P LINE ~~660~~ 650 C LINE ~~650~~ 660
MEAGER CREEK MAP AREA

R(a)	Dir	C# E	P# W	Ze	Xd	Yd	Zd	Vnor
345	67	3	1	1100	465291	5605040	640	2988
362	73	6	2	1332	465778	5604700	217	2399
371	35	2	2	1071	465376	5604930	628	2847
372	74	4	1	1186	465353	5604990	523	2911
418	49	1	1	998	465137	5605180	819	3195
418	57	2	1	1035	465229	5605120	753	3088
420	45	3	2	1055	465472	5604820	593	2702
430	54	4	2	1082	465501	5604520	555	2685
439	55	5	2	1233	465660	5604770	350	2535
442	82	5	1	1407	465468	5605070	294	2882
453	13	2	3	1235	465487	5604330	367	2700
463	26	1	2	1106	465295	5604930	619	2958
468	35	4	3	1119	465679	5604650	390	2437
476	91	9	2	1706	465915	5604530	-291	2184
494	30	7	2	1445	465836	5604640	60	2315
507	27	3	3	1153	465597	5604710	347	2541
510	58	6	3	1219	465021	5604460	192	2050
519	43	5	3	1180	465391	5504550	256	2215
519	33	6	1	1550	465574	5605030	128	2792
522	92	7	1	1701	465631	5604910	-65	2711
535	15	4	4	1218	465392	5604500	190	2177
545	35	10	2	1399	465395	5604430	-555	2128
575	173	2	5	1717	465775	5604640	-279	2359
600	3	2	4	1433	465677	5604720	79	2486
600	13	3	4	1302	465794	5604530	143	2309
603	35	8	2	1557	465369	5604590	-93	2262
612	36	10	3	1603	465162	5604130	-423	1736
616	76	8	1	1839	465561	5604940	-243	2654
634	2	4	5	1142	466008	5604400	-112	2030
640	103	10	1	2218	465637	5604570	-775	2431
641	43	9	5	1093	465562	5503340	-52	1167
642	66	7	3	1277	466080	5604390	79	1967
645	67	9	4	1215	466396	5604110	-32	1545
652	180	5	6	1556	466290	5604170	-333	1665
663	11	1	3	1320	465398	5604910	306	2818
663	99	11	2	2058	465914	5604380	-771	2080
668	30	5	4	1182	466105	5604400	160	1955
671	75	10	4	1322	466418	5604000	-229	1458
678	29	9	6	1103	466739	5603720	-91	1027
678	165	2	5	2024	465796	5604490	-625	2245
682	57	3	4	1163	465320	5604190	76	1661
692	80	9	3	1458	466166	5604280	-190	1928
697	13	5	5	1332	466226	5604300	-63	1805
700	39	6	4	1152	466192	5604340	179	1858
702	49	7	4	1142	466268	5604260	142	1744
716	6	6	5	1425	466409	5604030	-222	1519
716	73	3	3	1350	466111	5604350	-31	1920
718	172	4	5	1715	466053	5604270	-427	1903
718	177	3	5	1553	465999	5604500	-186	2173
729	162	1	5	2173	465670	5504590	-745	2402
736	91	11	3	1757	466190	5604130	-621	1711
737	68	11	5	1294	466700	5603720	-274	1059
744	82	11	4	1445	466459	5603960	-399	1395
752	40	10	6	1058	466873	5603520	-179	793
754	21	6	5	1241	466325	5604230	13	1682
756	50	11	6	1067	466856	5603520	-191	309
760	13	7	5	1296	466534	5603960	-156	1342
774	168	3	5	1349	465932	5604350	-518	2054
778	30	7	5	1161	466432	5604110	34	1525
781	178	1	4	1554	465567	5604810	-11	2630
802	59	10	5	1129	466649	5603780	-149	1136
805	29	8	6	1292	466621	5603850	-120	1203
812	38	3	5	1119	466523	5604010	13	1385
856	159	1	5	1859	465661	5604740	-333	2510

POLE-POLE RESISTIVITY DATA: 1978
CORRIDOR 205 P LINE 210 C LINE 200
LILLOOET RIVER MAP AREA

R(a)	Dir	C#	P#	Ze	Xd	Yd	Zd	Vnor
132	21	3	26	1582	471122	5610150	-841	3709
170	74	21	6	2331	468970	5603350	-1218	911
196	143	25	25	782	469690	5508980	-243	1964
214	165	25	24	961	469438	5508660	-210	1459
217	81	22	25	1245	469026	5608190	-232	836
219	90	22	6	1961	469413	5603390	-1054	1272
219	31	22	26	1572	469099	5608510	-664	1121
225	136	3	4	1344	472144	5610510	-428	4729
228	32	2	25	2178	471035	5610490	-1232	3987
239	72	21	25	1632	468672	5607930	-413	400
242	109	25	5	1930	470955	5609330	-1377	3074
251	6	3	6	1412	471376	5610210	-657	3940
252	179	25	23	1291	469207	5608300	-333	1054
253	28	4	25	1343	470643	5609700	-597	3051
255	97	24	4	2437	470995	5610040	-1683	3539
259	23	5	24	1378	470147	5609040	-667	2250
259	32	4	23	2068	469969	5609020	-1090	2096
266	92	23	26	1324	469372	5608710	-567	1453
269	96	23	25	1003	469217	5608440	-129	1152
272	23	25	21	1627	468666	5608130	-495	556
276	123	24	25	776	469496	5608760	-107	1573
277	113	3	3	1657	472623	5610940	-553	5375
281	10	25	22	1551	468926	5608090	-448	701
281	31	4	24	1681	470270	5609390	-893	2567
283	125	25	26	966	470073	5609230	-521	2317
293	92	5	3	1998	472372	5610520	-1130	4917
296	16	4	26	1178	470963	5609770	-563	3344
299	24	5	25	1020	470462	5609390	-479	2714
300	35	4	22	2393	469594	5608950	-1273	1707
301	88	23	6	1713	469565	5608630	-952	1619
304	110	24	26	1039	469344	5609150	-508	2095
334	24	2	26	1998	471351	5610540	-1082	4145
352	101	24	6	1403	470120	5609210	-869	2334
354	34	5	22	2114	469552	5608430	-1065	1416
361	169	24	23	1079	469112	5608230	-46	334
367	19	24	21	1350	468536	5608100	-155	486
368	6	5	26	879	470754	5609490	-379	3007
373	30	5	23	1732	469887	5608640	-374	1805
385	112	25	6	1234	470352	5609290	-332	2562
403	85	25	3	2890	471774	5610480	-2067	4420
409	3	24	22	1302	468845	5608030	-132	603
420	106	5	4	1433	471388	5610100	-726	4230
429	149	24	24	819	469322	5608540	22	1234
434	162	3	5	1595	471904	5610080	-754	4283
455	18	1	6	2174	471786	5610970	-1067	4736
481	158	5	6	850	471036	5609590	-337	3289
554	135	5	5	1324	471722	5609670	-653	3905
619	152	2	4	1477	472344	5610820	-393	5078
654	148	4	5	1379	471700	5609760	-665	3933
674	100	4	3	1790	472455	5610620	-842	5044
689	119	4	4	1316	471970	5610230	-527	4420
770	127	2	3	1599	472749	5611110	-375	5574
795	180	1	5	2171	472339	5610770	-997	5038
822	172	2	5	1869	472128	5610430	-960	4663
851	164	1	4	1694	472547	5611130	-444	5427
865	30	21	24	1271	468633	5607830	57	353
1034	140	1	3	1647	472145	5610740	-336	4370
1049	96	22	24	939	468990	5608100	189	757
1255	117	23	24	905	469135	5608320	201	1010
1513	6	23	21	894	468558	5608040	405	422
1686	96	21	23	976	468653	5607740	463	297
1688	164	23	22	932	468776	5607960	352	502
1907	143	23	23	337	468997	5608110	326	771
2241	119	22	23	783	468917	5607970	471	627
2559	113	21	22	740	468529	5607640	813	160
2774	126	21	21	434	468484	5607990	1038	346
3174	144	22	22	726	468726	5607850	647	401
3244	170	22	21	530	468548	5607970	791	353

APPENDIX B-2

PSEUDOSECTION DATA PLOTS AND R(A) Vs. DEPTH PLOTS

The apparent resistivity R(A) data are plotted on topographic sections located through each data corridor. The position of each pseudosection and accompanying R(A) vs. Depth Plot is shown on plan maps of Figures 4.1 and 4.6 by two triangles

▷ ◀

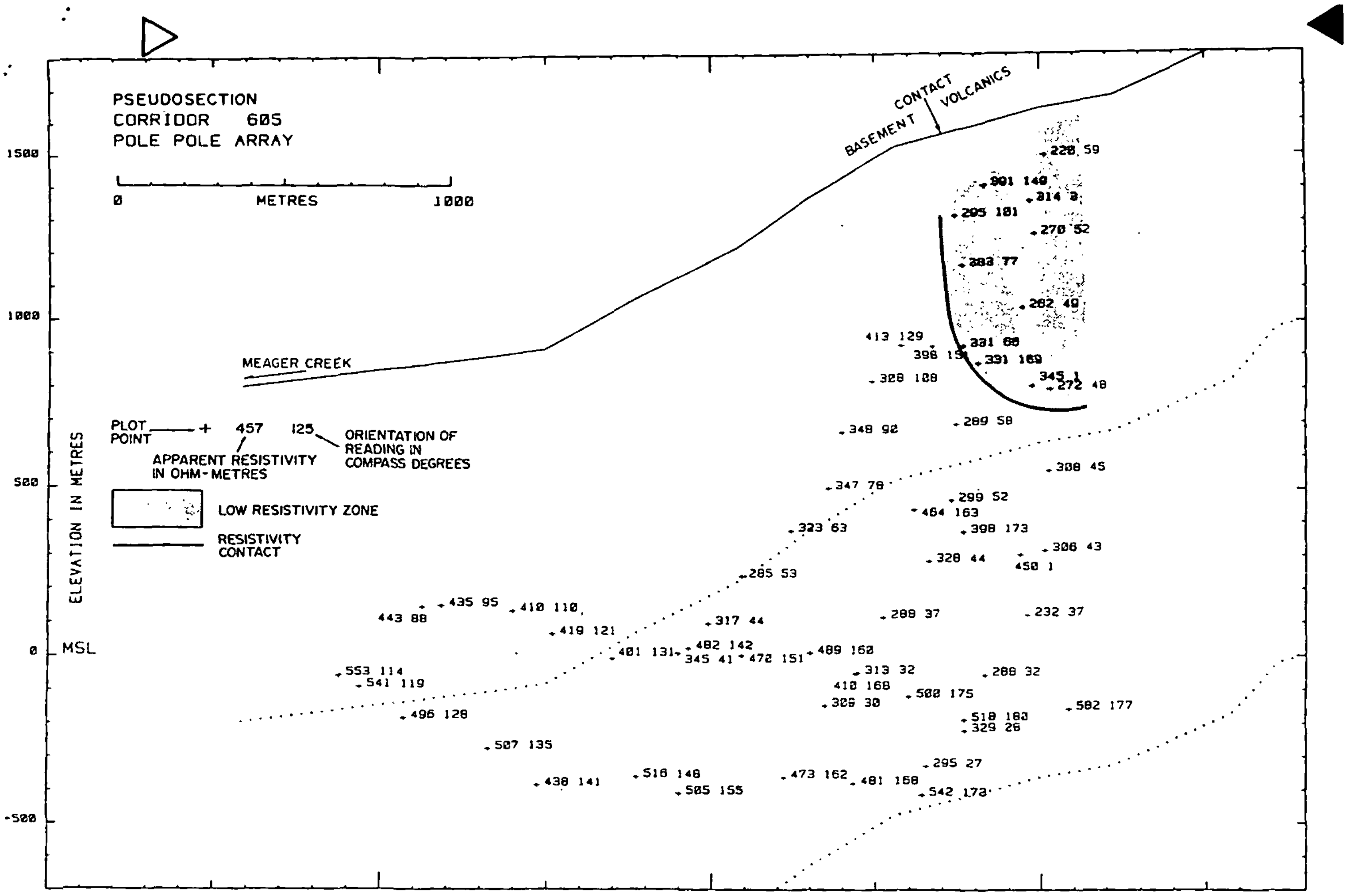
marking the horizontal limits of the section. Triangles on the plan maps correspond with those at the top of the section plots.

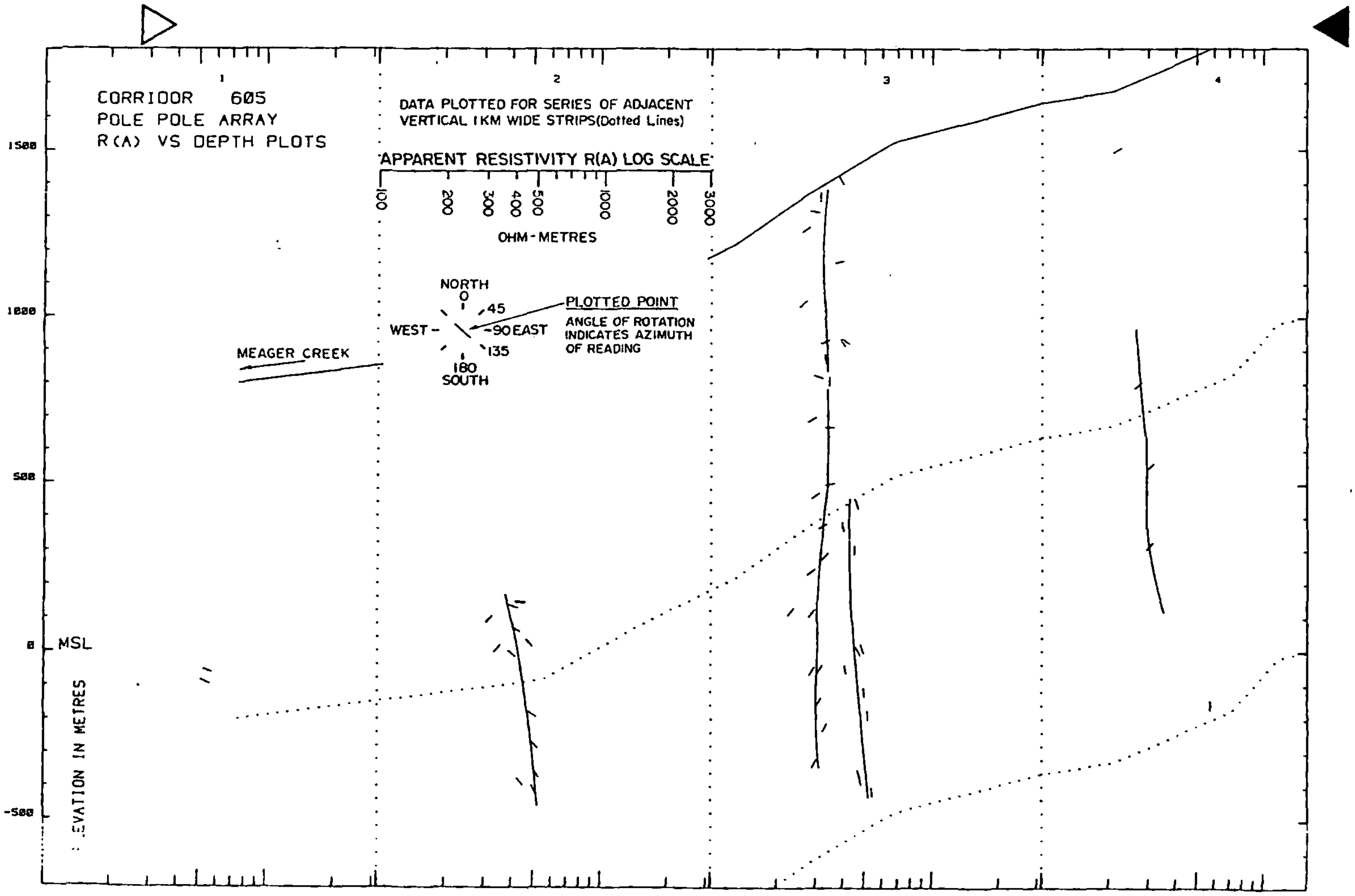
The pseudosection plots are not true sections of resistivity values - they are a conventional means of graphically presenting data for purposes of analysis and interpretation. The vertical coordinate is plotted according to a method described by Edwards (1977).

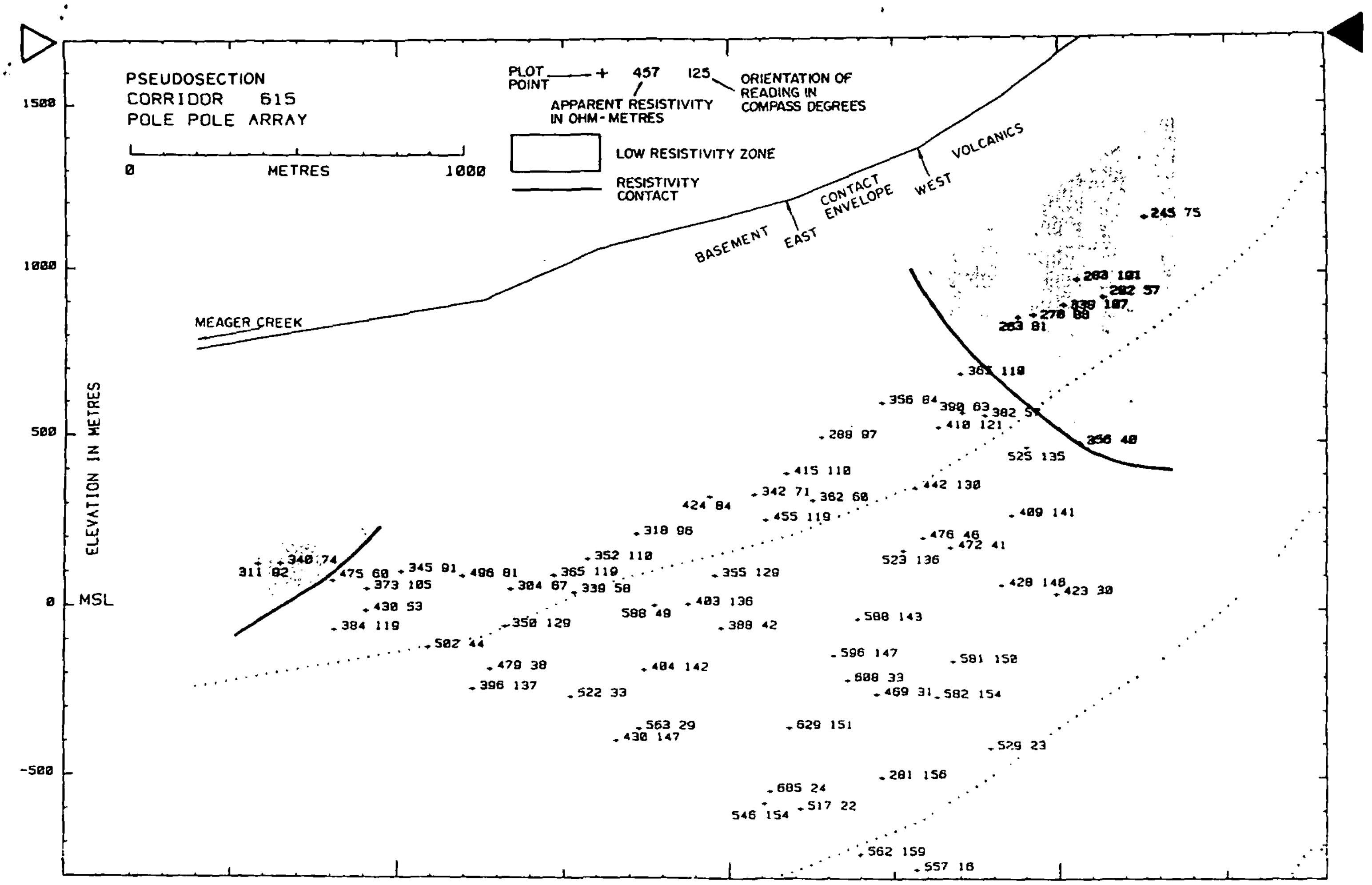
R(A) vs. Depth plots are constructed to facilitate observation of trends of apparent resistivity with depth over the width of the pseudosection and to improve resolution of anisotropic conditions if any. These also follow standard geophysical convention. Two steps are taken in the construction:

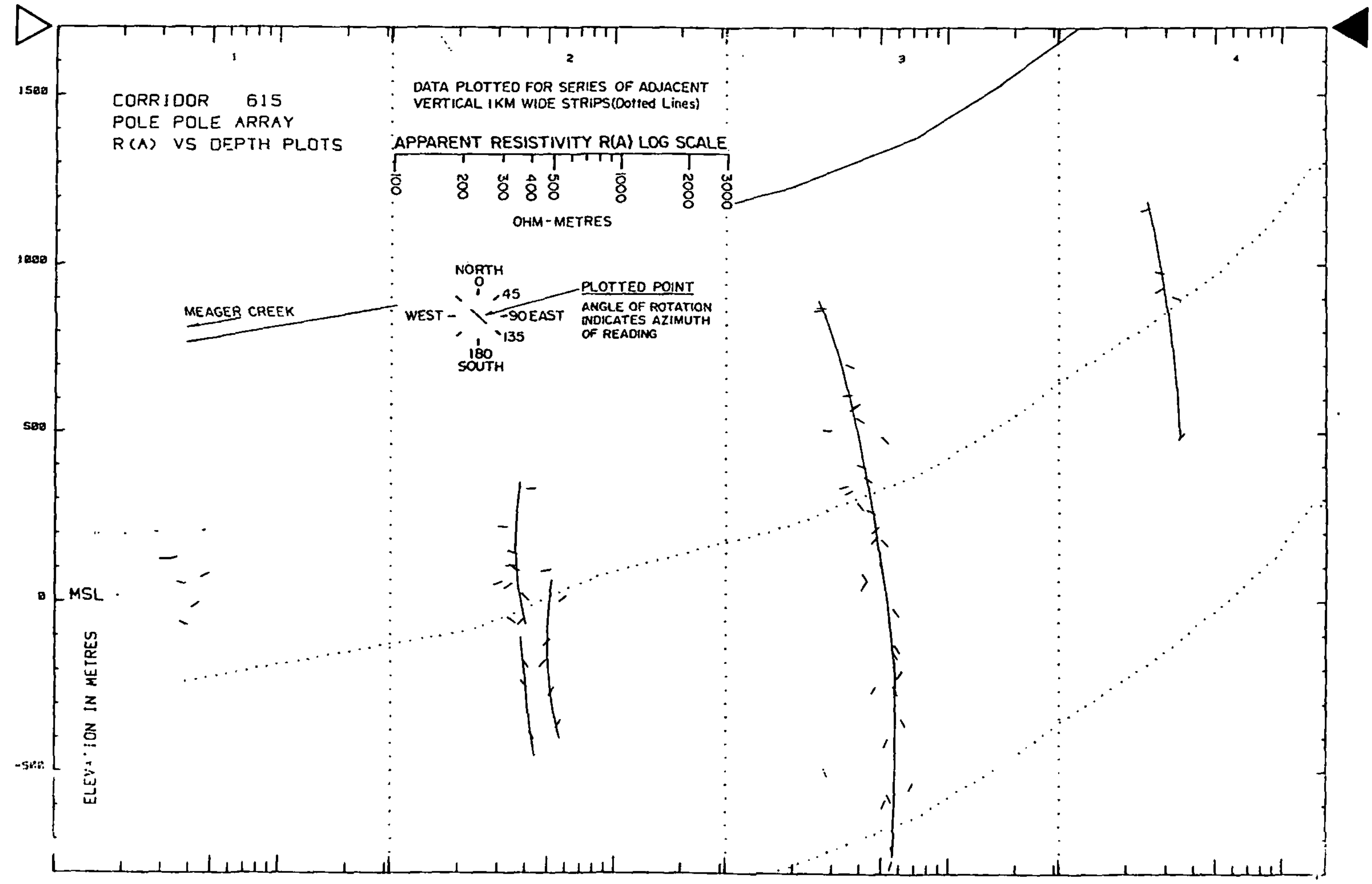
a) The pseudosection is divided into 1 km wide slices, defined by the vertical dotted lines on the plots. Data located within each slice are grouped and designated as representative of conditions within the area represented by the slice.

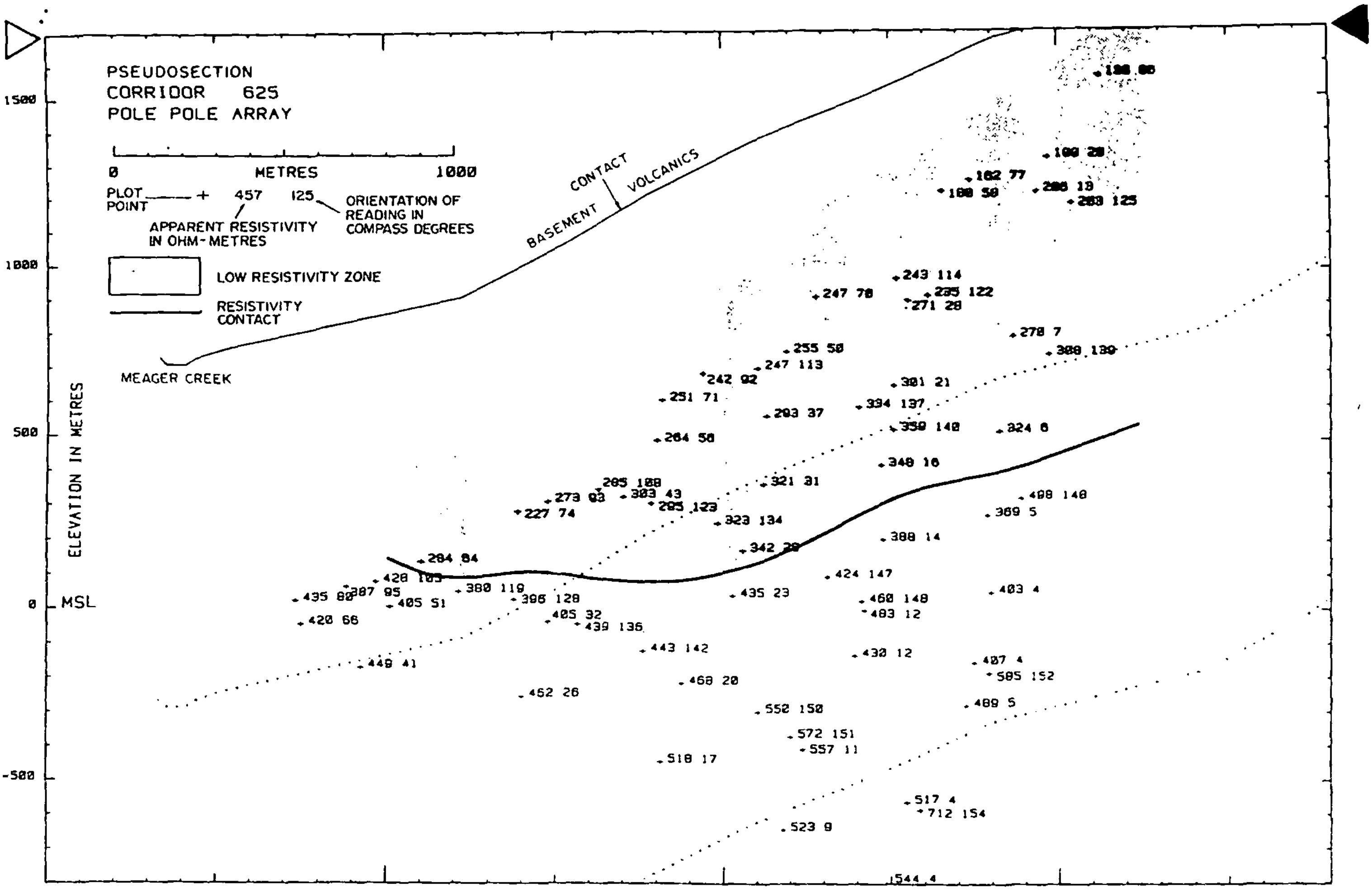
b) The areas defined for each slice are reformatted as individual graphs plotting the log of apparent resistivity on the X axis and the elevation of the plotting point (Zd) on the Y axis. The orientation of each resistivity reading is indicated by the angle of rotation (from the perpendicular) of the plot symbol. North is 0°, East is 90°, as indicated on the legend.

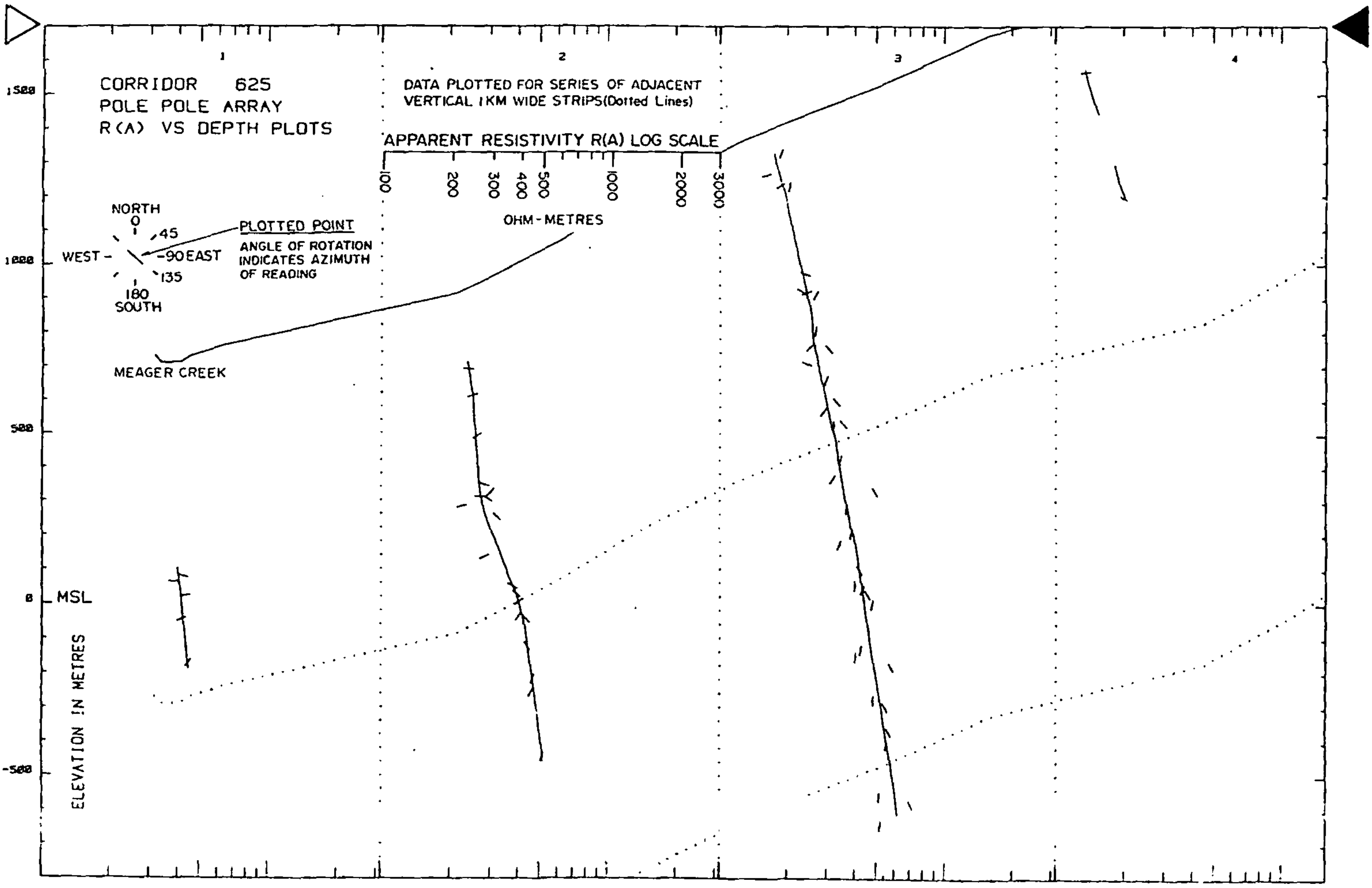

PSEUDOSECTION
CORRIDOR 605
POLE POLE ARRAY
0
METRES
1000
BASEMENT
CONTACT
VOLCANICS
MEAGER CREEK
1500
1000
500
0
-500
MSL
ELEVATION IN METRES
PLOT POINT
457
125
APPARENT RESISTIVITY IN OHM-METRES
ORIENTATION OF READING IN COMPASS DEGREES
LOW RESISTIVITY ZONE
RESISTIVITY CONTACT
228 59
801 140
314 3
295 101
270 52
283 77
282 40
413 129
398 15
331 88
391 169
345 1
272 48
328 108
348 92
289 58
308 45
347 78
299 52
464 163
323 63
398 173
306 43
328 44
450 1
285 53
443 88
435 95
410 110
419 121
317 44
288 37
232 37
401 131
482 142
345 41
472 151
489 160
553 114
541 119
313 32
288 32
410 168
500 175
309 30
582 177
496 128
518 180
329 26
507 135
295 27
516 148
473 162
481 160
438 141
505 155
542 173

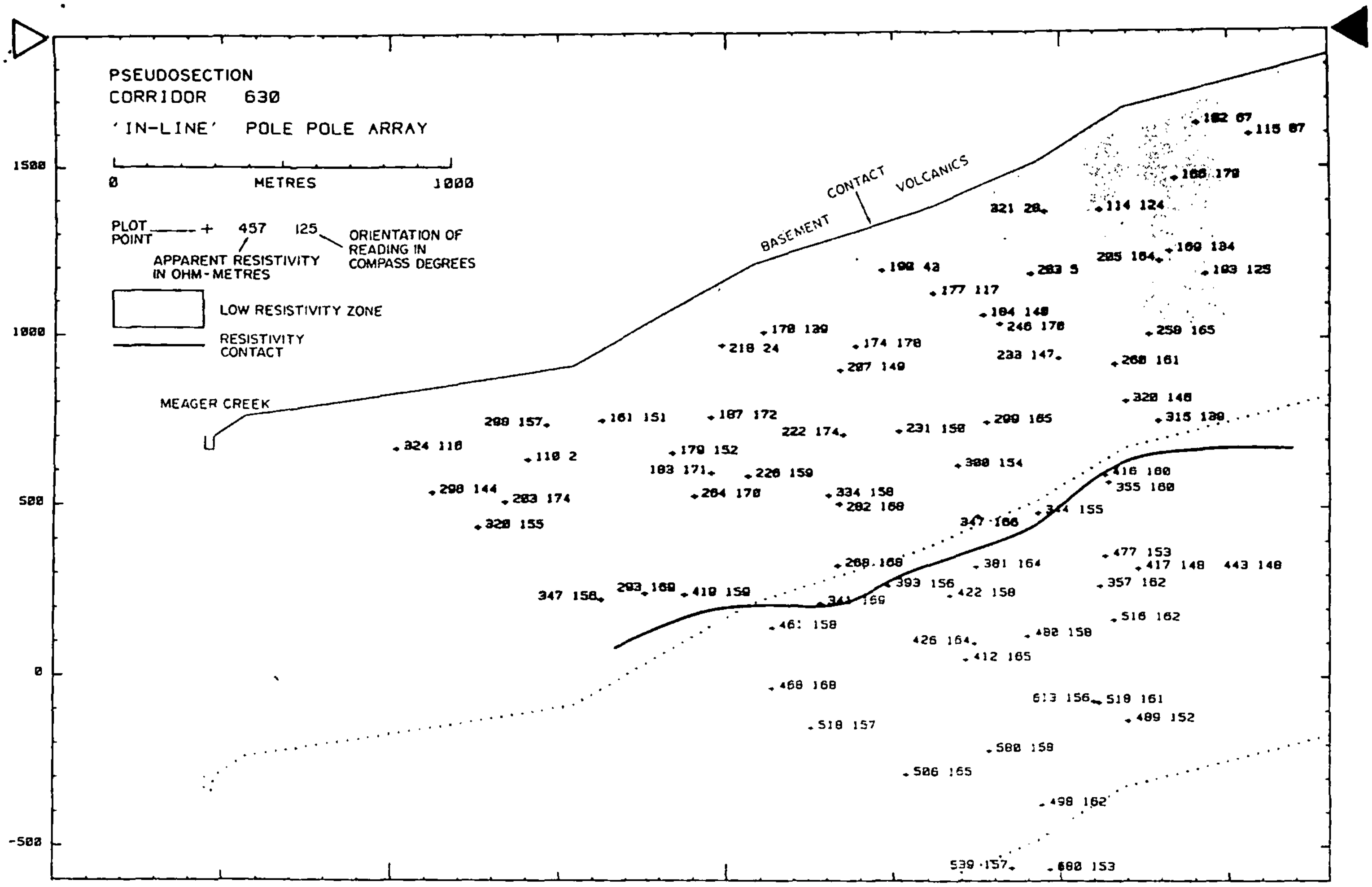

1
2
3
4
CORRIDOR 605
POLE POLE ARRAY
R(A) VS DEPTH PLOTS
DATA PLOTTED FOR SERIES OF ADJACENT VERTICAL 1KM WIDE STRIPS(Dotted Lines)
APPARENT RESISTIVITY R(A) LOG SCALE
100
200
300
400
500
1000
2000
3000
OHM-METRES
NORTH
0
45
WEST
90 EAST
135
180
SOUTH
PLOTTED POINT
ANGLE OF ROTATION INDICATES AZIMUTH OF READING
MEAGER CREEK
1500
1000
500
0
-500
MSL
ELEVATION IN METRES

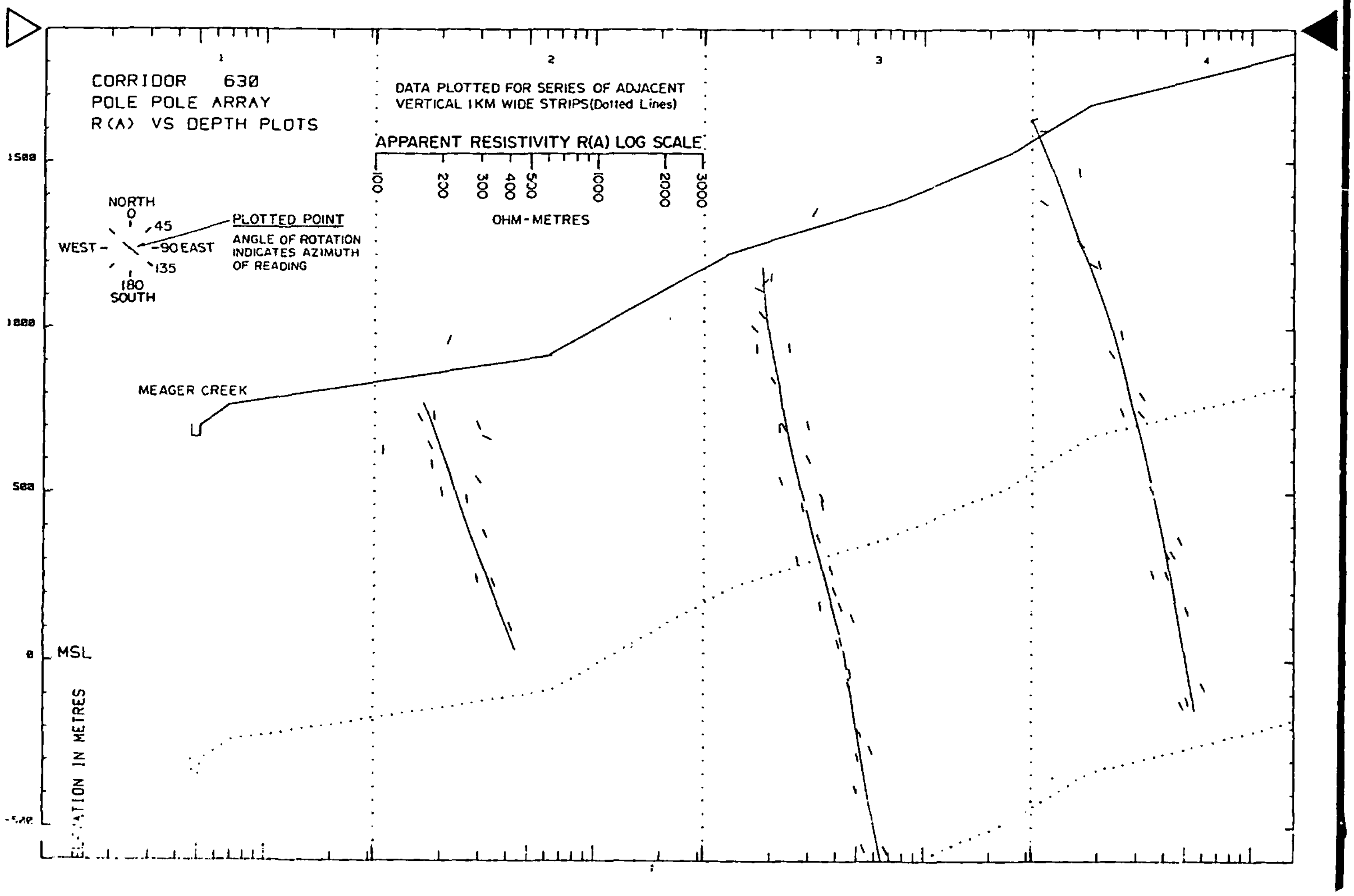

PSEUDOSECTION
CORRIDOR 615
POLE POLE ARRAY
0
METRES
1000
PLOT POINT
457
125
APPARENT RESISTIVITY IN OHM-METRES
ORIENTATION OF READING IN COMPASS DEGREES
LOW RESISTIVITY ZONE
RESISTIVITY CONTACT
1500
1000
500
0
MSL
-500
ELEVATION IN METRES
MEAGER CREEK
BASEMENT
EAST
CONTACT ENVELOPE
WEST
VOLCANICS
245 75
283 101
282 57
330 107
270 80
283 81
361 110
356 84
390 83
382 57
410 121
356 40
288 97
525 135
415 110
442 130
424 84
342 71
362 60
455 119
409 141
318 96
476 46
472 41
523 136
340 74
311 82
352 110
475 60
345 91
496 81
365 119
355 129
373 105
304 87
339 58
428 148
423 30
430 53
588 49
403 136
588 143
384 119
350 129
388 42
502 44
596 147
581 150
479 38
404 142
608 33
396 137
522 33
469 31
582 154
563 29
629 151
430 147
529 23
281 156
685 24
517 22
546 154
562 159
557 16

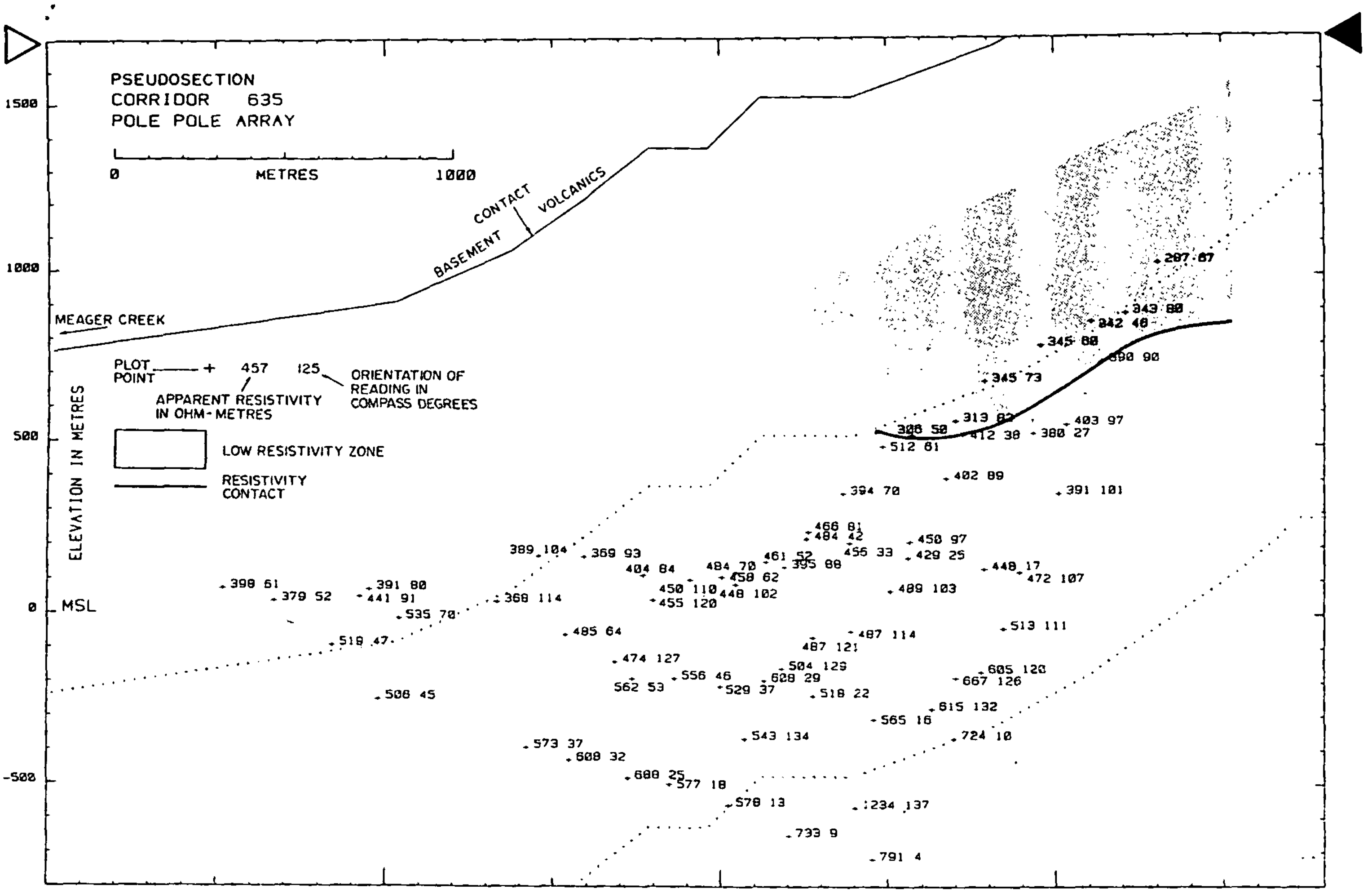

1
2
3
4
CORRIDOR 615
POLE POLE ARRAY
R(A) VS DEPTH PLOTS
DATA PLOTTED FOR SERIES OF ADJACENT VERTICAL 1KM WIDE STRIPS (Dotted Lines)
APPARENT RESISTIVITY R(A) LOG SCALE
100
200
300
400
500
1000
2000
3000
OHM-METRES
1500
1000
500
0
MSL
-500
ELEVATION IN METRES
MEAGER CREEK
NORTH
0
45
WEST
90 EAST
135
180
SOUTH
PLOTTED POINT
ANGLE OF ROTATION INDICATES AZIMUTH OF READING

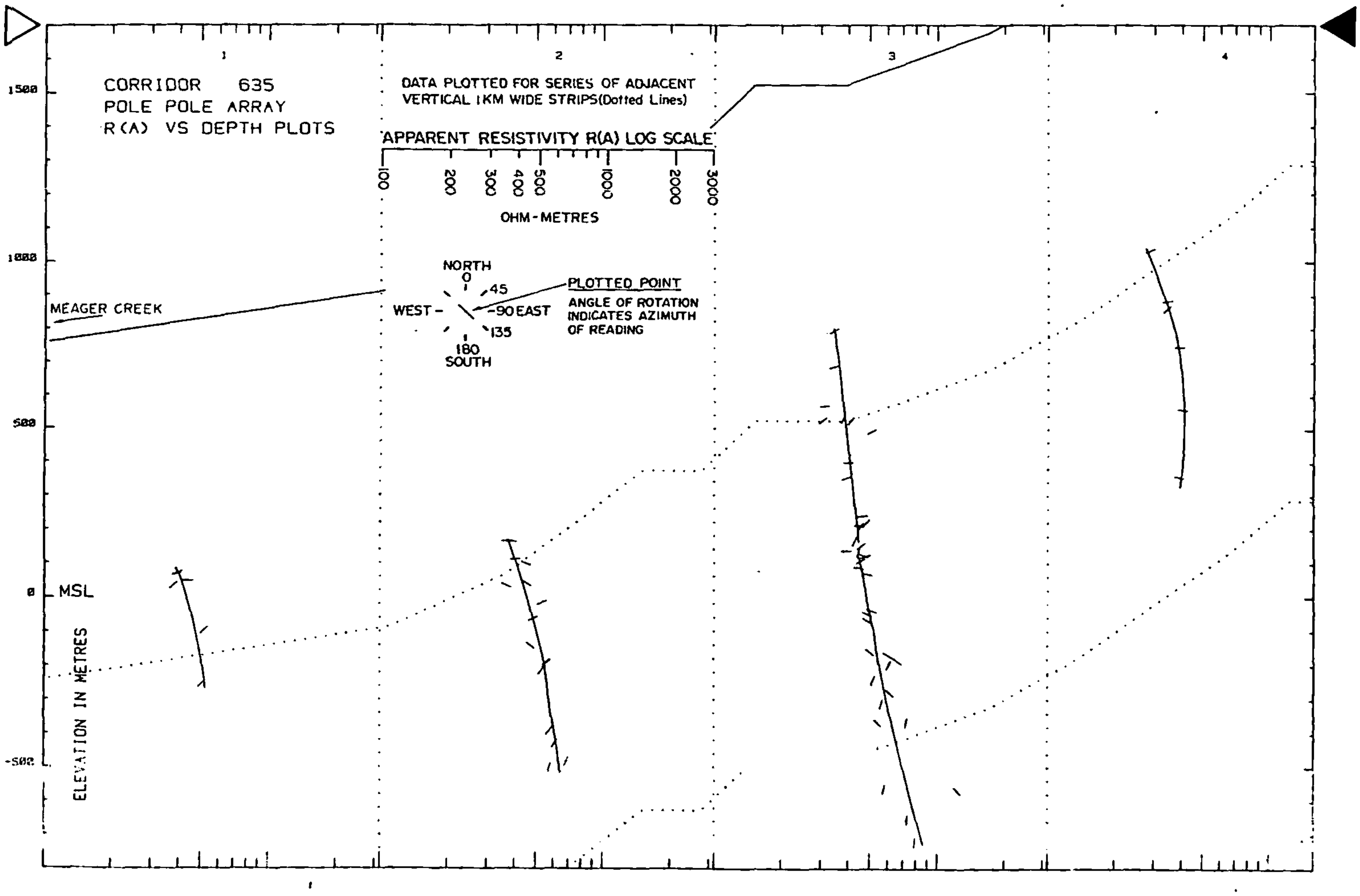

PSEUDOSECTION
CORRIDOR 625
POLE POLE ARRAY
0 METRES 1000
PLOT POINT + 457 125
APPARENT RESISTIVITY IN OHM-METRES
ORIENTATION OF READING IN COMPASS DEGREES
LOW RESISTIVITY ZONE
RESISTIVITY CONTACT
MEAGER CREEK
CONTACT
BASEMENT
VOLCANICS
ELEVATION IN METRES
1500
1000
500
0 MSL
-500
100 80
100 20
102 77
100 50
200 19
203 125
243 114
247 78
235 122
271 28
278 7
308 139
255 50
247 113
242 92
301 21
251 71
334 137
203 37
350 140
324 6
264 50
340 16
285 100
321 31
273 93
303 43
498 140
227 74
295 123
369 5
323 134
300 14
342 20
284 84
424 147
420 103
435 80
307 95
380 119
435 23
403 4
405 51
396 128
460 140
420 66
483 12
405 32
439 136
443 142
430 12
449 41
407 4
505 152
460 20
462 26
550 150
489 5
572 151
557 11
518 17
517 4
712 154
523 9
544 4

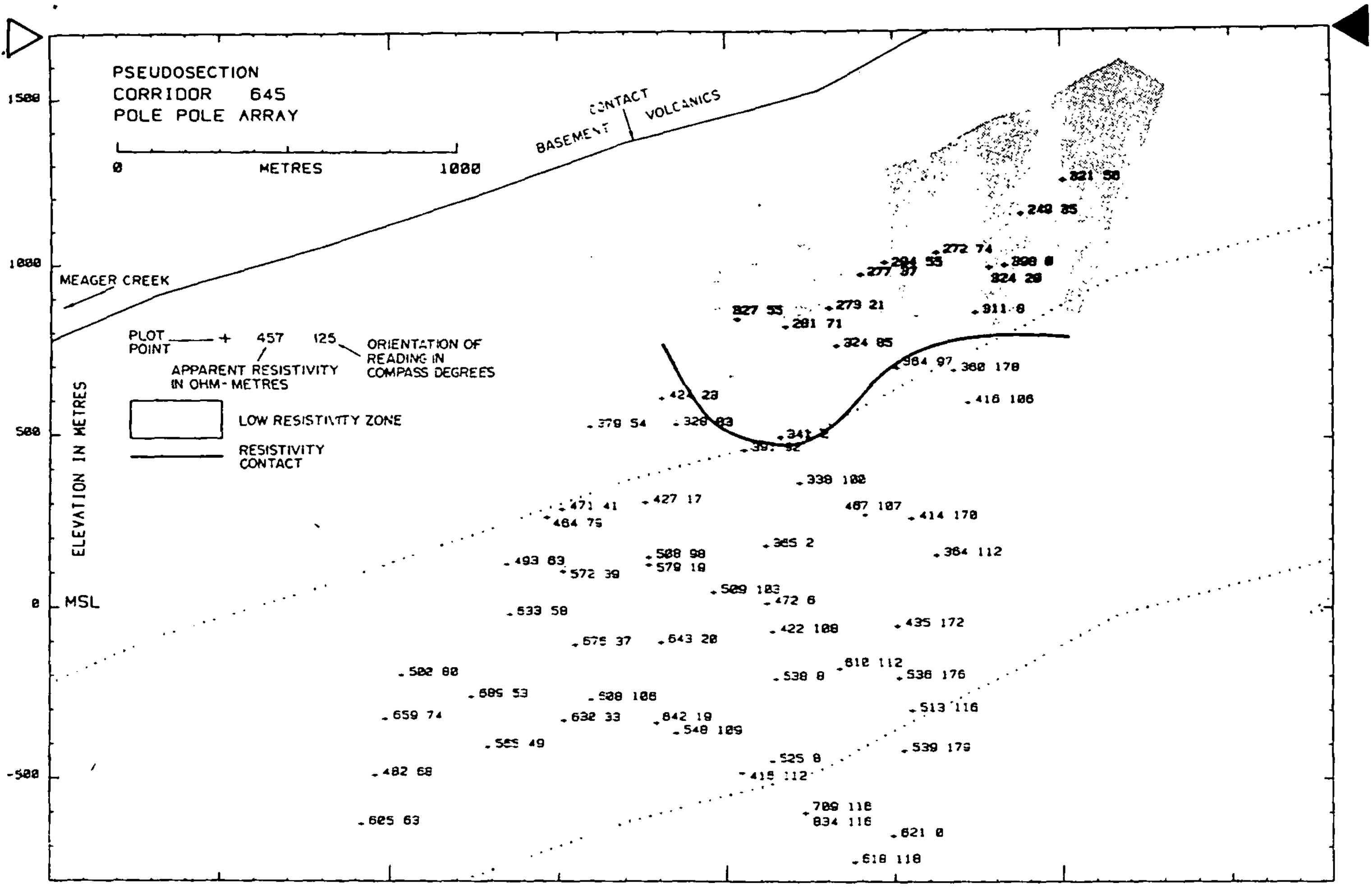

CORRIDOR 625
POLE POLE ARRAY
R(A) VS DEPTH PLOTS
1
2
3
4
DATA PLOTTED FOR SERIES OF ADJACENT VERTICAL 1KM WIDE STRIPS(Dotted Lines)
APPARENT RESISTIVITY R(A) LOG SCALE
100
200
300
400
500
1000
2000
3000
OHM-METRES
NORTH
0
45
WEST
90 EAST
135
180
SOUTH
PLOTTED POINT
ANGLE OF ROTATION INDICATES AZIMUTH OF READING
MEAGER CREEK
ELEVATION IN METRES
1500
1000
500
0 MSL
-500

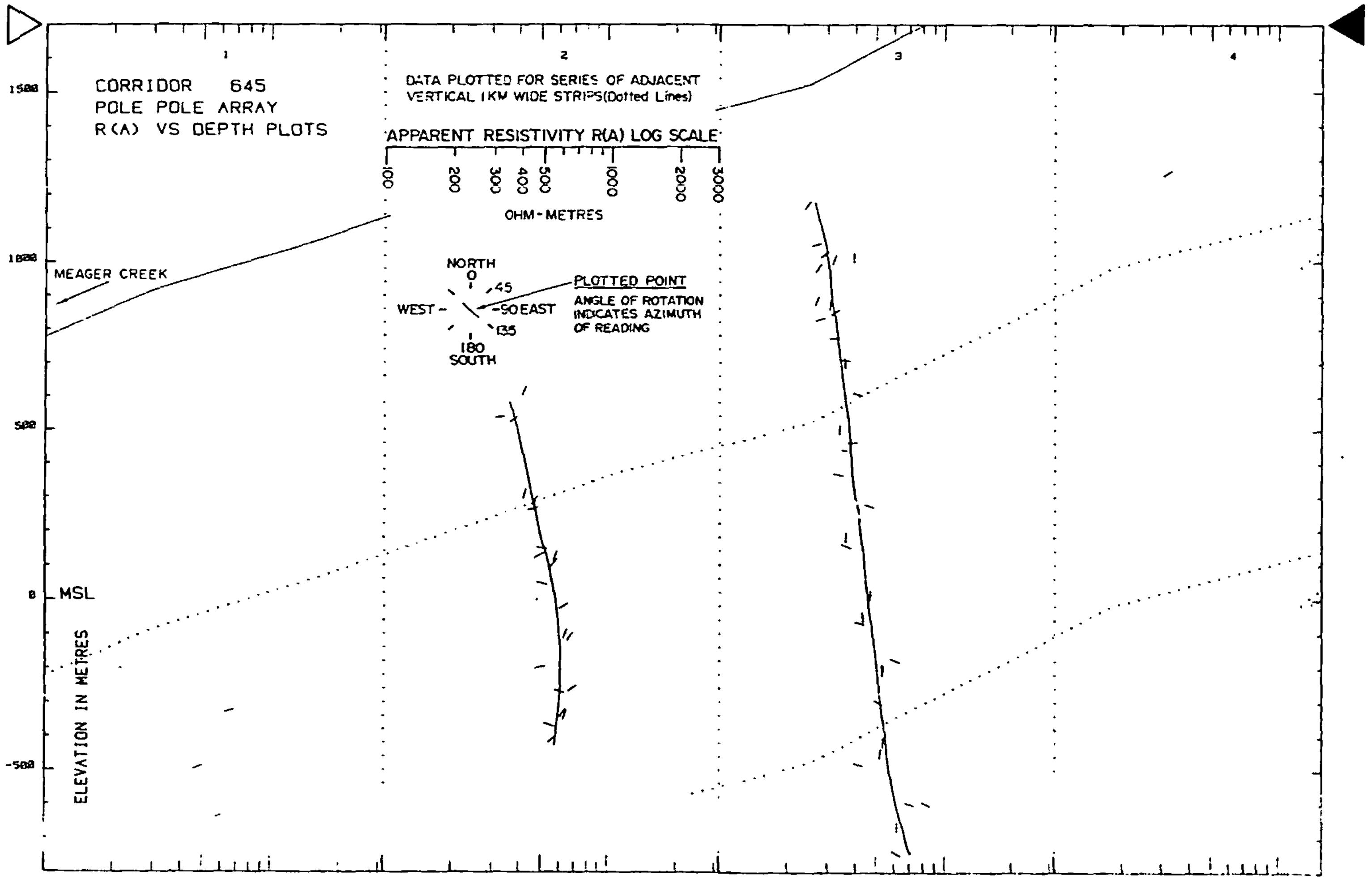

PSEUDOSECTION
CORRIDOR 630
'IN-LINE' POLE POLE ARRAY
0
METRES
1000
PLOT POINT
457
125
APPARENT RESISTIVITY IN OHM-METRES
ORIENTATION OF READING IN COMPASS DEGREES
LOW RESISTIVITY ZONE
RESISTIVITY CONTACT
MEAGER CREEK
BASEMENT
CONTACT
VOLCANICS
1500
1000
500
0
-500
182 67
115 87
188 178
321 28
114 124
285 184
160 184
190 42
283 5
193 125
177 117
184 148
246 178
258 165
178 139
218 24
174 178
233 147
268 161
287 149
328 148
288 157
161 151
187 172
222 174
231 158
290 165
315 139
324 118
110 2
179 152
388 154
183 171
226 159
416 180
355 180
298 144
283 174
284 178
334 158
282 168
344 155
328 155
347 166
477 153
268 168
381 164
417 148
443 148
393 156
357 162
347 158
293 169
419 159
341 169
422 158
516 162
461 158
426 164
482 158
412 165
468 168
613 156
519 161
489 152
518 157
580 159
586 165
498 162
539 157
680 153

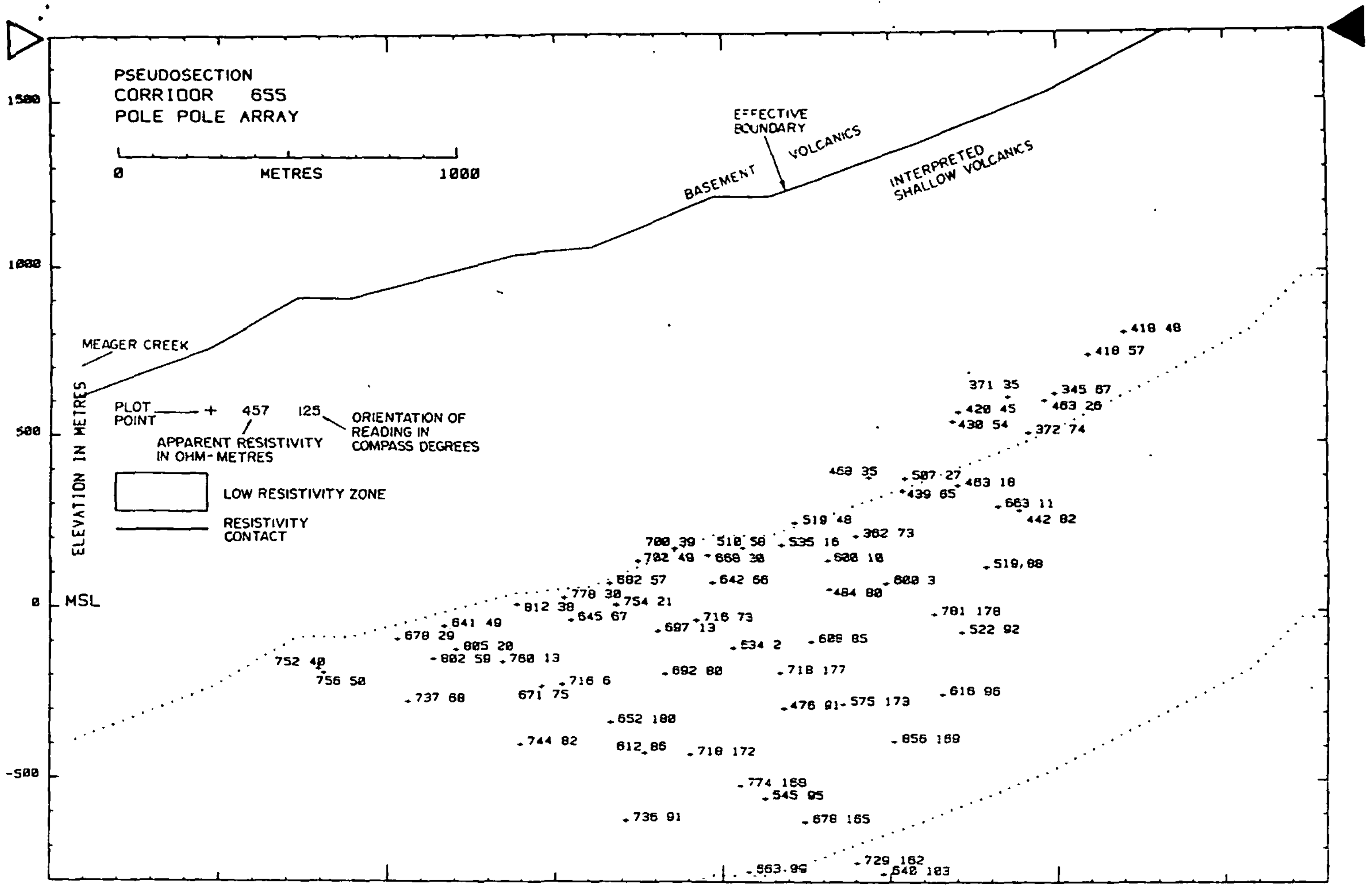

1
2
3
4
CORRIDOR 630
POLE POLE ARRAY
R(A) VS DEPTH PLOTS
DATA PLOTTED FOR SERIES OF ADJACENT VERTICAL 1KM WIDE STRIPS(Dotted Lines)
APPARENT RESISTIVITY R(A) LOG SCALE
100
200
300
400
500
1000
2000
3000
OHM-METRES
NORTH
0
45
WEST
90 EAST
135
180
SOUTH
PLOTTED POINT
ANGLE OF ROTATION INDICATES AZIMUTH OF READING
MEAGER CREEK
1500
1000
500
0
MSL
-500
ELEVATION IN METRES

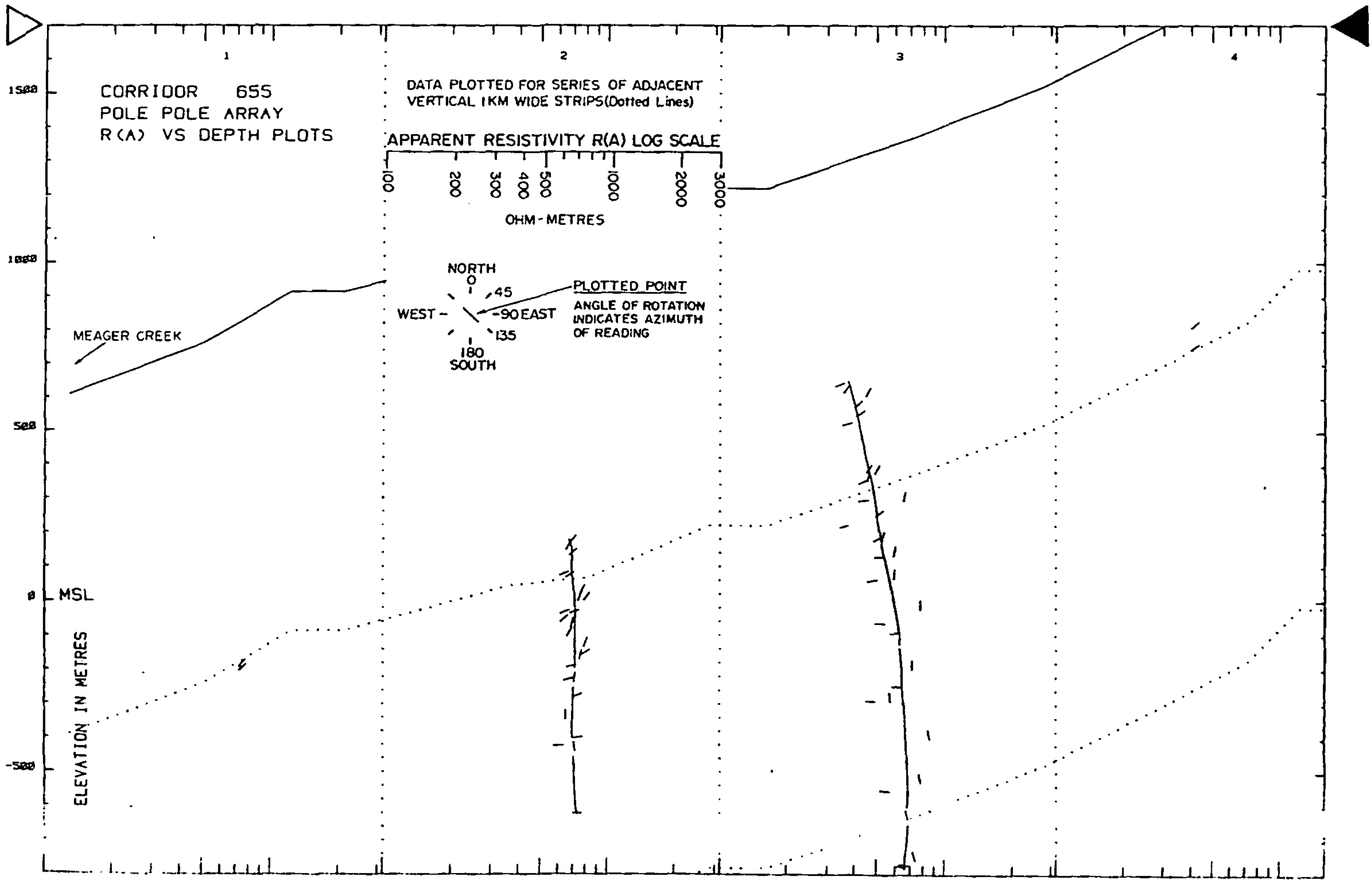

PSEUDOSECTION
CORRIDOR 635
POLE POLE ARRAY
0
METRES
1000
CONTACT
VOLCANICS
BASEMENT
MEAGER CREEK
PLOT POINT
457
125
APPARENT RESISTIVITY IN OHM-METRES
ORIENTATION OF READING IN COMPASS DEGREES
LOW RESISTIVITY ZONE
RESISTIVITY CONTACT
ELEVATION IN METRES
1500
1000
500
0
MSL
-500
287 87
343 80
342 40
345 80
390 90
345 73
313 82
403 97
308 50
412 38
380 27
512 81
402 89
394 70
391 101
466 81
484 42
450 97
456 33
429 25
389 104
369 93
461 52
395 88
404 84
484 70
458 62
448 17
472 107
398 61
391 80
450 110
448 102
489 103
379 52
441 91
368 114
455 120
535 70
485 64
513 111
487 114
518 47
487 121
474 127
504 129
605 120
556 46
608 29
667 126
562 53
529 37
518 22
508 45
615 132
565 16
543 134
724 10
573 37
608 32
688 25
577 18
578 13
1234 137
733 9
791 4


1
2
3
4
CORRIDOR 635
POLE POLE ARRAY
R(A) VS DEPTH PLOTS
DATA PLOTTED FOR SERIES OF ADJACENT VERTICAL 1KM WIDE STRIPS (Dotted Lines)
APPARENT RESISTIVITY R(A) LOG SCALE
100
200
300
400
500
1000
2000
3000
OHM-METRES
NORTH
0
45
WEST
90 EAST
135
180
SOUTH
PLOTTED POINT
ANGLE OF ROTATION INDICATES AZIMUTH OF READING
MEAGER CREEK
1500
1000
500
0
MSL
-500
ELEVATION IN METRES


PSEUDOSECTION
CORRIDOR 645
POLE POLE ARRAY
0
METRES
1000
CONTACT
BASEMENT
VOLCANICS
1500
1000
500
0
MSL
-500
MEAGER CREEK
PLOT POINT
457
125
APPARENT RESISTIVITY IN OHM-METRES
ORIENTATION OF READING IN COMPASS DEGREES
LOW RESISTIVITY ZONE
RESISTIVITY CONTACT
ELEVATION IN METRES
821 58
249 85
272 74
284 55
277 37
898 8
824 28
827 55
279 21
281 71
911 8
324 85
984 97
360 170
416 106
424 28
379 54
328 83
341 2
39? 92
338 100
471 41
427 17
464 75
487 107
414 170
365 2
493 63
508 98
579 10
572 39
364 112
509 103
472 6
533 58
422 108
435 172
675 37
643 20
612 112
502 80
538 8
536 176
685 53
508 106
513 116
659 74
632 33
842 19
548 109
565 49
539 179
525 8
415 112
482 68
709 118
834 116
605 63
621 0
618 118


CORRIDOR 645
POLE POLE ARRAY
R(A) VS DEPTH PLOTS
1
2
3
4
DATA PLOTTED FOR SERIES OF ADJACENT VERTICAL 1KM WIDE STRIPS(Dotted Lines)
APPARENT RESISTIVITY R(A) LOG SCALE
100
200
300
400
500
1000
2000
3000
OHM-METRES
1500
1000
500
0
MSL
-500
MEAGER CREEK
NORTH
0
45
WEST
90 EAST
135
180
SOUTH
PLOTTED POINT
ANGLE OF ROTATION INDICATES AZIMUTH OF READING
ELEVATION IN METRES


PSEUDOSECTION
CORRIDOR 655
POLE POLE ARRAY
0
METRES
1000
1500
1000
500
0
MSL
-500
ELEVATION IN METRES
MEAGER CREEK
PLOT POINT
+
457
125
APPARENT RESISTIVITY IN OHM-METRES
ORIENTATION OF READING IN COMPASS DEGREES
LOW RESISTIVITY ZONE
RESISTIVITY CONTACT
EFFECTIVE BOUNDARY
BASEMENT
VOLCANICS
INTERPRETED SHALLOW VOLCANICS
418 48
418 57
371 35
345 67
420 45
463 26
430 54
372 74
460 35
507 27
483 18
439 65
663 11
442 82
519 48
382 73
700 39
510 58
535 16
702 49
668 38
600 18
519,88
682 57
642 66
800 3
484 80
778 30
754 21
812 38
645 67
716 73
781 178
641 49
697 13
522 92
678 29
805 20
534 2
609 85
752 40
802 59
760 13
692 80
718 177
756 50
716 6
671 75
737 68
616 96
476 91
575 173
652 180
744 82
612 86
718 172
856 169
774 168
545 95
736 91
678 165
563 99
729 162
640 183


1
2
3
4
CORRIDOR 655
POLE POLE ARRAY
R(A) VS DEPTH PLOTS
DATA PLOTTED FOR SERIES OF ADJACENT VERTICAL 1KM WIDE STRIPS(Dotted Lines)
APPARENT RESISTIVITY R(A) LOG SCALE
100
200
300
400
500
1000
2000
3000
OHM-METRES
NORTH
0
45
WEST
90 EAST
135
180
SOUTH
PLOTTED POINT
ANGLE OF ROTATION INDICATES AZIMUTH OF READING
MEAGER CREEK
1500
1000
500
0
MSL
-500
ELEVATION IN METRES

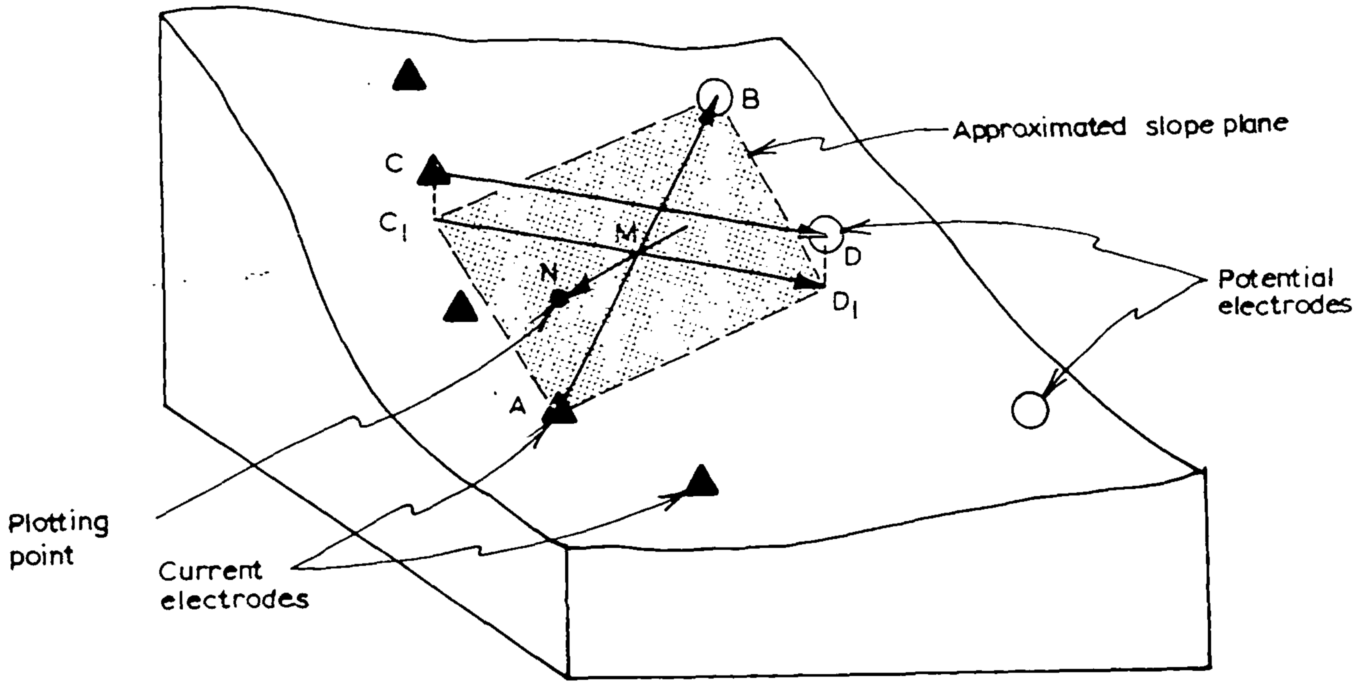
APPENDIX B-3

PLOTTING PROGRAM

The survey grid installed at Meager Creek is irregular in all three dimensions, due to the variable topography. Calculation of a nominal, conventional plotting point for each measurement required a computer program to estimate the local slope characteristics for each reading, and to compute the position of the plot point relative to the slope.

All electrode coordinates (X, Y, Z) and measurement data are stored on magnetic tape. In the example pictured below, current electrode "A" and potential electrode "B" are measurement electrodes. Positions "C" and "D", on the operative lines, are inactive electrode stations providing topographic reference points opposite each of the measurement electrodes. The effective ground slope for the measurement is approximated by the plane defined by vectors $\overrightarrow{AB}$ and $\overrightarrow{CD}$. The plot point is perpendicular to this plane from the midpoint between the measurement electrodes at penetration depth Ze.

The computer uses the stored coordinates of A,B,C and D to perform the following calculation steps:



B-3(ii)

1) compute distance AB
2) compute coordinates of bisectrix of AB (point "M")
3) identify vector $\overrightarrow{CD}$
4) compute the cross product of $\overrightarrow{CD}$ and $\overrightarrow{AB}$ ($\overrightarrow{CD} \times \overrightarrow{AB}$), a vector perpendicular to the estimated effective surface plane.
5) identify directed line segment MN parallel to $\overrightarrow{CD} \times \overrightarrow{AB}$ and length equal to Ze = 0.75(AB) into the earth.
6) compute and record the coordinates of plot point "N" (Xd, Yd, Zd).

APPENDIX B-4

RESISTIVITY SURVEY EQUIPMENT

SURVEY EQUIPMENT

All field potential measurements were taken in analog form on a Hewlett Packard chart recorder model 7155B, using self-potential offset circuitry at the input terminals. The full waveform was recorded.

Transmitter equipment for the pole-pole survey consisted of a Phoenix Geophysics IPT-1 transmitter and 3 kilowatt generator, and a Huntec Mark III LOPO transmitter.

Dipole-dipole survey used the Phoenix transmitter exclusively.

Operating frequency for the two transmitters was 0.25 Hertz, reversing square wave.

DATA PROCESSING EQUIPMENT

All data was entered by keyboard into a Hewlett Packard (HP) 9825A computer, and stored on magnetic tape cassettes in ASC11 form. Processing and graphics peripherals used were:

HP 9885 flexible disk system
HP 9827A four colour X-Y plotter
HP 9871A printing/plotting impact printer

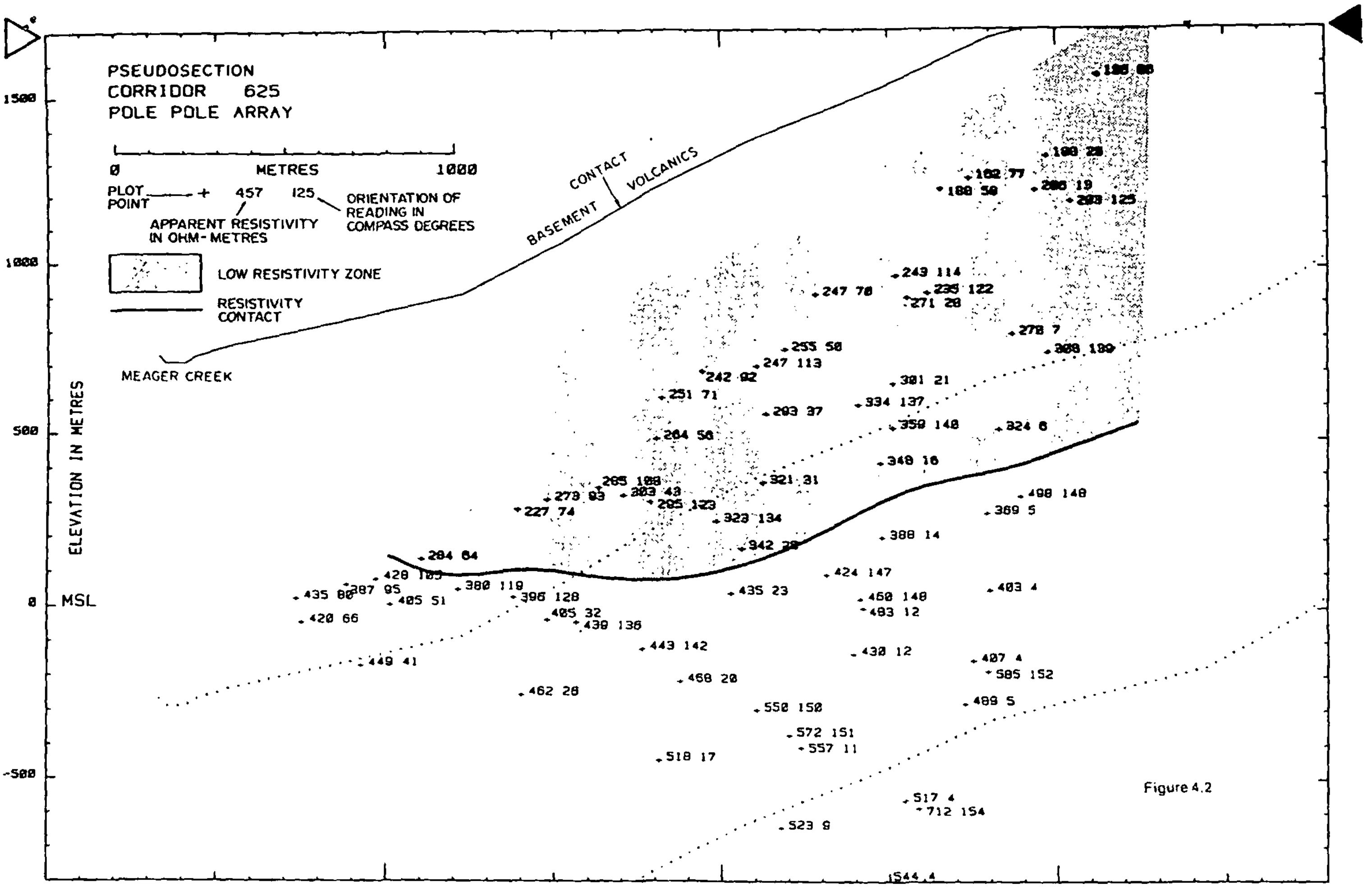


Figure 4.2

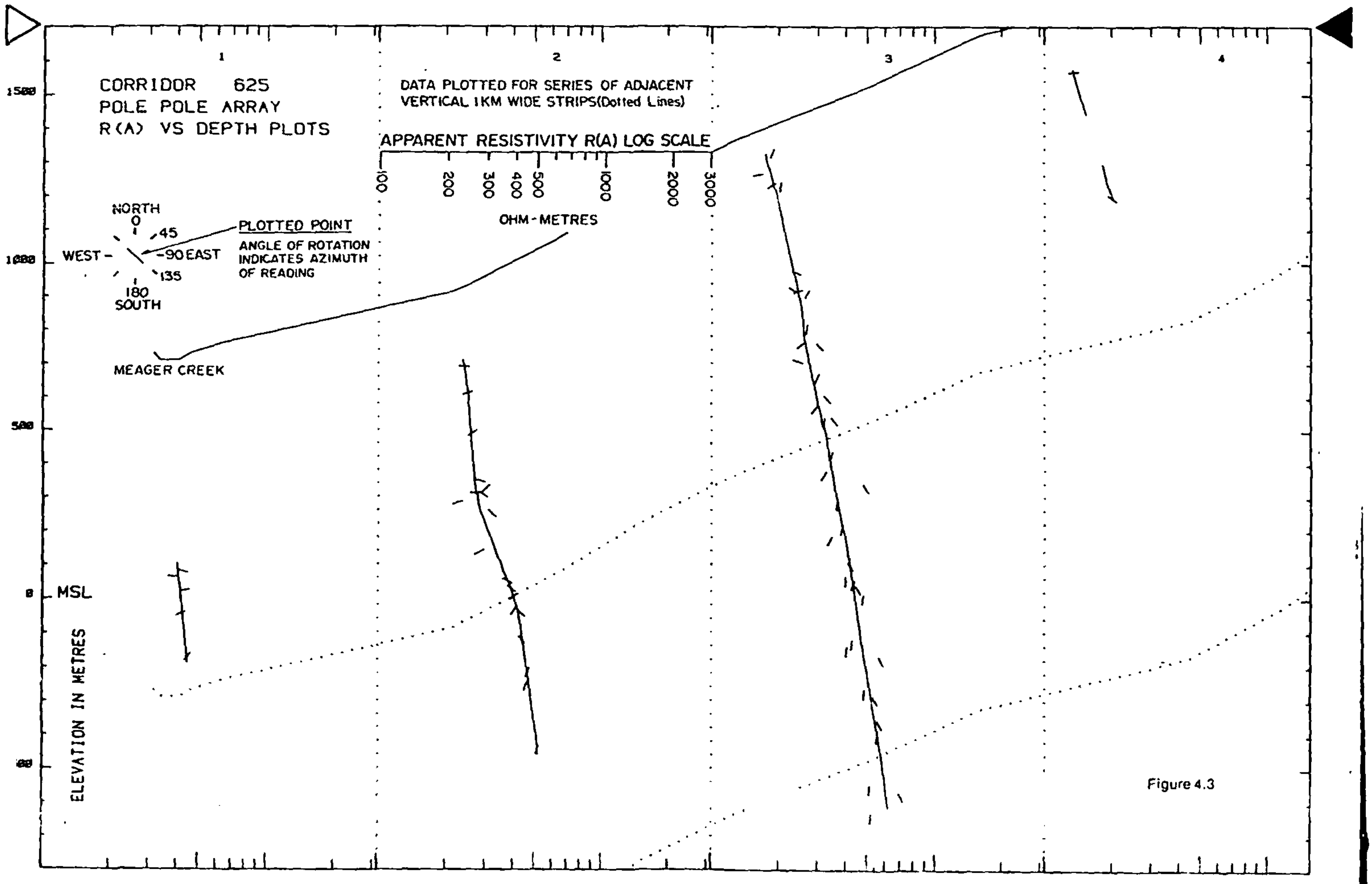


Figure 4.3

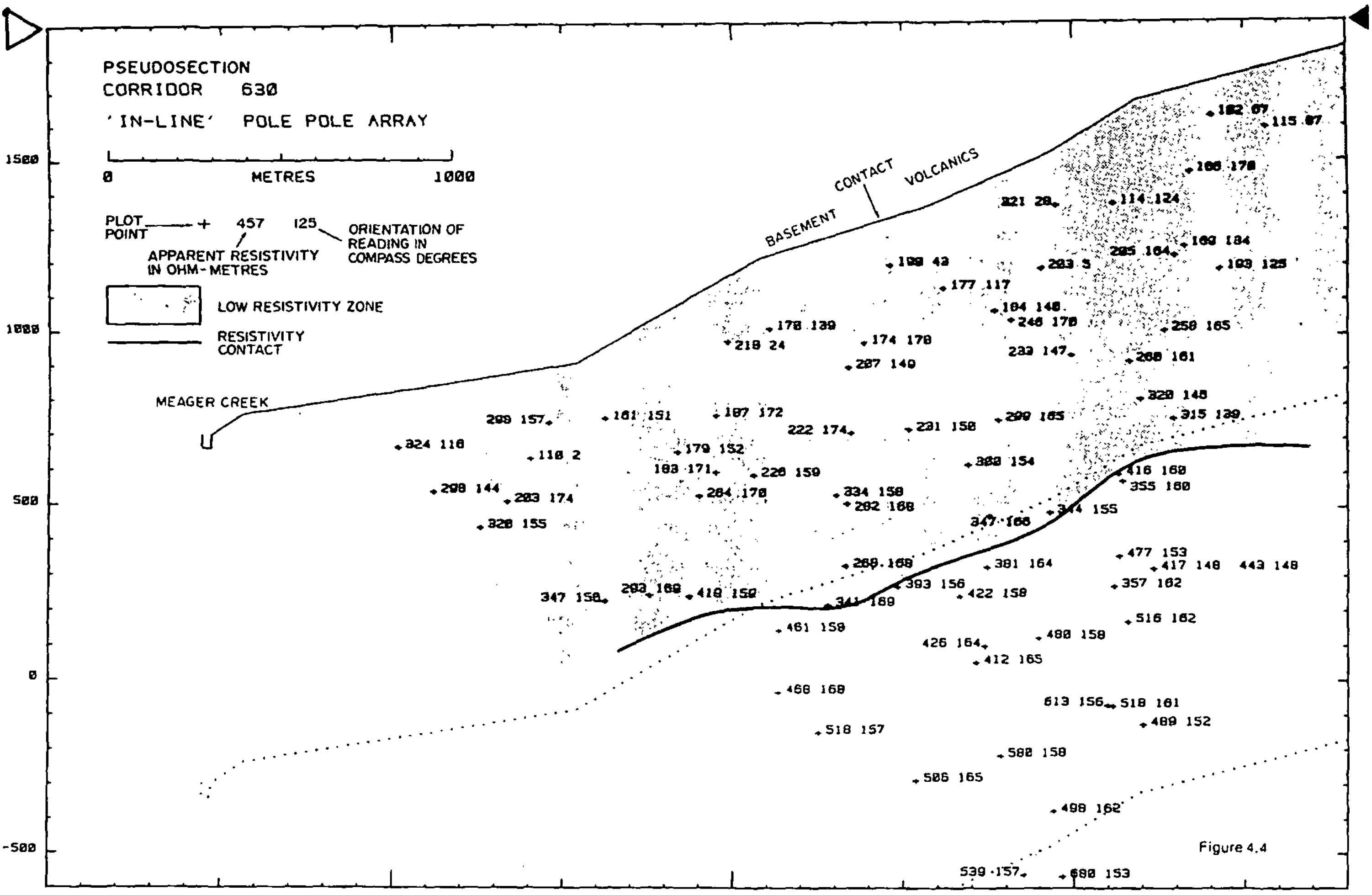


Figure 4.4

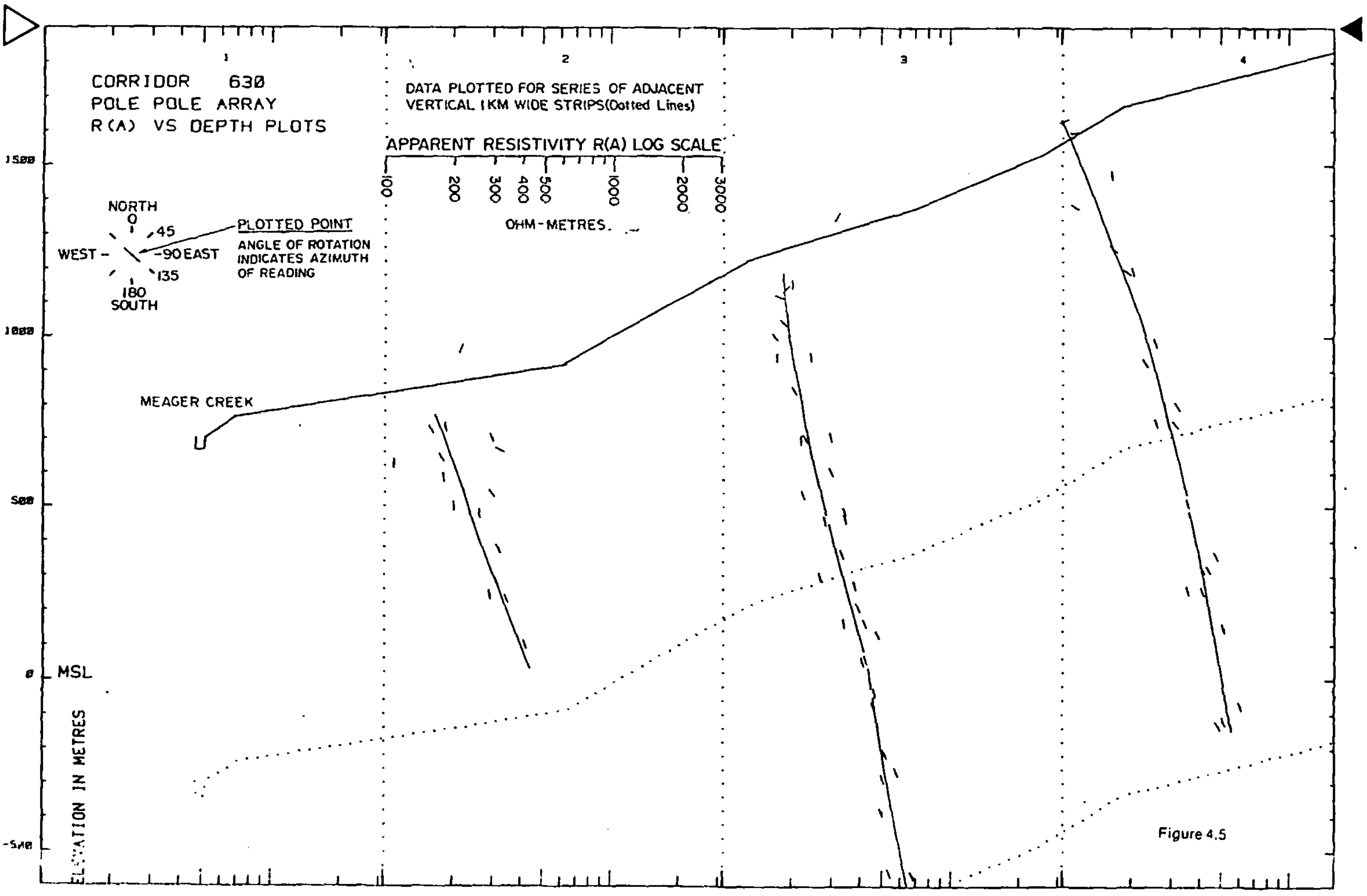


Figure 4.5

MEMORANDUM

To : Dr. Joe Moore
UURI

From : O. Leiva
Commonwealth

Date : 02 February, 1994

Subject: G. Shore: Meager Creek Report on Resistivity Surveys

---

Dear Joe:

Please find enclosed the final report on the resistivity survey results written by Shore and Schlax. I am also including a letter from Greg Shore with some comments in this regard.

We are planning to travel to Salt Lake City wednesday the 9th of March probably arriving at 3:30 PM. I will contact you by phone next week to let you know our final schedule.

Best Regards,

Octavio.

GREG A. SHORE, P.Geo.
Consulting Geophysicist
1184 Forge Walk, Vancouver, BC, Canada V6H 3P9
Telephone 604 732 5778

March 1, 1994

Mr. Octavio Leixa
Commonwealth Construction Company
4599 Tillicum Street
Burnaby, BC V5J 3J9

Dear Mr. Leixa:

Here is an unbound copy of the main volume of the report you were looking for, and a number of plot mylars, principally from the south side of the complex..

Please make a copy of the report, and send the original back to me.

Figure 5.1 is a folded map supplied in a pocket. Rather than copy it, just keep the one that is there (I have others). This map is complete except for the Figure number (5.1) and the addition of references in the comment boxes, for example, "see ____". It is otherwise quite useable in the context of the report.

Make blacklines from the mylars, if you wish, and send the mylars back to me.

I will look for the missing plots, for south side lines numbered D and K and north side lines H, M, N, O, P Q, R and X. In any case, plots of these lines are available from the individual reports that were submitted to Hydro or NSBG after each increment of field work.

As I turn these data over to you, it is appropriate for me to note that while the pseudosection and other observed data are accurately represented as measured, I will not today endorse the interpretations, conclusions or recommendations that may have been reached and reported over a decade ago. As my two papers in last year's GRC Proceedings indicate, the interpretation of these resistivity results (beyond simply focusing interest on a sub-area) is now known to be overwhelmingly error-prone, given the preponderance of effectively single-line data and near-surface variations. To understand the sub-surface, truly three-dimensional data acquisition followed by truly three-dimensional processing is required.

This is not to say that resistivity did not accomplish something. However, in truth, the Meager South target was recognized from the 1974 McPhar traverse line D, and all subsequent work simply confirmed that the source was north of the traverse, not south. The 2D inversions, the regional Schlumberger mapping, the extra traverses - these have provided no useful guidance for drilling the deep source structures. We now know why these methods failed to help - none were 3D in this very 3D environment.

Best of luck at Meager. It's a lovely place with good potential.

Yours truly,

Greg A. Shore, P.Geo.

Report on

Co-ordination and review of resistivity survey results from the Meager Creek Geothermal Area, 1974 to present.

by

Greg A. Shore
and
Michael G. Schlax

for

B. C. Hydro and Power Authority

April 27, 1982

PREMIER GEOPHYSICS INC.
#4 - 11220 VOYAGEUR WAY, RICHMOND, B.C., CANADA V6X 3E1 • (604) 270-6885

TABLE OF CONTENTS

Page

1.0 SUMMARY AND CONCLUSIONS

2.0 INTRODUCTION

3.0 DISCUSSION OF RESISTIVITY APPROACH

TABLE OF CONTENTS, cont'd

LIST OF FIGURES

LIST OF FIGURES, cont'd

APPENDICES

Note: The accompanying volume "Resistivity survey results from the Meager Creek Geothermal Area, 1974 to present" is a part of This report.

1.0 SUMMARY AND CONCLUSIONS

1.1 General Statement

The electrical resistivity survey method has provided important exploration information and guidance in the program of geothermal exploration at Meager Creek since its introduction in 1974. The method is recognized internationally as one of the most useful tools in the location and delineation of geothermal resources.

The steep, highly dissected terrain of the Meager area provides both advantages and disadvantages in the application of resistivity methods. On the one hand, the glacier-scoured valleys provide good low elevation access for direct measurement of basement rock resistivity and of transported signs of nearby geothermal activity in the form of outflow brine accumulations. On the other hand, having provided for the relatively simple mapping of signs of initial interest, the same terrain provides for extreme difficulty in extending exploration into the higher elevations in search of the a major geothermal system.

The resistivity method has been effective in programs around the world. Its continued effectiveness at Meager Creek and throughout B.C. depends on the continuous testing and reevaluation of results as exploration progresses, so that resistivity survey designs of maximum cost-effectiveness can be consistently applied. At present, the principal challenge is to find a cost-effective method for measuring in the difficult terrain typical of the central Meager Mountain complex.

Since there has been no commercial discovery to date at Meager, any analysis of the cost-effectiveness of methods which have provided interpretatble results to date can be made only on a relative, quite academic level. By continued implementation of conventional exploration methods adapted to local conditions, some measure of appropriate cost-effectiveness control is applied vis-a-vis demonstrated effectiveness in other areas of the world. The fine-tuning of what approach is most useful and effective at Meager Creek can only occur following at least one commercial discovery.

1.2 The Basis for Ongoing Analysis

The present report brings the resistivity data from 1974 to 1980 (and part of 1981) together in a standard drafted format with directly comparable measurement units. A summary map showing coverage and the location of anomalous results to date allows independent interpretation of the overall resistivity picture by other workers, and serves as a means of interrelating the individual pseudosection plots of results. Both the catalog of results and the summary map should be updated as new information becomes available, in order that a complete interpretation can be maintained , and an organized recollection of prior work and results can be used to assist planning of new measurements.

1.3 Computer-assisted Interpretation

The state of the art in computer-assisted interpretation of resistivity data is in a state of rapid advance, with a number of techniques available for use. One of the most advanced routines, the interactive forward modelling two-dimensional program "IP2D" of the Earth Sciences Laboratory of the University of Utah Research Institute has been most recently used on south reservoir data. The results of this modelling will be substantially tested with the current rotary drill hole (well MC3). A favourable correlation between the modelled results and the temperature and permeability characteristics in this test well should result in a wider program of evaluation and usage of this routine.

One-dimensional inverse and forward modelling routines are available for assisting in the interpretation of Schlumberger soundings and partial soundings; their usefulness in routinely extending the knowledge gained from such measurements should be further investigated. The program presently in development by Dr. Doug Oldenburg of the University of British Columbia may be of most use in handling the irregular data obtained in the Meager terrain. This program is being tested on Meager data at present and should be available by late 1982.

2.0 INTRODUCTION

2.1 Terms of reference

Premier Geophysics Inc. was retained by B.C. Hydro to review and co-ordinate resistivity survey data obtained in the Meager Creek geothermal area between 1974 and 1980. The work is undertaken under B.C. Hydro purchase order # 142 345, dated January 16, 1981.

2.2 Scope of this report

The principal task undertaken has been the redrafting of some resistivity data to make it compatible with the larger body of accumulated data in etrms of units and scale. The format used has been employed in 1981 survey reporting, and these plots have been included as well. The compiled resistivity data from 1974 to 1980 and part of 1981 accompanies this report as a separate volume.

Summary map figure 5.1 includes 1981 resistivity survey results, and marks the location of KRTA alpine resistivity measurements obtained in 1981. The KRTA data are analysed elsewhere, and are noted here to complete the coverage picture for planning purposes.

The major anomaly systems at Meager are reinterpreted to the extent possible with existing data. Areas of interest are identified on figure 5.1 and commented on informally in order to place observations before a readership of other workers in all specialties.

The principal author (Shore) has been involved at Meager since 1975 in designing and operating resistivity surveys. It is his intention in this report to present the objective data listings for others to analyse, and to present a general chronology of the development of the geophysical approach. Complete objectivity under the circumstances is unlikely to be achieved by one so close to the project; however, it is hoped that in this orgainization of complete documentation of the work to date, the accumulated experience from the area can be utilized in assessing and implementing increasingly effective techniques for ongoing exploration.

3.0 DISCUSSION OF RESISTIVITY APPROACH

3.1 Causes of resistivity anomalies at Meager Creek

Dry or unfractured impermeable rock exhibits very high electrical resistivity characteristics. In the absence of continuous conductors of metallic minerals or graphite, the conductance of electricity through most rocks is dependent upon connected fractures or pore spaces filled with water. Rock resistivity is therefore dependent upon the amount of connected pore space (density of fractures, or inherent permeability of the rock) and upon the resistivity of the water within the pore space.

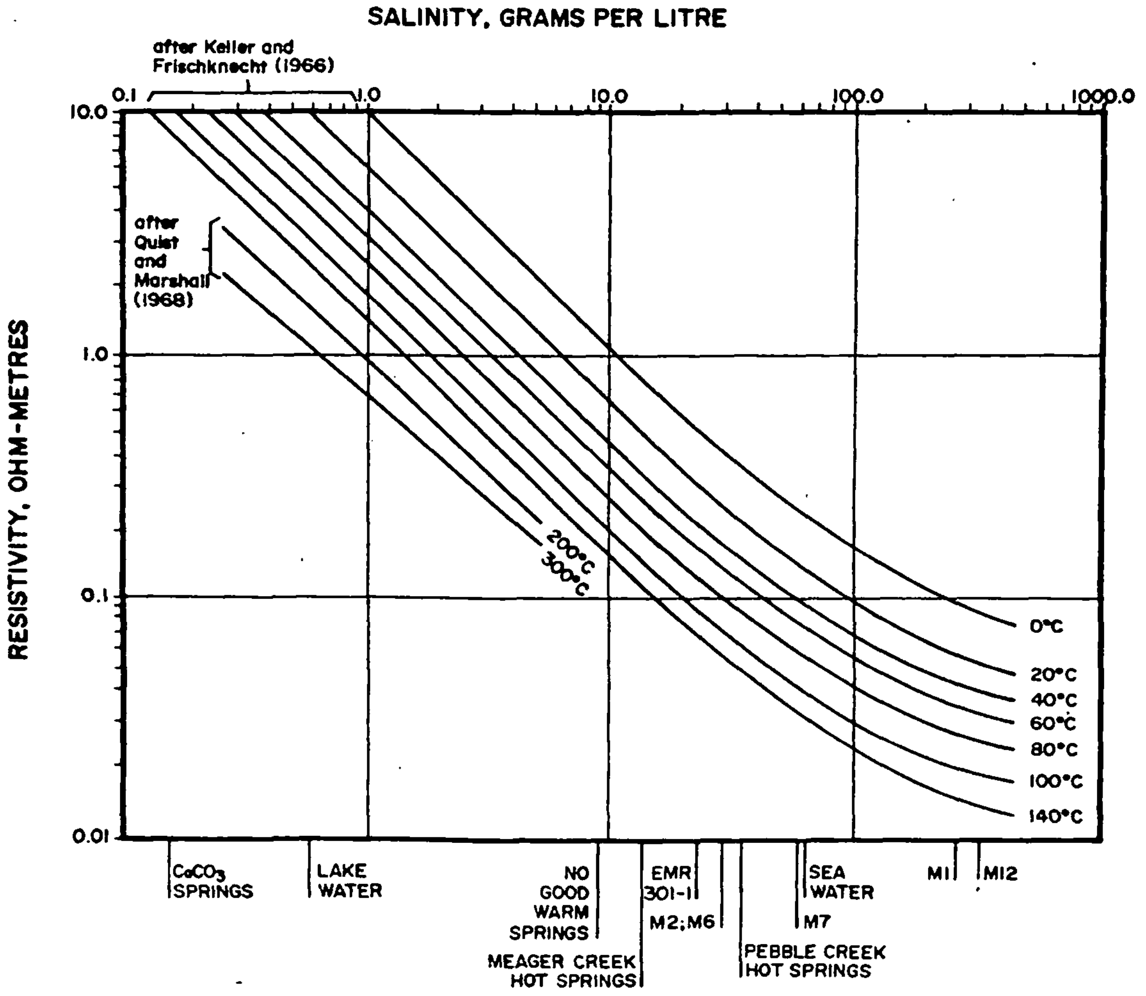


Figure 3.1 Variation of water resistivity with temperature and salinity

Several factors common to geothermal environments contribute to the creation of resistivity anomalies which are relatively simple to detect. The fracturing of otherwise impermeable crystalline rocks by regional stresses, forcible emplacement of volcanics, and by thermal shock provides connected channels for the circulation of water, the chief mechanism for the conducting of electricity in the earth.

Alteration of rocks over a geothermal cell by heat, fluids and gases increases permeability, thereby lowering electrical resistivity. The alteration products, chiefly clays, serve as ion donors to effectively reduce the resistivity of the pore waters further.

Concentration of dissolved salts in a convecting geothermal cell lowers the resistivity of the geothermal waters, increasing the likelihood of detecting and discriminating a low resistivity geothermal signature directly within the cell or in any outflow leakage plume by resistivity survey methods. The effect of salinity on water resistivity is shown in Figure 3.1.

Temperature plays a further role in establishing a readily detectable resistivity signature for geothermal fluids or structures. As shown in Figure 3.1, the greatest temperature effect occurs between 0°C and about 100°C, which is the range of temepratures most likely encountered in shallow (upper kilometre) exploration coverage.

The presence of substantial areas of crystalline basement rocks at surface in B.C. geothermal areas enhances the "visibility" of geothermal anomalies, since these rocks are normally of a high resistivity characteristic (500 to 10,000 ohm-metres) in the absence of geothermal factors. Thus, an anomaly registering 100 ohm-metres in this environment is clearly worthy of investigation, since it may represent .1 ohm-metre geothermal fluids in fractures in 1000 ohm-metre rock.

This advantage of high background:anomaly ratio becomes less reliable in volcanic terranes. Some volcanic units weather rapidly to a highly altered, low resistivity state similar to that which would be expected to result from hydrothermal alteration, in a current, ongoing state or in a long-cooled earlier phase. Geological, petrological and geochemical studies may indicate the nature of the alteration mechanism, but to the initial resistivity survey, it is simply a low resistivity response. The altered tuff unit in the Pylon assemblage is an example; 1978 resistivity measurements of this unit were uniformly low, with a transition to higher resistivities clearly defined at the contact of this unit with basement rocks. The coincidence of the resistivity low with the volcanic unit cannot be dismissed outright; on the other hand, it provides an impediment to interpreting the meaning of any resistivity measurements which sample across the boundaries of these units on a less than systematic scale.

On the north slopes of the complex, rhyodacite flows exhibit resistivities higher than any crystalline basement measurements: up to 14,000 ohm-metres. This does not guarantee reliable interpretation of high ratio anomalies however. Such flow units can (and do) cover prior alluvial deposits, including conductive clay beds, providing an initial appearance of sharply increasing conductivity with depth. Such a situation can occur over an area sufficiently large to constitute a reasonably sized geothermal cell zone; only a measurement program of sufficient vertical resolution can establish whether the conductivity trend continues to depth, as over a geothermal cell, or represents only a conductive basal till. Computer-assisted data interpretation using full Schlumberger soundings (where a one-dimensional layered earth is likely) or using dipole-dipole traverses (where two dimensional complications may be present) can quickly establish which situation may exist.

Anomalous low resistivities will occur directly over a geothermal system at a depth from surface determined by local water table characteristics, local fresh-water hydrology, and by the nature of surface cover, ice, alluvium, or rock structures. Direct detection of a system requires survey methods which are chosen to ensure adequate penetration to sample the system in a way that permits its signature to be discriminated from other area effects.

While a geothermal system may have a surface area of 10 to 30 km^2, outflow plumes may involve more or less area in one or more zones of outflow. Outflow waters will follow structural conduits at depth and will ususally eventually be controlled by local drainage basin hydrology, following surface drainage patterns. Outflow plumes and near-surface reservoir leakages provide a useful indicator of nearby geothermal activity, and may provide the most efficient means of preliminary evaulation of an area of interest.

Systematic measurement of valley bottom resistivities has been used at Meager Creek to identify at an early stage the present south reservoir zone, the north anomaly area of interest, and the South Fork anomaly. The valley alluvium appears to act as a concentrator of brine volume, so that a small outflow volume will accumulate in the overburden, presenting a large resistivity anomaly to the resistivity reconnaissance survey.

3.2 Resistivity survey methods applied at Meager Creek

The objective of resistivity survey is to map the apparent resistivity of the earth in an area of interest, to assist in the generation of geological models for testing. In the selection of the specific type of electrode layout, there is a large and well-established body of experience, both in the field and in theoretical and in test-modelling programs, on which to base the decision. Exploration requirements (how deep to the target, what is the target characteristic in resistivity, dimension, isotropy, etc.) will dictate a limited range of array types and sizes; local terrain and geologic factors will further limit the choice of method.

Two factors influence the decision on array type in the final analysis: having narrowed the range to several methods which will sample as required, the final factors are often 1) the array's ability to provide unambiguous data under local conditions, or 2) the array's ability to obtain support data which will allow less ambiguous interpretation of probably ambiguous data.

The obvious choice, if it can be established to exist, is the array which provides unambiguous data in the first place, provided the cost-effectiveness is comparable. The selection of array approach is never "final"; effective use of the resistivity tool requires continuous reassessment of array performance and the implementation of whatever modifications are required to obtain the specific information needed. Thus, an area of interest may be identified by a certain reconnaissance array valued for its low cost and rapid coverage, but of limited use in delineating the observed anomaly. A second array more suited to mapping reservoir boundaries may be employed, followed by one which is useful in generating data for modelling of deep structure or perhaps responsive to the anisotropic signature of aligned fissures.

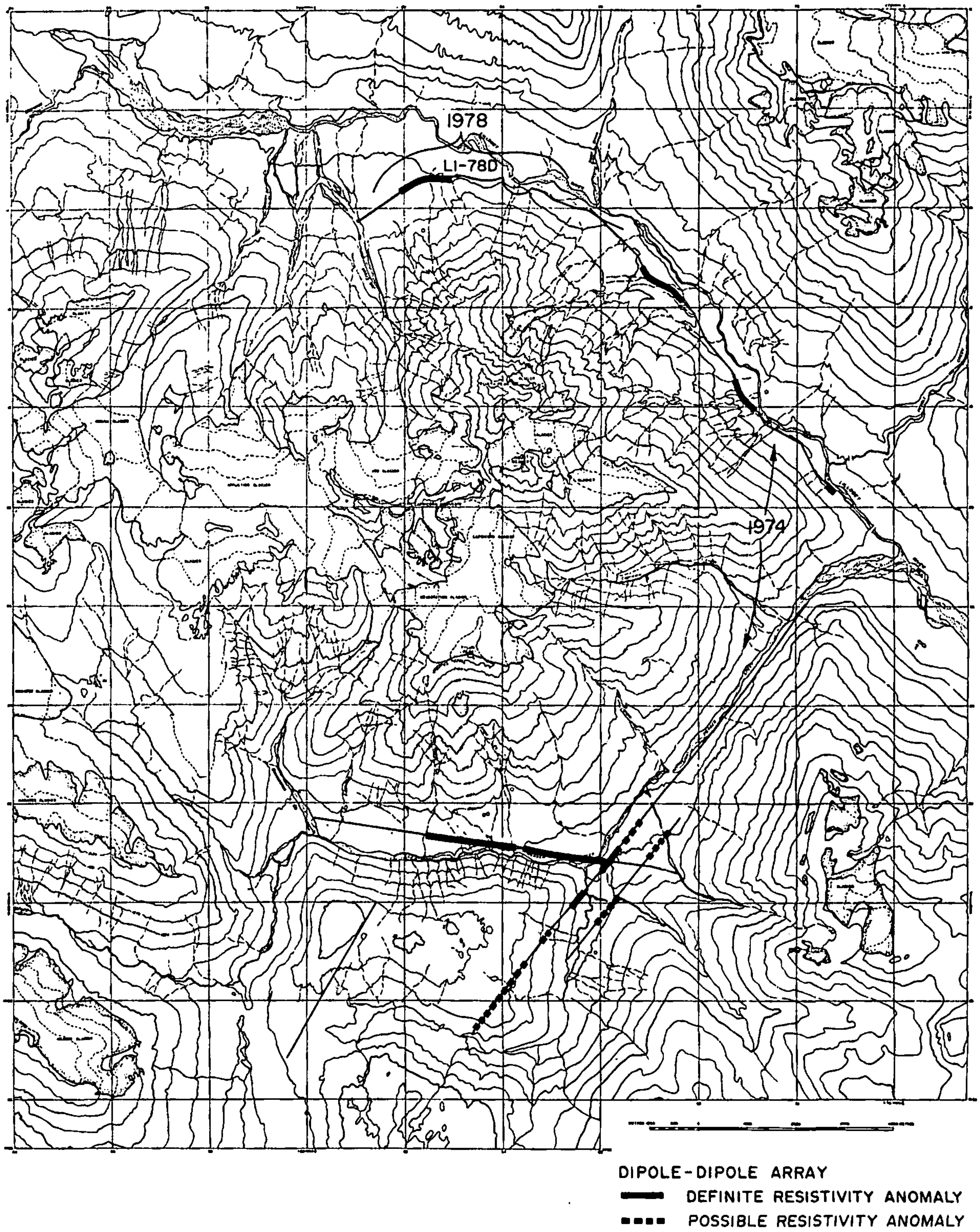
3.2.1 Reconnaissance resistivity

Following identification of the Meager Mountain volcanic complex in 1973 as a prime geothermal prospect, a reconnaissance resistivity survey was designed and operated around the northeast, east and south sides of the complex. The array was a dipole-dipole array, (dimensions a=1000 feet, n=1 to 4) as used in a large number of geothermal exploration programs around the world.

The results of this initial survey, and of an extension to this survey undertaken in a few days late in 1978 (Line L) are shown in Figure 3.2. The 1974 data identified the present south reservoir zone, identified the conductive signature of the lower South Fork anomaly, and identified several still untested anomalies in the Lillooet River valley. The 1978 extension of this coverage identified the north anomaly area of interest (the 1978 test well L1-78D remains the highest temperature well on the north side to date).

All three areas of current exploration interest were thus identified in the initial reconnaissance valley-bottom surveys. At the south reservoir area, the reconnaissance survey may have directly sampled a portion of a reservoir structure; the drilling of this area has not yet established the conditions at depth in the area. In all three cases, however, all or part of the anomaly has been shown to be measuring some geothermal characteristics which indicate the presence of a geothermal system somewhere in the area.

Such reconnaissance surveys are cost-effective, requiring minimal line preparation in most areas, and no line preparation in valleys served by logging or other roads. An advantage is the broad lateral sweep of measurement afforded by the dipole-dipole array, allowing a single-pass evaluation of most valley bottoms and part of their lower slopes, in search of brine saturation.



RESULTS OF VALLEY-BOTTOM RECONNAISSANCE RESISTIVITY SURVEYS

Figure 3.2

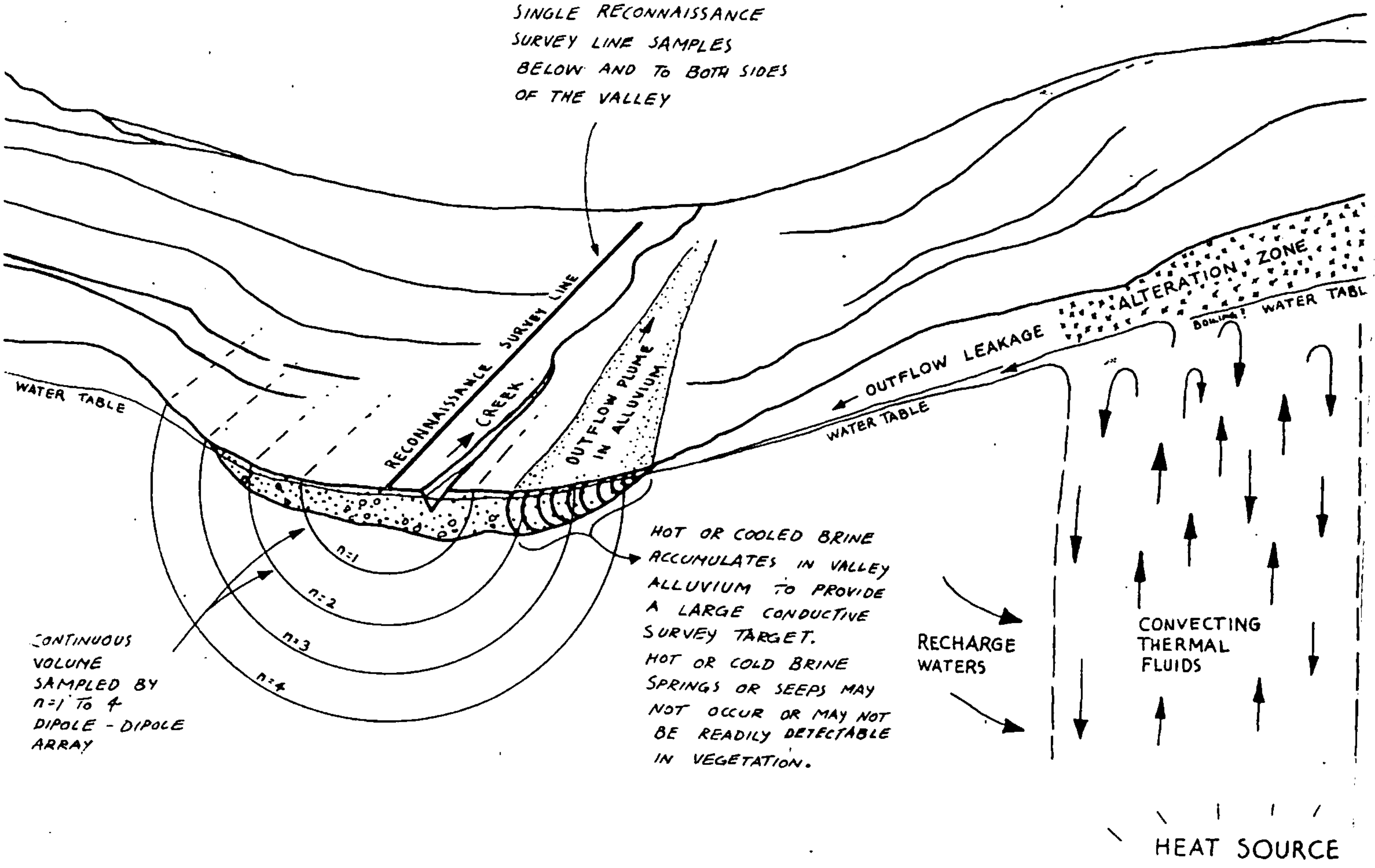


Figure 3.3 LOWER VALLEY RECONNAISSANCE RESISTIVITY LINE DETECTING CONDUCTIVE OUTFLOW LEAKAGE FROM GEOTHERMAL RESERVOIR SOMEWHERE IN THE AREA'S WATERSHED. NO CONVENTIONAL GEOTHERMAL MANIFESTATIONS (SPRINGS, SEEPS) MAY BE VISIBLE.

3.2.2 Follow-up resistivity

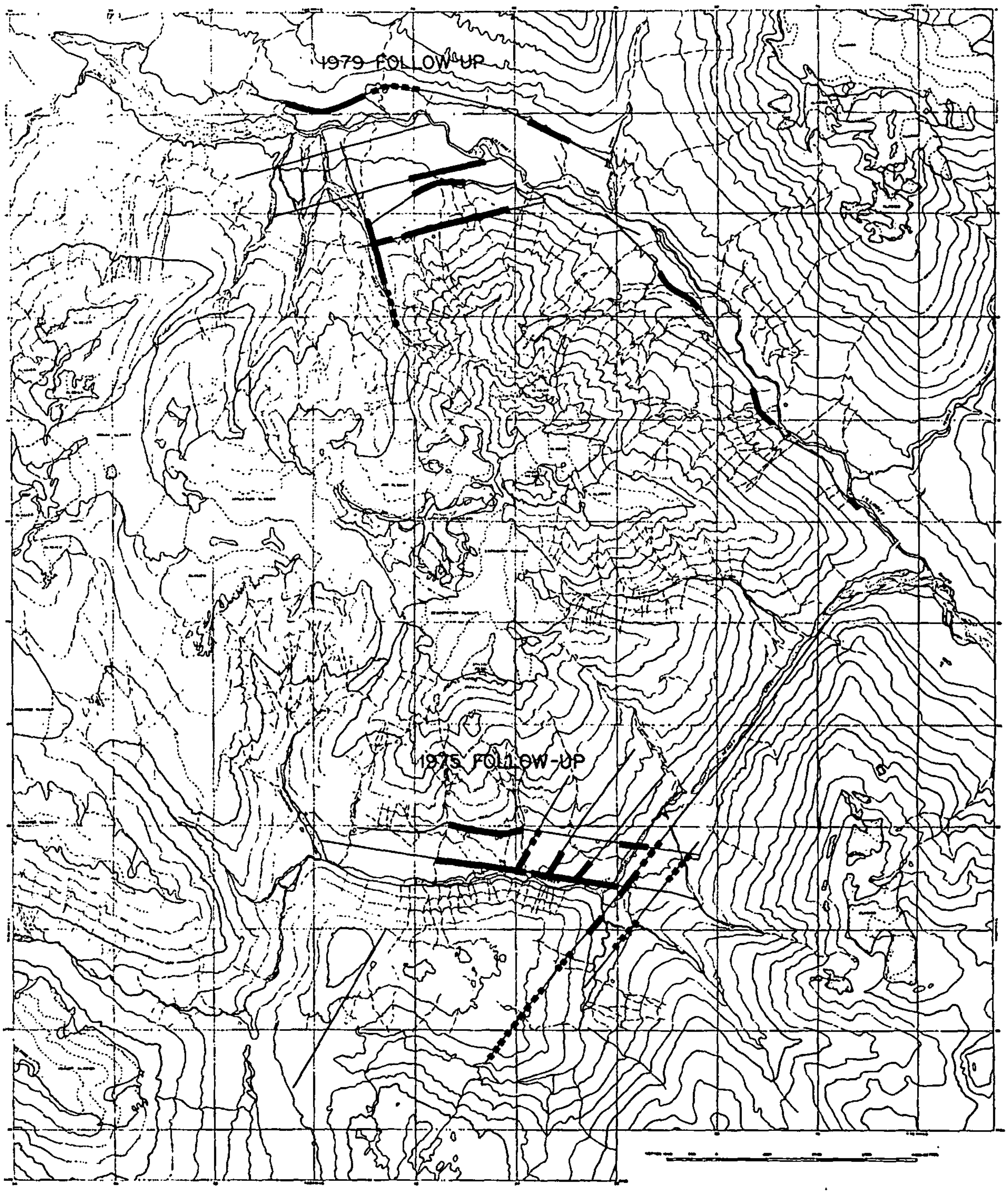
At Meager, the initial discoveries resulting from the single line valley-bottom reconnaissance surveys were detailed with additional resistivity surveys. Figure 3.4 shows the extent of the three anomalous zones after additional dipole-dipole array survey was undertaken.

In the south reservoir area, 1975 follow-up mapped the main area of anomaly within which most of the drilling to date has taken place. This work also isolated the outflow plume along Meager Creek. Drill results matched resistivity results.

At the north anomaly, the areal extent of the anomaly was partially defined, leaving an open boundary uphill to the south, indicating the direction for future exploration. This work took place in 1979.

The South Fork anomaly expression in the 1974 data was not tested until 1980 and 1981, when dipole-dipole survey lines indicated that the South Fork valley was anomalous over much of its length.

Figure 3.5 shows the full results of all resistivity surveys to the end of 1981, except for results from the KRTA alpine area survey which is reported elsewhere. 1978 pole-pole survey in the south reservoir area has extended the anomalous zone high into the volcanics, while isolating the breccia pipe unit as resistive. More dipole-dipole survey on the north side has extended the area of the north anomaly to Job and Affliction Creeks, with a northern cutoff and southward open boundary. Another anomaly is seen on lower Polychrome ridge west of Affliction Creek. In the Lillooet valley, pole-pole survey maps a large lower resistivity unit on the south slopes of the valley, and



DIPOLE-DIPOLE ARRAY

▬ DEFINITE RESISTIVITY ANOMALY

■■■■ POSSIBLE RESISTIVITY ANOMALY

RESULTS OF FIRST LEVEL OF FOLLOW-UP ON RECONNAISSANCE ANOMALIES

Figure 3.4

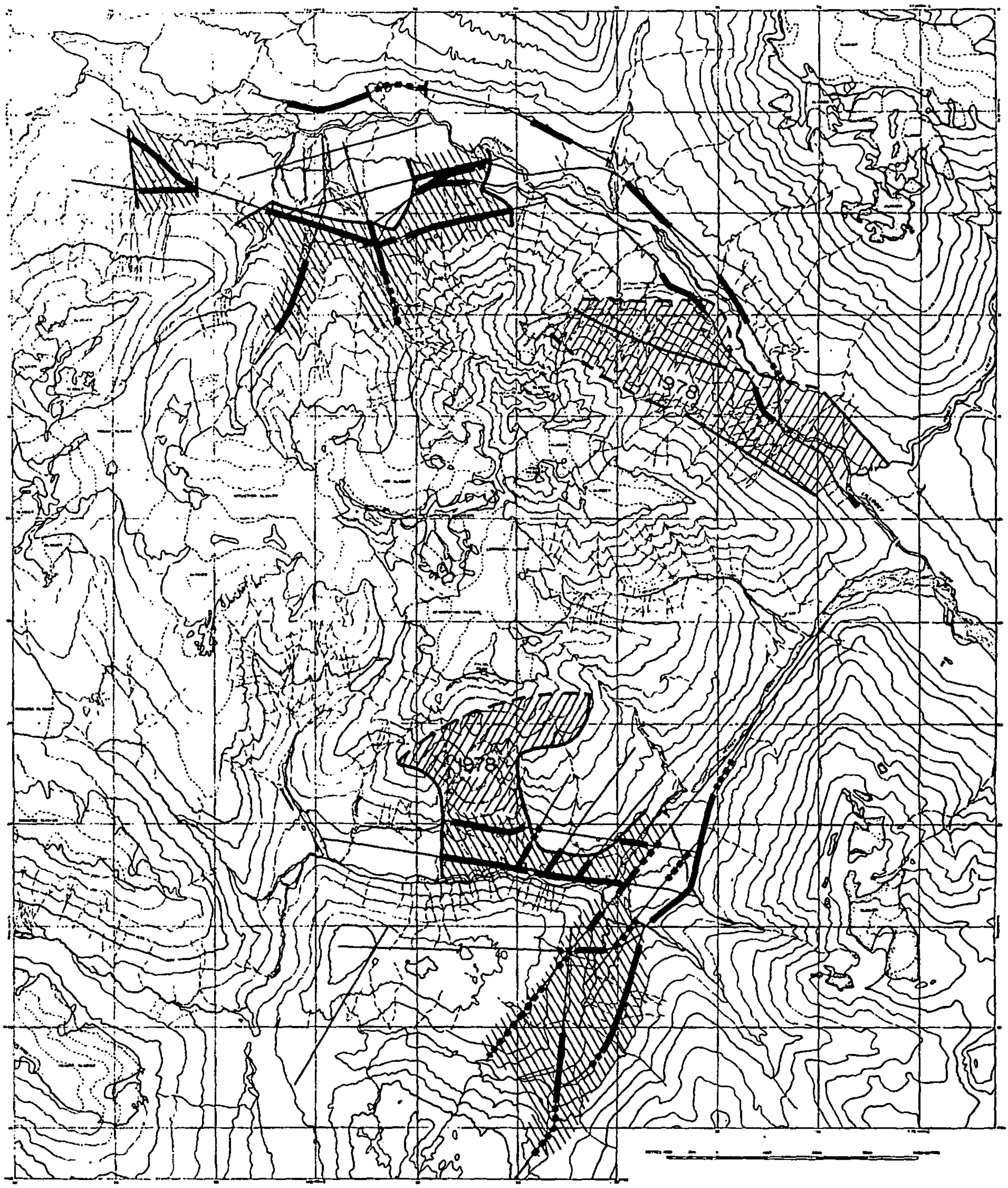
extended dipole-dipole coverage on the north side provides some correlation to 1974 reconnaissance anomalies in the valley.

3.2.3 Follow-up analysis

Immediate manual modelling of the 1978 reconnaissance line L anomaly assisted in the decision to place the test well L1-78D immediately adjacent to the anomaly. The resultant high temperature (103°C) and close correlation of temperature curve inflections, core lithology and interpreted model all suggested that modelling of early resistivity data could be very useful.

As a result, 1979 dipole-dipole data in the north anomaly area was extensively modelled, using a one-dimensional inverse method of limited flexibility and potentially substantial ambiguity owing to the necessity for a 1-D simplifying assumption. The results provided some insights into the layering in the area, and suggested strong conductivity beneath the rhyodacite flows in the area. The results have not yet been fully evaluated by drilling or mapping.

As part of the present report, 1975 data from the south reservoir area were submitted to consultants at the University of Utah Research Institute Earth Sciences Laboratory for modelling with an advanced two-dimensional forward modelling system. The results provide a strong case favouring a deep conductive structure on the west side of the south reservoir anomaly, and a very resistive unit on the east half. This correlates with known drill information at present, as does the model's assertion of a conductive lobe extending west of No Good Creek. These were preliminary models which have not taken into consideration any information except the resistivity data themselves; further modelling has been proposed using other available data to refine the result. The south reservoir anomaly and modelling techniques are discussed subsequently in this report.



DIPOLE-DIPOLE ARRAY

▬ DEFINITE RESISTIVITY ANOMALY

■■■■ POSSIBLE RESISTIVITY ANOMALY

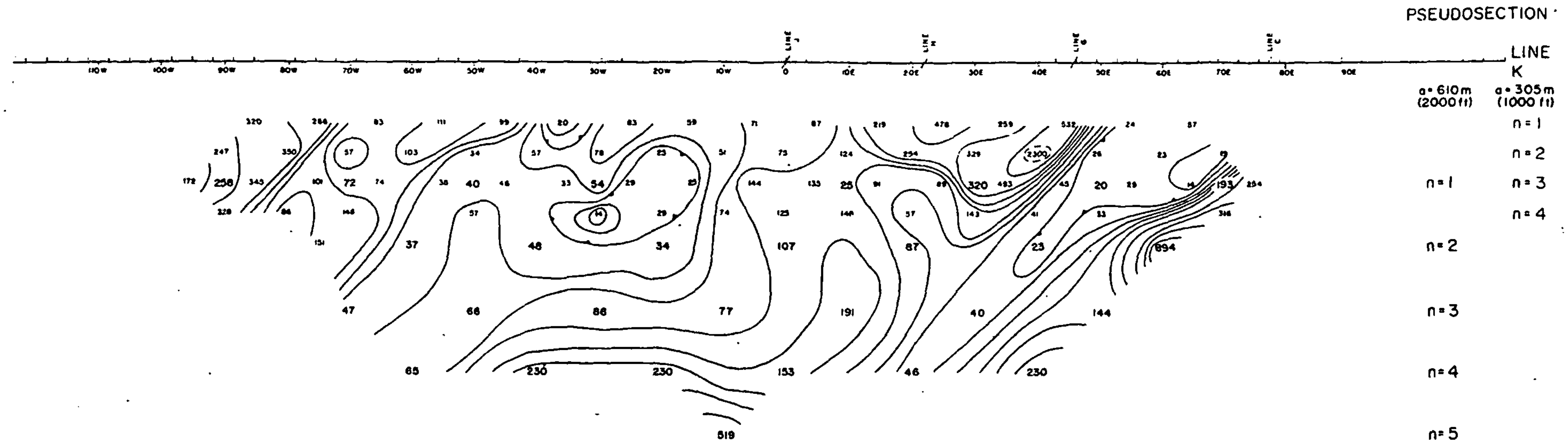
▧ ANOMALOUS AREA

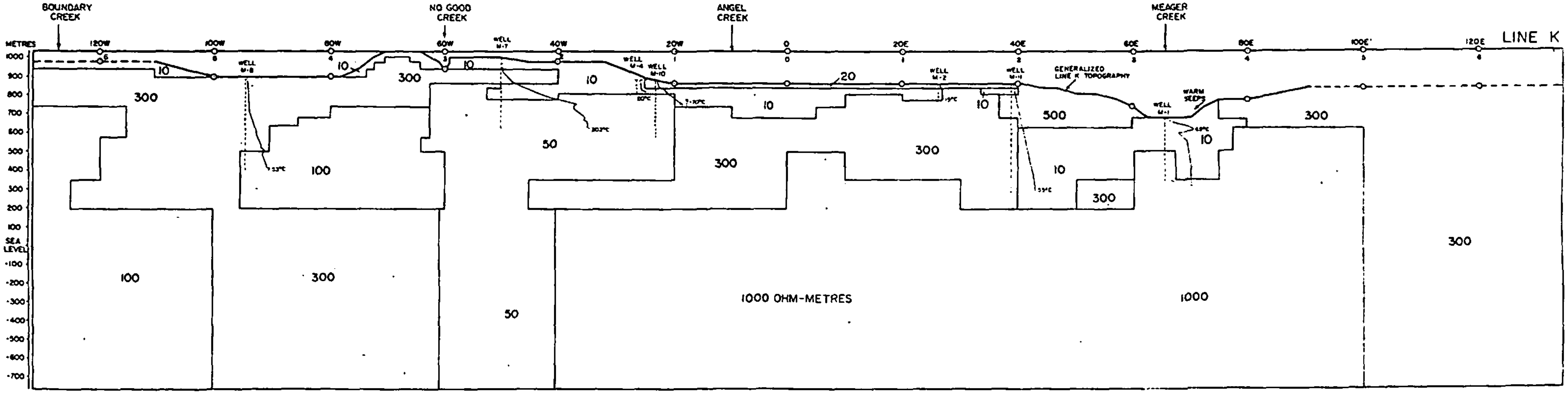
POLE-POLE ARRAY

▨ ANOMALOUS AREA

1978 POLE-POLE RESULTS AND SUBSEQUENT DIPOLE-DIPOLE DETAILING

Figure 3.5

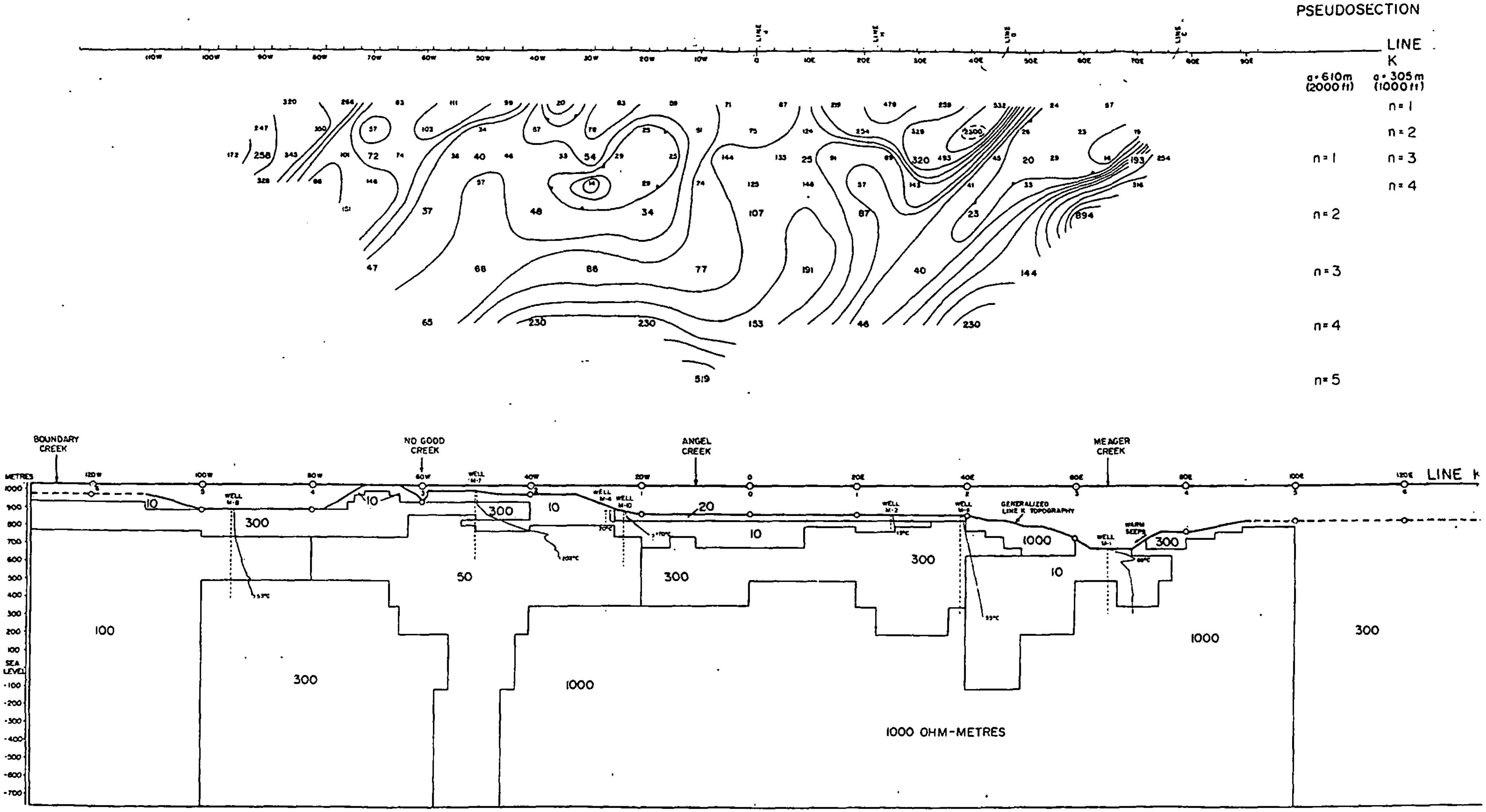




MODEL A One result of "IP-2D" (University of Utah Research Institute) forward two-dimensional modelling program. A=610m data only were used. Test well collar elevations are adjusted to fit Line K topography in order to compare temperature profiles with interpreted resistivities.

Figure 3.6

COMPUTER MODELLING OF RESISTIVITY DATA - LINE K SOUTH RESERVOIR AREA



MODEL B One result of "IP-20" (University of Utah Research Institute) forward two-dimensional modelling program. A = 610 m data only were used. Test well collar elevations are adjusted to fit Line K topography in order to compare temperature profiles with interpreted resistivities.

Figure 3.7

COMPUTER MODELLING OF RESISTIVITY DATA - LINE K SOUTH RESERVOIR AREA

4.0 Data Interpretation

4.1 Procedures

The pseudosections of apparent resistivity obtained with the dipole-dipole survey method were interpreted qualitatively with due regard for the factors entering the discussions of 2.5 and 3.0 above. Zones of low resistivity which are believed to be of significance to delineating the convective hydrothermal system have been marked of Figure 4, which is an overlay for Peter B. Read's 1:20,000 geologic map of Open File 603, Geological Survey of Canada. For Line K, a preliminary quantitative interpretation was available as noted earlier. The zones of anomalously low resistivity have been correlated with geology and topography for purposes of discussion.

4.2 South Reservoir

The resistivity low in the vicinity of the so-called South Reservoir is defined by resistivity data on lines D, K, and T, as follows:

4.2.1 Line D

There is an abrupt increase in resistivity west of 110W on Line D, approximately at the location of No Good Creek. East of 110W on this line, the resistivity are low to 10E, but from about 90W to 10E they are underlain by much higher resistivities. No quantitative interpretation of the data for this line has yet been made. The low resistivities at shallow depths from about 90W eastward may be attributed either to conductive glacial clay or to brine saturated valley fill. The latter explanation is preferred because of the abrupt increase in resistivity west of 110W, ie: No Good Creek, and because warm and hot springs occur to the east but not to the west of No Good Creek. No attempt has been made to define the eastern boundary of the deep conductive zone, believed to exist between 110W and 90W, because no quantitative interpretation of this data has been made.

4.2.2. Line K

The resistivity pseudosection for Line K is similar to that for Line D, with the exception of a pronounced resistivity low associated with Meager Creek at 65E. While this latter feature may result from local hydrothermal convection, it is more likely results from brine filled alluvium wherein the brine originated upstream, ie: near No Good Creek. More resistivity work is required to verify this preferred interpretation.

A preliminary quantitative interpretation of Line K has indicated a deep conductive zone, ie: well below valley fill, of 50 ohm metre material occurring between 40W and 60W. The western boundary of this zone coincides approximately with No Good Creek.

4.2.3. Line T

A very weak and surficial low resistivity anomaly occurs on Line T as an extension of the anomaly found on lines D and K. The significance of the anomaly is unknown.

4.2.4. Recommendations

1) The effects of overburden seem to be adequately accounted for in modelling the data from Line K, but there is a need to remodel the data using for control the following:

a) the latest geologic plan map,
b) the available geological sections for AA', BB', CC', and DD',
c) the available seismic data depicting the bedrock profile beneath Meager Creek,
d) the inversely interpreted Schlumberger soundings when extended to AB/2 of 2 km.,
e) sensitivity test involving variation of width, depth, extent, and resistivity of the 50 ohm metre block of low resistivity material in the bedrock.

2) Line D should be modelled with the same attention to detail recommended for Line K above.

3) If a deep production test well is to be drilled at an early date, then its most logical location would

be within 200m east to west of gradient hole M7, with the western part of this zone preferred. However, the resistivity interpretation noted above should be completed and two shallow (600m) gradient holes should be drilled, 200m on either side of gradient hole M7, prior to spudding the production test well. Local vertical and lateral temperature gradients are expected to be markedly influenced by convecting fractures so that much attention is required to optimize the location of the deep production test well.

4.3 M12 Area

4.3.1. Lines T and S

A resistivity low exists between 10E and 13E on Line T. This may be due to hydrothermal alteration but seems more likely to be due to brine saturated valley sediments since gradient hole M12 intersected a warm brine. Note, however, the resistivity low east of M12 on Line S. There is some question about the validity of some of the data on Line T, due to the loss of shallow resistivity measurements between 9E and 18E.

4.3.2. Recommendations

Much more resistivity data is required in order to ascertain the significance of the M12 Area and its relationship to the South Reservoir and the North Anomaly. Accordingly, the following are recommended:

1) Conduct a dipole-dipole traverse up the South fork of Meager Creek in order to determine where the assumed brine satruation of the alluvium ceases. The southermost upwelling of brine may be located by this technique.

2) Conduct a dipole-dipole traverse SSW through M12 between Line S and the South fork of Meager Creek. A possible east-west resistivity low through M12 may be delineated by the data for this traverse and for Line S.

3) Repeat Line T from 3E to Barr Creek in order to fill in the missing data points.

4) Map the area south from M12 in search for a volcanic vent which may be a source of heat.

4.4 The Hot Springs Creek Area

4.4.1. Observations

Some unusual resistivity readings occurred beneath 112S on Line S and a resistivity low occurred beneath 125S on Line S. Both could be attributed to some form of current channeling along orthogonally connected (fracture-controlled?) streambeds.

4.4.2. Recommendations

It is recommended that Line S be repeated with 100m dipoles from 114W to 133W so as to restrict the survey to one streambed.

4.5 South Area, General

4.5.1. Observations

There is considerable uncertainty about the resistivity response of streambeds downstream from Meager Creek Hot Spring. Hence a need arises to conduct Schlumberger soundings at selected locations along Meager Creek.

4.5.2. Recommendations

Conduct five or six carefully selected Schlumberger soundings along Meager Creek (using AB/2 of 2km if possible) in order to assess the importance of variation of brine saturation of valley sediments to the interpretation of Meager Creek. Some dipole-dipole data has gone uninterpreted because of our uncertainty over how to proceed (ie: we are lacking data vital to interpretation).

4.6 North Anomaly

4.6.1. Observations

A continuous zone of low resistivity (of order 150 to 200 ohm metres) has been indicated on Lines L, N, O, Q, and W. This zone is permitted by the data on Line P but the latter line is insufficiently long to provide definitive data. While not of as low resistivity as the South Reservoir anomaly, it is still worthy of attention.

4.6.2. Recommendations

1) Line P should be completed with dipole-dipole resistivity data from its current eastern end to about 83W on Line Q.

2) The west halves of Lines L and Q should be modelled quantitatively.

5.0 Resistivity and the Conceptual Models

1) The resistivity data at the South Reservoir and at the North Anomaly both support the conceptual model presented in 2.3 above.

2) The resistivity data neither confirm nor deny the dipping sheet conceptual model presented in 2.4 above.

3) The resistivity data at the M12 Area and the Hot Spring Creek Area are not easily related to either conceptual model because of a lack of data.

4) Were it appropriate to do so, given all of the constraints of the exploration program at Meager Creek, both the recommended resistivity surveys and interpretation and the trace element geochemistry study proposed elsewhere would be completed prior to spudding the first deep production test well. This recommendation is based on the observation that any conceptual models so far presented to the writer, including those described herein, are tenuous at best.

5) The dipole-dipole resistivity method certainly seems capable of contributing to development of a reasonably firm conceptual model of the Meager Mountain convective hydrothermal system.

Respectfully submitted

Vancouver, B.C. Stanley H. Ward
May 9, 1981

(original signed by author)

References

Lewis, T.J., and Souther, J.G., 1978, Meager Mountain, B.C.- A Possible Geothermal Energy Resource, EMR, Earth Physics Branch, Geothermal Series Number 9, Ottawa, Canada, 17p.

Roddick, J.A., and Woodsworth, G.J., 1975, Coast Mountains Project; Pemberton (92J West Half) Map-Area, British Columbia, Geol. Surv. Can., Paper 75-1, Part A, Ottawa, Canada, p.37-40.

Read, P.E., 1978. Meager Creek Geothermal System, British Columbia, Part II. Geology, Trans., Geothermal Resources Council, p.494-497.

Hammerstrom, L.T., and Brown, T.H., 1977, The Geochemistry of Thermal waters from the Mount Meager Hot Springs Area, B.C.: Geol. Surv. of Canada, Open File Report, 34p.

Nevin, A.E., Crandall, J.T., Souther, J.G., and Stauder, J., 1978, Meager Creek Geothermal System, British Columbia, Part I: Exploration and Research Program, Trans., Geothermal Resources Council, p. 491-493.

Dr. Stanley Ward was retained by Premier Geophysics in 1981 to review the dipole-dipole data from the Meager area and to comment on its effectiveness and offer interpretive comments. His report is appended. Dr. Ward was not asked to comment on the cost-effectiveness of the surveys, or on the possible merits of other survey approaches.

3.3 Summary of resistivity survey approach at Meager Creek

A pattern of step-by-step exploration has been established in which an area of interest is first tested for obvious signs of nearby geothermal activity by sweeping the lower valleys with a dipole-dipole reconnaissance array. A second stage followup survey establishes the shape or partial shape of the anomaly, allowing other tests such as drilling to be sited. Computer-assisted evaluation of some of the data can be applied at any point to guide planning. The result of this two-step routine is the confirmation of geothermal indicators, and if not a direct discovery, a firm indication of the direction from which the measured geothermal manifestation must have originated.

The exploration to this point has been cost-effective by conventional exploration standards. In an attempt to obtain information at higher elevations where no known methods have yet functioned at Meager, very high costs were incurred to develop and test a new method. The pole-pole method was not demonstrated to be capable of routine cost-effectiveness, but in the course of testing, valuable information was obtained about the upper extension of the south reservoir area, and an as-yet unevaluated anomaly was mapped in the Lillooet Valley.

The search continues for methods to obtain cost-effective data from terrain such as that in the central Meager complex. In the interim, valley-bottom dipole-dipole reconnaissance has been shown to be a cost-effective method of determining just where these alpine efforts need to be concentrated.

4.0 CHRONOLOGICAL SUMMARIES OF RESISTIVITY SURVEYS

In this section the background and objectives of successive surveys are outlined, and the equipment used and coverage obtained is reported. A brief outline of results is provided.

4.1 1974 Dipole-dipole Resistivity Survey

Reconnaissance survey lines in Lillooet and Meager valleys.

4.1.1 Background

By the summer of 1974, the Meager Mountain volcanic complex had been selected for intensive exploration for geothermal resources. 1974 was the first year in which a co-ordinated program of geology, geophysics, geochemistry and diamond drill investigations was employed.

Electrical resistivity survey was by 1974 an established leading tool in the world-wide exploration for geothermal reservoirs. A reconnaissance dipole-dipole survey approach was planned and managed by Nevin Sadlier-Brown Goodbrand Ltd. The geophysical contractor was McPhar Geophysics Ltd. of Vancouver.

4.1.2 Survey Objectives

The reconnaissance resistivity survey was intended to provide an initial evaluation of the electrical characteristics of the overburden and bedrock in a line encircling much of the volcanic complex. The principal geothermal manifestations at that time were the Meager Creek Hot Springs and the Pebble Creek Hot Springs. The survey lines were designed to approach and pass over the area near both of these hot springs. It was expected that this initial reconnaissance survey would identify specific areas of anomalous low resistivity in which to conduct more detailed exploration.

4.1.3 Method and Coverage

Logistics: In 1974 the logging road along the southwest bank of the Lillooet River terminated about six miles southeast of the confluence of Meager Creek and the Lillooet River. Access to the prospect was accomplished by helicopter operating from the end of the road. A tent camp was established, and for most of the survey the geophysical crew was set out by helicopter in the morning and picked up in the evening to return to camp. A crew of linecutters cut and chained the survey lines, and cleared helicopter landing pads at intervals along the survey line.

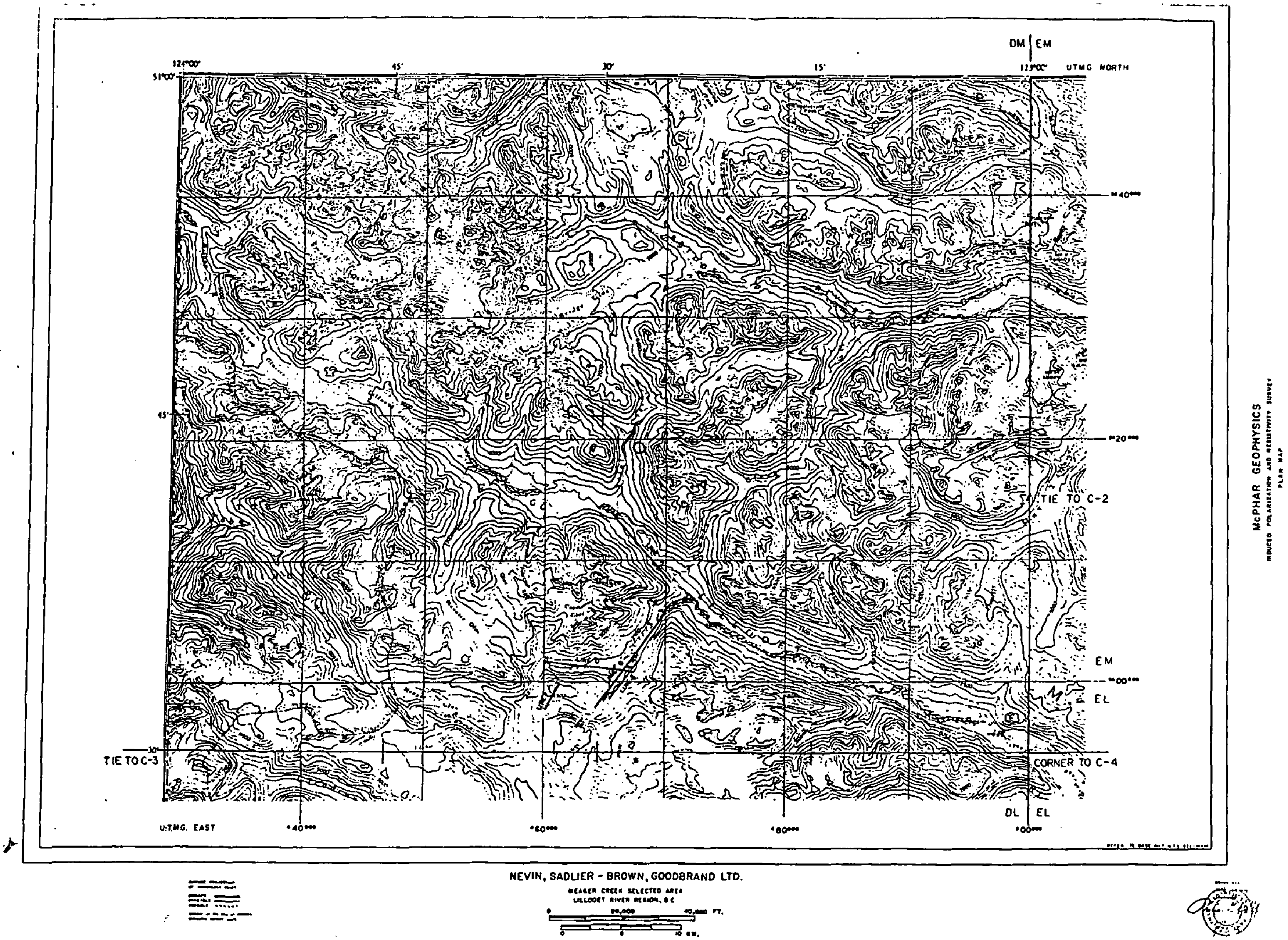
Equipment: Transmitter: McPhar 1 kw reversing square wave at 0.13 Hz.
Receiver: McPhar frequency domain induced polarization and resistivity receiver.
Communications: citizens band walkie-talkies.

Arrays: Dipole-dipole, a=1,000 feet, n=1 to 4.
Dipole-dipole, a=500 feet, n=1 to 4 (detail line).

Coverage: The survey lines were located on the lower slopes or valley floor on three sides of the Meager Mountain volcanic complex. A long line (A) extended along the southwest side of the Lillooet River from Salal Creek to approximately Pebble Creek. Survey line C was placed along the southeast side of Meager Creek from Capricorn Creek, through the Meager Creek Hot Springs area, and up into the South Fork area of Meager Creek. Line D followed the westerly reach of Meager Creek on the south side of the complex. Two other short lines (E,F) were also placed in the south complex. The location of the survey lines is shown in Figure 4.1

4.1.4 Results

Approximately 360 resistivity measurements were obtained on five survey lines extending over a distance of approximately 37 line km (23 line miles). Anomalies were identified on four of the five survey lines. Six definite anomalies and numerous probable and possible anomalies were identified.

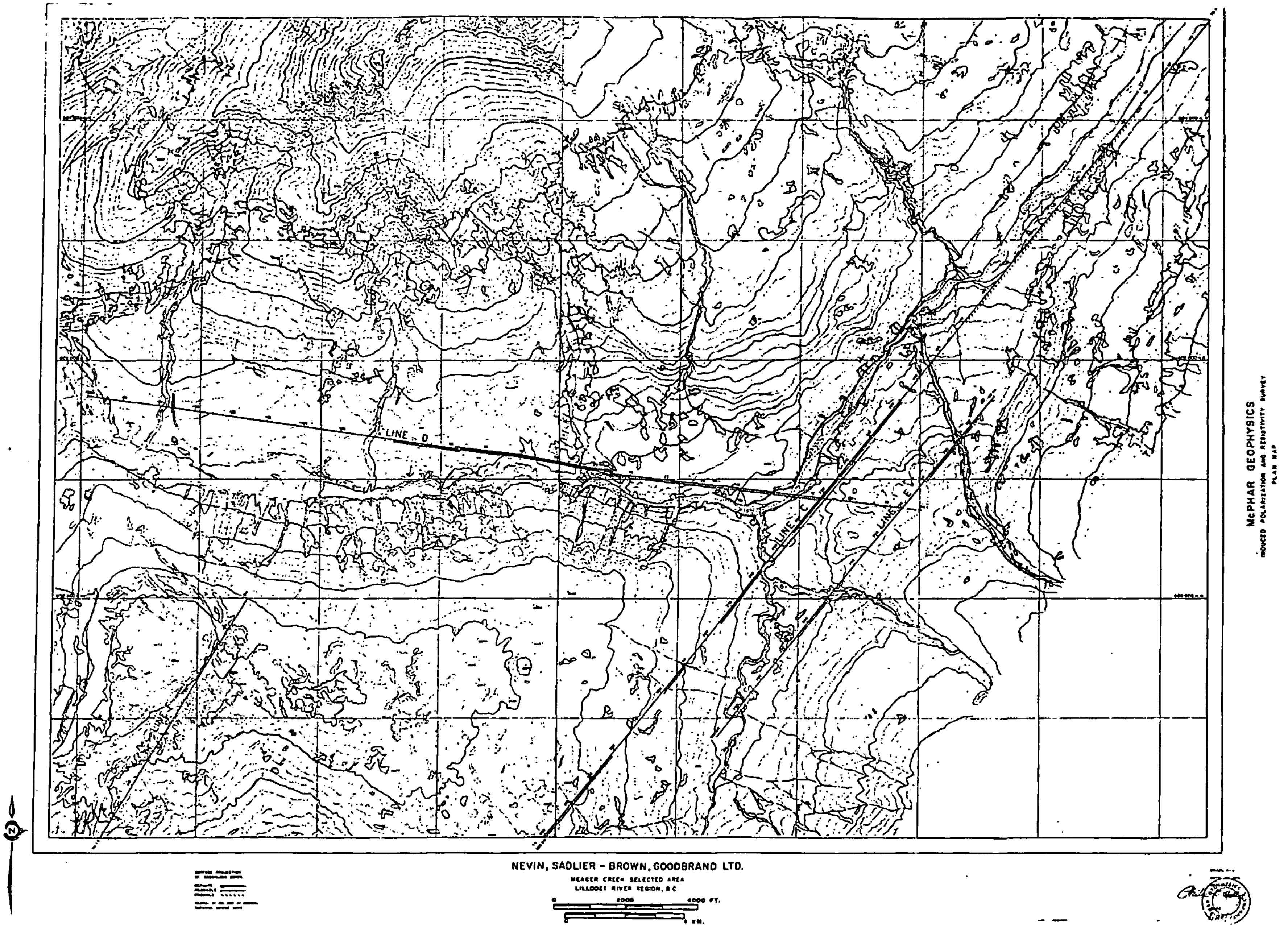


Location of 1974 dipole-dipole reconnaissance resistivity lines.

The lines circle the south, east and northeast flanks of the volcanic complex.

Figure 4.1

from report # GP1A-1974-1



1974 summary map showing dipole-dipole resistivity anomalies.

The line D anomaly is the South Reservoir "discovery anomaly".

The line C anomalies relate to salinity in Meager Creek sediments (upper anomaly) and in South Fork Creek sediments (lower anomaly).

Both areas of current exploration interest on the south side were thus indicated in the 1974 initial resistivity reconnaissance.

Figure 4.2

from report # GP1A-1974-1

4.2 1975 Dipole-dipole Resistivity Survey

Dipole-dipole detailed survey on south side of the Meager Complex.

4.2.1 Background

The 1974 reconnaissance dipole-dipole survey (4.1) had provided several resistivity anomalies surrounding the volcanic complex. Based on the results of the integrated exploration program initiated in 1974, Nevin Sadlier-Brown Goodbrand Ltd. selected the south flank of the Meager mountain volcanic complex as the site of the majority of 1975 exploration activity.

Additional dipole-dipole survey lines were planned for the south flank of the complex, to more fully define the location and extent of the resistivity anomalies measured on 1974 reconnaissance lines C, D and E. Greg Shore of Deep Grid Analysis Ltd. was the geophysical consultant and contractor for this work.

4.2.2 Survey Objectives

The 1975 dipole-dipole survey was intended to define the lateral extent and depth characteristic of the anomaly on 1974 line D, and to further define the nature of the anomalous expressions on 1974 lines C and E.

4.2.3 Method and Coverage

Logistics: In the summer of 1975, access to the exploration area continued to be accomplished by helicopter operating from the end of the logging road. A tent camp was established beside Angel Creek on the south flank of the complex. A crew of linecutters based in the camp cut and chained the survey lines. The entire 1975 survey program was conducted from this camp, without the day to day assistance of a helicopter.

Equipment: The measured data showed that the 1974 survey equipment was operating at its maximum power and resolution in much of the 1974 survey. With the requirement for larger arrays and greater "n" separations for the 1975 detailed survey program, a different set of instrumentation was used.

Transmitter: DGA, 40 kw, reversing square wave at 0.016 Hz.
Receiver: Hewlett-Packard 970A millivoltmeter.
Communications: Motorola walkie-talkies and base station, assigned frequency in business band.

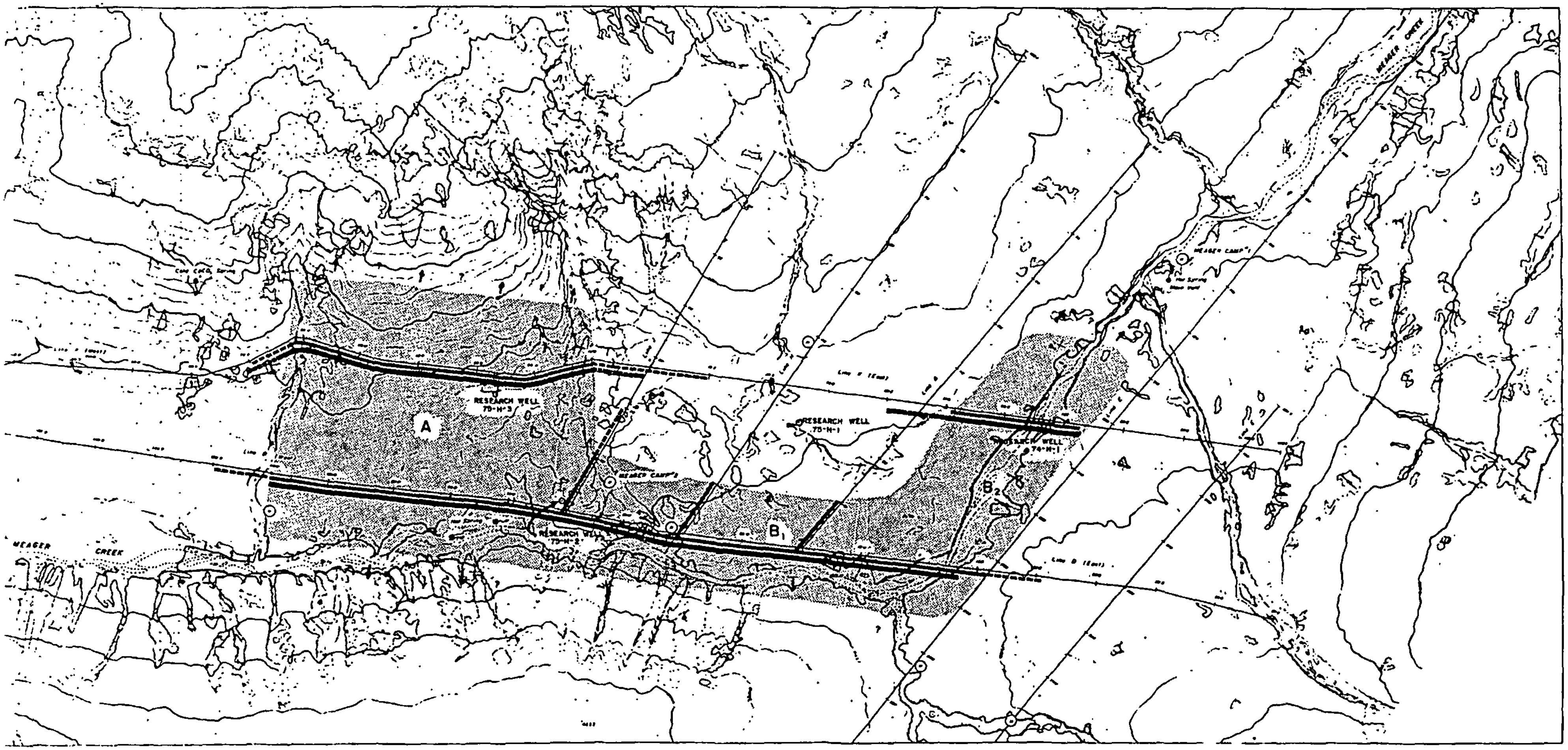
Arrays: Dipole-dipole, a=1,000 feet, n=1 to 4.
Dipole-dipole, a-2,000 feet, n=1 to 7.

Coverage: 1974 line D was resurveyed with the larger (a=2,000 feet) arrays. A new line (K) was established along the break in slope north of and parallel to line D. This line was surveyed twice, at a=1,000 and at a=2,000 feet. Three additional detail lines, G, H and J, were established striking northeast from line D, crossing line K, in the area between Angel Creek and the northeast reach of Meager Creek, and were surveyed at a=1,000 feet.

The line locations are shown in Figure 4.3.

4.2.4 Results

The results of the 1975 dipole-dipole survey line provided some lateral definition of the 1974 line D resistivity anomaly, to define a broad anomalous zone (A) and an apparent outflow plume along the Meager Creek Valley (B_1, B_2) as shown in Figure 4.3.

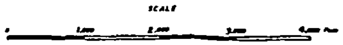


LEGEND

▨ Lateral extent of low resistivity media

↑? Data not available - extension of zone possible

━━ Definite low resistivity anomaly, A = 1000 feet array
╍╍ Possible " " " " " "
━━ Definite " " " A = 2000 " "
╍╍ Possible " " " " " "



DEEP GRID ANALYSIS, LTD.
TO ACCOMPANY REPORT
DGA GEOPHYSICS - Project 0275
DATE SEPT. 1975
REVISED: 11/75

B.C. HYDRO AND POWER AUTHORITY
DEEP RESISTIVITY SURVEY
LINE LOCATION AND ANOMALY PLAN
GEOTHERMAL INVESTIGATION
MEAGER CREEK SELECTED AREA B.C.
SCALE AS INDICATED
DWG NO 1

FROM REPORT #GPIA-1975-I *Figure 4.3*

4.3 1976 3-Array Shallow Resistivity Soundings

Seven shallow soundings in the Lillooet-Pebble Creek area.

4.3.1 Background

The 1975 dipole-dipole surveys extended the definition of the 1974 resistivity anomaly on line D to the practical limit of conventional resistivity instrumentation and field techniques.

1976 was essentially a year of program review. The geophysical fieldwork consisted of a large self-potential survey in the Lillooet River valley, and a two day program of vertical electrical soundings in the Lillooet River-Pebble Creek area.

4.3.2 Survey Objectives

The soundings were intended to measure the resistivity of the valley sediments near two of the three 1974 line A anomalies.

4.3.3 Method and Coverage

Logistics: By September of 1975 a logging road extended along the northeast side of the Lillooet River to a point just short of Pebble Creek. Most of the soundings were operated from a 2-man camp at the head of the logging road, using portable equipment and accessing the survey sites by foot. A canoe was used to cross to the southwest side of the Lillooet River for the soundings in that area.

Equipment: Transmitter: Huntec M-3, 200 watts, reversing square wave, 50% duty cycle, at 0.125 Hz.

Receiver: Hewlett-Packard 970A millivoltmeter.

Communications: Motorola walkie-talkies and base station, assigned frequency in business band.

Arrays: Expanding 3-array spreads were used, with spacings (a) of 10, 20, 40, 80, 160, 320, 640, 1250 and 2500 feet.

Coverage: Soundings S-1 and S-2 were placed on the southwest side of the Lillooet River between Pebble Creek and Meager Creek. Soundings S-3 and S-4 were similarly located, but on the northeast side of the Lillooet River. These four soundings were intended to test for conductive materials suggested in the 1974 line A anomaly at Pebble Creek. Soundings S-5, S-6 and S-7 were placed at 1 km intervals northwest from Pebble Creek on the northeast side of the Lillooet River.

4.3.4 Results

Soundings S-1, S-2, S-3 and S-4, all located downstream from Pebble Creek on both sides of the Lillooet River, indicate anomalous low resistivity valley fill. Soundings S-5 and S-6 indicate somewhat less conductive valley fill, and sounding S-7 shows little sign of anomalous conductivity, which may result from its location in an area of limited overburden.

The results serve to confirm that near surface anomalous low resistivities occur in the Lillooet River valley downstream from Pebble Creek.

4.4 1977 Multiple Pole-pole Resistivity Survey

Multiple pole-pole survey attempt, Lillooet-Pebble Creek area.

4.4.1 Background

By the end of 1975, most of the accessible ground on the lower slopes of the volcanic complex had been surveyed. Much of the complex remained untested, due to the extremely steep nature of the higher terrain. Geophysical consultant Greg Shore proposed in 1977 to design and operate a multiple electrode survey array which would permit the measurement of resistivities throughout the extremely rough topography. The proposed method would eliminate the need for regularly spaced collinear arrays, and would permit effective survey coverage based on indirectly accessed survey electrode locations. The basic measurement array would be a conventional pole-pole array.

4.4.2 Survey Objectives

The objective of the 1977 program was to obtain survey results throughout the area of the confluence of Meager Creek with the Lillooet River, an area known from 1974 and 1976 resistivity measurements to be anomalously conductive.

4.4.3 Method and Coverage

Logistics: By the summer of 1977, a good quality logging road extended to Pebble Creek on the northeast side of the Lillooet River. There was still no road access to the southwest side of the Lillooet River or the Meager Creek Valley. Access to that side was accomplished initially by helicopter, and later by means of a rubber boat secured to a fixed cable spanning the river.

A helicopter was used extensively in the placement of survey wires between the central operating station and the surrounding peaks and intermediate high areas.

Equipment:

Transmitter: DGA, 40 kw, reversing square wave at 0.25 Hz.

Receiver: Hewlett-Packard 3456A microvoltmeter.

Overall Control: Hewlett-Packard 9825A computer controlled the transmitter, receiver, and input scanner.

Communications: Motorola walkie-talkies and base station, assigned frequency in business band.

Wire and tools: conventional backpack reels and spools, and helicopter-carried Turair wire dispenser.

Arrays: Multiple pole-pole array measurements, variable separation, variable orientation.

Coverage: A single multiple pole-pole array installation covered the valley area around the confluence of Meager Creek with the Lillooet River. Electrodes were extended to the upper slopes of the surrounding mountains, and electrode positions were placed on the lower slopes and valley floor area.

4.4.4 Results

The results contained an unacceptably high level of ambiguity, which permitted only the most general observations that the valley area was generally anomalously conductive near surface and probably conductive at substantial depth. The distribution and orientation pattern of the data was irregular and of low density. Part of the reason for this was the fact that the majority of the field operation time was spent trouble-shooting this ioneer array development.

4.5 1978 Multiple Pole-pole Resistivity Surveys

Multiple pole-pole survey, Lillooet Valley.

4.5.1 Background

The 1977 pole-pole survey provided very little useful survey information. The 1977 data lacked sufficient density and regularity of spacing to permit straightforward interpretation. This factor, combined with a need to improve the array layout efficiencies, led to the design of the 1978 pole-pole survey method.

4.5.2 Survey Objectives

The 1978 pole-pole survey work was intended to provide resistivity information from the upper valley slopes above existing dipole-dipole anomalies located on line A in the Lillooet River valley.

4.5.3 Method and Coverage

Logistics: The logging road on the northeast side of the Lillooet River extended as far as Pebble Creek. A bridge was installed at Pebble Creek and a tote road extended approximately two kilometres northwest of Pebble Creek. A tent camp was established near the road at Pebble Creek.

A bridge over Meager Creek was in place, and a logging road extended in to the south reservoir area on the south side of the volcanic complex. These roads were used as much as possible in course of operating the 1978 pole-pole survey. The survey method required the daily use of a light helicopter which was stationed in camp.

Equipment: Transmitter: Huntec M-3, 200 watts, reversing square wave, 50% duty cycle, at 0.125 Hz.

Receiver: Hewlett-Packard 7155B strip chart recording microvoltmeter.

Communications: Motorola walkie-talkies and base station, assigned frequency in business band.

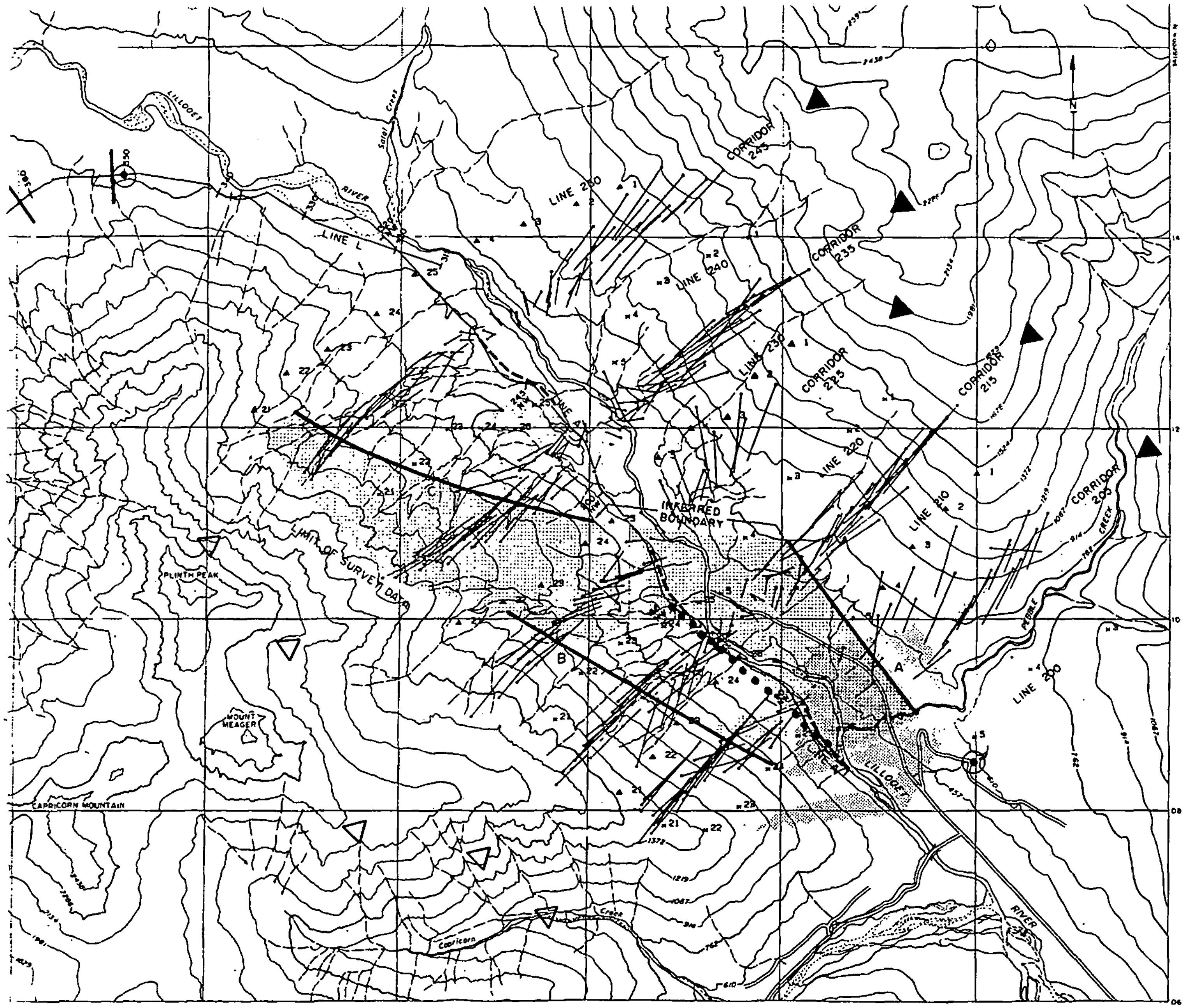
Wire Tools: conventional backpack reel and spool units, and Turair airborne wire dispenser.

Arrays: Multiple pole-pole array measurements, variable separation, variable orientation.

Coverage: The array layout and area covered is outlined in Figure 4.4. The survey area covered the valley of the Lilloet River and both slopes up to treeline from Pebble Creek northwest to within one kilometre of Salal Creek.

4.5.4 Results:

The survey data indicated a broad WNW trending resistivity anomaly extending from the vicinity of Pebble Creek diagonally upslope toward the upper northern slopes of Plinth Peak. A deep anomalous resistivity zone was indicated under the southwest valley slopes extending to a point approximately beneath the Pebble Creek hot springs. The overall anomaly is known as the Lillooet Valley Resistivity Anomaly.



1977-78 Geophysical data by Deep Grid Analysis (1977) Ltd., Vancouver, B.C.
1974 Geophysical data by McPhar Geophysics Ltd., Vancouver, B.C.

Figure 4-6

GEOPHYSICAL DATA LOCATION
AND SUMMARY RESULTS
LILLOOET MAP AREA
FROM REPORT #GPIA-1978-1
Figure 4.4

4.6 1978 Multiple Pole-Pole Resistivity Surveys

Multiple pole-pole survey, South Meager area.

4.6.1 Background

The 1977 pole-pole survey provided very little useful survey information. The 1977 data lacked sufficient density and regularity of spacing to permit straightforward interpretation. This factor, combined with a need to improve the array layout efficiencies, led to the design of the 1978 pole-pole survey method.

4.6.2 Survey Objectives

The 1978 pole-pole survey work was intended to provide resistivity information from the upper slopes above the developing South Reservoir area.

4.6.3 Method and Coverage

Logistics: The logging road on the northeast side of the Lillooet River extended as far as Pebble Creek. A bridge was installed at Pebble Creek and a tote road extended approximately two kilometres northwest of Pebble Creek. A tent camp was established near the road at Pebble Creek.

A bridge over Meager Creek was in place, and a logging road extended in to the south reservoir area on the south side of the volcanic complex. These roads were used as much as possible in course of operating the 1978 pole-pole survey. The survey method required the daily use of a light helicopter which was stationed in camp.

Equipment: Transmitter: Hunted M-3, 200 watts, reversing square wave, 50% duty cycle, at 0.125 Hz.

Receiver: Hewlett-Packard 7155B strip chart recording microvoltmeter.

Communications: Motorola walkie-talkies and base station, assigned frequency in business band.

Wire Tools: conventional backpack reel and spool units, and Turair airborne wire dispenser.

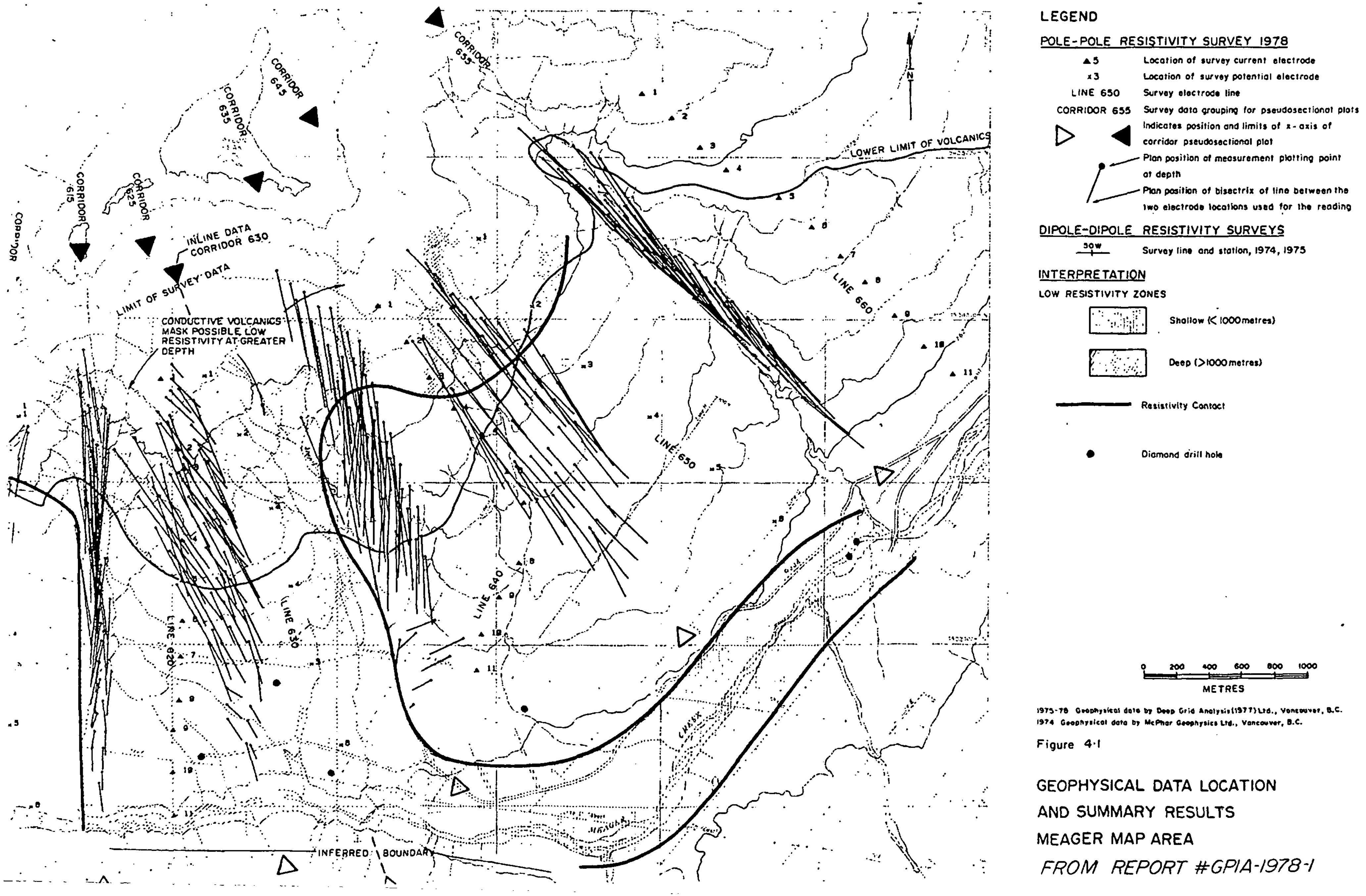
Arrays: Multiple pole-pole array measurements, variable separation, variable orientation, supplemented by one line of in-line pole-pole measurements.

Coverage: The array layout and area covered is outlined in Figure 4.6.1. Six corridors of measurements extended from the high alpine to the lower valley on the south side of the volcanic complex, bracketing the South Reservoir area.

4.6.4 Results:

The survey results extended the South Reservoir resistivity anomaly substantially northward into the volcanics. A conductive response was also obtained from volcanics lying to the east and west of the northward projection of the South Reservoir zone, raising the possibility that the volcanic flow units on the south flank of Pylon Peak are inherently conductive, perhaps due to weathering. A notable exception is a resistive signature obtained in the breccia pipe zone east of Angel Creek.

Resistive measurements obtained from the few electrodes located near Meager Creek suggested a south boundary for the South Reservoir anomaly, as shown on figure 4.5.



1975-78 Geophysical data by Deep Grid Analysis(1977) Ltd., Vancouver, B.C.
1974 Geophysical data by McPhar Geophysics Ltd., Vancouver, B.C.

Figure 4·1

GEOPHYSICAL DATA LOCATION
AND SUMMARY RESULTS
MEAGER MAP AREA

FROM REPORT #GPIA-1978-1

4.7 1978 Dipole-dipole Resistivity Survey

Single reconnaissance line on north side.

4.7.1 Background

The 1978 multiple pole-pole survey in the Lillooet valley had been completed, with the data extending northwest almost to Salal Creek. A test drill hole was being planned for some position on the north flank of Plinth Peak, an area without previous resistivity investigation.

4.7.2 Survey Objective

The dipole-dipole reconnaissance line was intended to extend reconnaissance resistivity coverage from the northwest end of line A (1974) west across the base of the north flank of Plinth Peak. The results of this reconnaissance line would be considered in the final selection of a drill site in the area.

4.7.3 Method and Coverage

Logistics: There was no road access into the survey area in 1978. The resistivity crew was housed at the tent camp at Pebble Creek and taxied to and from the exploration area each day by helicopter.

Equipment: Transmitter: Phoenix IPT-1, 3 kw, reversing square wave at 0.25 Hz.
Receiver: Hewlett-Packard 3465B 4 1/2 digit microvoltmeter

Communications: Motorola walkie-talkies and base station, assigned frequency in business band.

Arrays: Dipole-dipole, a=300 metres, n=1 to 5.

Coverage: 1978 line L extended from the northwest end of 1974 line A west along the break in slope below Plinth Peak, to its terminus at Affliction Creek. Effective measurement coverage stopped at Job Creek.

4.7.4 Results

A single substantial resistivity low was observed between 351W and 361W on line L. Initial subjective interpretation (later confirmed by a 2-D computer inversion) indicated a kilometre wide zone of 200 ohm-metres resistivity capped by a 250 metre thickness of 1,000 ohm-metres resistivity material. Flanking this feature to east and west were rocks of a mean 500 ohm-metres resistivity. The proposed site of the research well L1-78D was moved to a point 100 metres east of the anomaly, where bedrock appeared to be near-surface.

4.8 1979 Dipole-dipole Resistivity Surveys

Dipole-dipole reconnaissance and detail surveys, north side.

4.8.1 Background

By 1979, an area of exploration interest had been defined on the north side of the complex by geological mapping and inference, by the 1978 dipole-dipole resistivity survey line L, and by a 605 metre diamond drill hole (L1-78D). An anomaly on line L had indicated a zone of low resistivity beneath a cap of high resistivity. The adjacent test well L1-78D yielded a maximum temperature of 102.8°C at its deepest point (573.3 metres), and a temperature gradient of 210°C/km.

4.8.2 Survey Objectives

The 1979 survey was intended to expand resistivity coverage in the area around the 1978 resistivity anomaly and high-temperature test well L1-78D.

4.8.3 Method and Coverage

Logistics: The 1979 survey area was approximately 7 kilometres northwest of the end of the nearest logging road in the Lillooet River Valley. A tent camp was installed at the site of the 1978 drilling camp on the south side of the Lillooet River. From this base, survey lines were cut and chained, and the entire resistivity survey south of the Lillooet River was operated. The camp was serviced by occasional helicopter supply flights, but the survey operations were undertaken entirely on foot.

The camp was moved by helicopter to a sandbar on the north side of the Lillooet River, providing access to survey line Q on the north side of the river.

Equipment: Transmitter: Phoenix IPT-1, 3 kw, reversing square wave at 0.25 Hz.
Receiver: Hewlett-Packard 7155B strip chart recording microvoltmeter.
Communications: citizens band walkie-talkies and base station.

Arrays: Dipole-dipole, a=300 metres, n=1 through 7.

Coverage: A total of 38 line km (24 line miles) of survey was undertaken. A four line grid was installed to bracket the 1978 line L anomaly on the south, west and north sides. Survey coverage was extended to the north side of the Lillooet River by measuring on a line installed along the break in slope.

4.8.4 Results:

The 1979 results showed that 1978 line L anomaly L-1 is part of a large anomalous area extending southward up the slopes, and remaining open to the south, west, and possibly northeast. On the north side of the river, three anomalies were noted. A total of seven one-dimensional inversions were made on the data by Phoenix Geophysics of Toronto. Two test wells (L2-80D and L3-80D) were sited partially on the basis of the resistivity anomaly.

4.9 1980 Dipole-dipole Resistivity Survey

Dipole-dipole traverse, Lillooet Valley, north side of complex.

4.9.1 Background

On the north side of the complex, the 1979 program of dipole-dipole survey had substantially extended the areal extent of the 1978 line L anomaly, and had identified new anomalous areas on the north side of the Lillooet River.

4.9.2 Survey Objectives

Survey line V was intended to determine the eastern boundary of the north resistivity anomaly, and provide further information about anomaly Q-3 on line Q north of the Lillooet River. The extension of line V down the northeast side of the Lillooet River toward Pebble Creek would provide detailed measurements from the north side of the Lillooet River behind Pebble Creek Hot Springs (which has been broadly sampled by multiple pole-pole survey in 1978).

A secondary objective was to obtain overlapping a=300 metre dipole data and a=600 metre dipole data, in order to permit evaluation of the resolution characteristics of both arrays. These overlapping data could be obtained from the same arrays, operating from vehicles on the road at negligible increased cost as compared to a single a=300 metre survey.

4.9.3 Method and Coverage

Logistics: Line V was operated along the general route of the access road between the B. C. Hydro main camp and Job Creek. The survey line left the road wherever necessary to maintain a reasonably straight line. The survey crew was housed at the B. C. Hydro main camp.

Equipment: Transmitter: Phoenix IPT-1, 3 kw, reversing square wave at 0.125 Hz.
Receiver: Hewlett-Packard 7155B strip chart recording microvoltmeter.
Communications: citizens band walkie-talkies and base station.

Arrays: Dipole-dipole a=300 metres, n=1 through 15.
Dipole-dipole a-600 metres, n=1 through 7.

Coverage: Line V extended from Job Creek, following the route of the access road east toward the B. C. Hydro main camp. The line crossed to the north side of the Lillooet River and continued east and southeast to a point approximately two kilometres west of the B. C. Hydro main camp.

4.9.4 Results

Line V establishes an eastern and north eastern boundary for the north anomaly zone. Two anomalies are identified on the northeast side of the Lillooet River, one located just east of Salal Creek, and the other located east of the Pebble Creek Hot Springs. The east end of the line appears to be approaching a low resistivity zone.

4.10 1980 Dipole-dipole Resistivity Survey

Dipole-dipole traverses, Meager Creek and South Fork Area.

4.10.1 Background

On the south side of the complex, a re-evaluation of 1974 dipole-dipole reconnaissance data emphasized existing anomalies in the South Fork Creek area as being potentially significant.

4.10.2 Survey Objectives

Survey line S, T and U were designed to extend the information about the anomalous indications obtained in 1974 and 1975. The data would also test for evidence of a south or southeast extension of the South Reservoir zone.

4.10.3 Method and Coverage

Logistics: Logging road provided access to several points on line S.

Most of line S was surveyed using equipment backpacked in.

The lower portion of line T near South Fork Creek was operated with backpacked equipment. The upper portion of line T was operated from a fly camp located near the lake on the line.

Line U was completed in 4 days using a helicopter to drop the survey crew in the alpine areas on both sides of the valley. The crew would work down to the road and return to the main camp.

Delays were experienced on line U and line S due to road blockages by logging equipment. Line U operation was further hampered by poor radio operation. Both lines S and U suffered severe disruption caused by large scale slash burning started without advance notice by the forestry department. The fires engulfed the survey route on two occasions with resultant loss of installed wire arrays on line S, and the loss of vital transmitter notes during a rush evacuation of transmitter equipment from the second fire area. The cost of these difficulties to the program were the extension of line S time requirements (by three days), and the complete loss of line U data usefulness, (at a cost of four days operation).

When not occupying the fly camp on line T, the crew boarded at the main camp facilities of B. C. Hydro near Pebble Creek.

Equipment: Transmitter: Phoenix IPT-1, 3 kw, reversing square wave at 0.125 Hz.

Receiver: Hewlett-Packard 7155B strip chart recording microvoltmeter.

Communications: citizens band walkie-talkies and base station.

Wire and Equipment: Conventional back-pack reel and spool units, using disposable, pre-measured five-spread arrays.

Arrays: Dipole-dipole, a=300 metres, n=1 through 8, occasionally greater than n=8.

Coverage: Line S extends along the southwest side of Meager Creek at the break in slope, from north of the Meager Creek Hot Springs south to Barr Creek and up the South Fork Creek valley. Line T branches off from line S at Barr Creek, running west across the South Fork Creek and passing south of the South Reservoir zone.

4.10.4 Results

Lines S and T produced several anomalies apparently associated with the drainage of the South Fork Creek. Test well M12-80D drilled in their midst yielded only moderate temperatures, but highly saline brine under an artesian head. An enigmatic anomaly (S-1) located west of the Meager Creek Hot Springs at Hot Springs Creek can not be interpreted on the basis of present data, but is suggestive of near-surface lateral flow of saline fluids, rather than a deep low resistivity anomaly.

5.0 SUMMARY OF AREA COVERAGE

Figure 5.1 (in pocket) shows the extent to survey coverage by dipole-dipole and pole-pole surveys, and the location of some vertical electrical sounding results.

The method used to show lateral range of measurement for the dipole-dipole arrays serves to indicate the actual earth which has been sampled. This is not adequately shown when the survey line location alone is plotted.

An envelope encloses sections of the plan map (Figure 5.1) to indicate the scope of array sampling along the route of the survey line. The distance from the line to the edge of the envelope is an estimate of the extent of effective search for the array dimensions used, a value based on the depth of investigation characteristic (D.I.C.) (Roy and Apparao, 1971) of the maximum array dimension used, as modified for pseudosection use by Edwards (1977), who calls it effective penetration, Z_e. In essence, any strongly anomalous conditions at the edge of or within the envelope, to either side or to corresponding depth below, will be apparent in the pseudosection data (provided other local effects do not obscure the results). Thus, where an anomaly is represented by a bar plotted along the line, the observer can use the envelope in conjunction with the pseudosection to identify and evaluate possible geologic or topographic explanations for the anomaly.

In broader terms, the envelope plot serves as an immediate visual catalog of resistivity data coverage (as opposed to resistivity line location). Where no anomaly exists and no indicators of topographic or stratigraphic masking or distortion are present, the terrain enclosed in the envelope can be considered "explored" to the limits of the Z_e definition of the envelope boundary. Where an anomaly exists, and no firm indication of anomaly source location can be determined (a shallow anomaly at distance "d" to one side may, in pseudosection data, look the same as an anomaly at depth "d" directly under the line) the combination of data envelope and anomaly bar allows the appropriate fitting of follow-up parallel or perpendicular lines to the area terrain. The trial plotting of any proposed detail line and its search envelope provides an opportunity to test the potential effectiveness of the proposed line in clarifying the anomaly source position.

5.1 Lower valley coverage

Much of the lower valley area around the volcanic complex has been sampled at least once. Notable areas of limited coverage are the zone west of the south reservoir anomaly, which is of interest due to the implications of drilling (M8-79D) and modelling of Line K data, and the area surrounding the confluence of Meager Creek and the Lillooet River, where numerous indications of local anomalous conditions have not been linked up.

The valley areas south and southwest of the south reservoir anomaly are not fully explored to date, and may contain the source of geothermal fluids observed in the South Fork anomaly system.

5.2 Alpine area coverage

The development of multiple pole-pole survey in 1977-1978 provided coverage of the northerly extension of the south reservoir anomaly, and sampled the breccia pipe area extensively. It also provided coverage of both sides of the Lillooet River valley for much of the distance between Plinth Peak and Pebble Creek, identifying a lower resistivity unit on the south side, and finding no anomalies on the north side.

Much of the alpine area remains untested. Three factors make the obtaining of results in the central complex area difficult:

a. Ice covers the greater protion of the alpine area, requiring special precautions for crew movement, and instruments capable of operating between bare patches, or through the ice.

b. Many areas are near-vertical, or are unstable and in frequent landslide or icefall, limiting crew access.

c. Dependence on helicopters for movements including access and return to camp on a daily basis increases operating costs and uncertainties due to weather variability.

6.0 INTERPRETATION OF MAJOR ANOMALY SYSTEMS

6.1 South Reservoir resistivity anomaly

The focus of interest in the resistivity description of the south reservoir anomaly has been sharpened by recent two-dimensional modelling of resistivity results. These results indicate a zone of low resistivity of about .5 km width lying east from No Good Creek, and oriented north into the complex. In both models, the structure apparently extends to depth beyond the range of interpretation, or a depth of 1500 metres below surface. The west half of the south reservoir anomaly is underlain by 1000 ohm-metre materials, probably relatively intact basement rocks.

These models (Figures 6.1 and 6.2) are a first interpretation based on the resistivity data alone, without presently available seismic data, drill logs, and other data. The model of the south reservoir structure could be significantly enhanced by further computer-assisted work using these data, and extending the modelling process to include Line D data in the same area, and using the a=1000 feet data to further pinpoint the shallow effects of the brine-soaked overburden.

Ward (appendix B) suggests that the south reservoir anomaly is part of a major regional structure which extends north and south of the Meager complex, and passes through in line with the south reservoir anomaly, most of the south-north eruptive centers trend, and through the north anomaly at line L. Extending this computer analysis would test the proposal of extensions of the present zone both north and south from the bench area.

It is interesting to note that the highest near-surface non-inverting temperature gradient is located at well M7-79D, located directly over the resistivity zone. The highest absolute temperature in the upper kilometre regime is also located there.

The models provide resistivity evidence of a cause for the isothermal nature of the lower part of well M10-80D: the drill passes through conductive materials for the first 200-250 metres, then enters an area marginal to a 300 ohm-metre block (this boundary between these units is approximate), heading toward 300 and 1000 ohm-metre rock units of probably marginal permeability and high temperature (approximately 160°C) that is probably resulting from very high temperatures in the 50 ohm-metre zone to the west.

Well M13-81D just west of No Good Creek penetrates the west edge of the main 50 ohm-metre zone, and yields a temeperature of 114°C within 600 metres.

All of the section data west of No Good Creek should be verified by additional measurements and modelling to eliminate the dependence on a few readings for the present interpretation. As it stands, the 100 ohm-metre zones are potential drill targets themselves, but require a better data base prior to further evaluation.

Recommendations:

a. Lines D and K should be extended west as far as possible (3 km) to obtain additional data for modelling in the area west of No Good Creek. Such modelling should be undertaken.
b. Existing Lines D and K data should be intensively modelled with the use of all existing hard measurement data from drilling and geophysics, as per the recommendation of S. Ward (appendix B). Mr. C. Mackelprang of UURI Earth Science Laboratory should undertake the modelling using their IP2D forward modelling routine.
c. The results of rotary hole #3 should be input into the interpretation process as soon as temepratures and indications of permeability are available.

6.2 North resistivity anomaly, north central anomaly area

The north resistivity anomaly was first identified on Line L from reconnaissance resistivity data. A one-dimensional inversion of anomaly data confirmed the manually derived model shown in figure 6.3. The adjacent test well L1-78D encountered a basal till underlying the rhyodacite flow unit at a point coincident with the interpreted top of the conductive resistivity unit. This implies that the main conductive unit and possibly the source of hot fluids influencing test well L1-78D lies within the basement rock complex, and is overlain with a more resistive portion of flow unit. The basement zone is about 1 km wide by this interpretation, and corresponds with the general north-south major structure model of Ward (appendix B).

Whatever is occurring to the south of this area, the anomaly L-1 itself is of sufficient interest to warrant a more detailed computer-assisted evaluation of the structure. The former inversion was a parametric method constrained to a two-layer case in one dimension, and represents a very minimal study by 1981 standards. The 2-D forward model would help to establish if it is a linear structure, if it might be of a form compatible with the Ward model, and if it is of similar character to the apparent linear structure on lines N and R on Polychrome Ridge to the west.

Very little else can be said about the north anomaly from the amount of data presently in hand.

Recommendations:

a. Model the data associated with the north anomaly itself, starting with line L anomaly L-1, and extending to the the data describing anomalies O-1, V-1, and N-1 (Figure 5.1). Use the UURI IP2D routine.

b. Model anomalies N-4 and R-1 to test for a linear conductor possibly marking an outflow from a system upslope. UURI IP2D.

c. Model anomalies Q-1 and Q-2 to determine their characteristics in general, and to determine if Q-2 marks the northward progression of Ward's north-south structural control model (appendix B).

d. Extend resistivity coverage south and west of present coverage.

6.3 South Fork anomaly system

This system loosely contains all of the known geothermal manifestations on the southeast side of Meager Creek, and up into the South Fork valley area. Of these manifestations (Figure 5.1), the Meager Creek Hot Springs and the warm seeps along the Meager Creek east bank may relate to the south reservoir outflow, but may also be partially or completely originated in the area southeast and south of the Meager Creek valley.

There are sufficient indicators in the South Fork valley (saline surface waters, saline brine in well M12-80D, strong resistivity anomalies up the hydrologic gradient from the south reservoir plume) to indicate a separate point of origin for the geothermal waters mapped throughout the area.

Ward's north-south structure model, with some faint support on Line T immediately south of the south reservoir, would cross the headwaters of the South Fork in a position suitable to supply saline waters to the full length of the South Fork creek valley. Such waters, originating from some geothermal system but cooled in travelling along this major structural conduit, could mix with hot south reservoir outflow waters at their junction at Meager Creek, providing the warm seeps and mixed, partially reequilibrated waters at Meager Creek Hot Springs.

Depending on controlling structures in the area, this explanation could cover all observed manifestations in the South Fork Anomaly System. The interpreted shallow anomaly S-2 high above the Hot Springs on Hot Springs Creek indicates lateral flow of saline waters eastward downhill in the area. The tentative explanation for the contorted character of the anomaly is a set of orthogonally connected fractures in the area. Such a fracture set could be loacted to fit the model of a single source of saline fluids, but there remains the likelihood that if saline fluids are indeed resposnible for the S-2 anomaly and the strong downhole resistivity variation in M14-81D, the source must be uphill to the east. This constitutes another possible source for much of the northern South Fork Anomaly System fluids, a source which can not exclude the probability of the South Fork headwaters inflow as well. The data available for interpretation near Hot Springs Creek (anomaly S-2) are inadequate. A simple detail line at smaller spacings would help to resolve the questions about an eastern source of brine.

Recommendations:

a. Extend Line S data coverage up to 6 km west, crossing the South Fork headwaters area and the southward projection of Ward's north-south model.
b. Operate an a=100 metres detail line across Hot Springs Creek on Line S to resolve the inetrpretation of S-2 and the eastern brine source possibility.
c. Complete the shallow readings of anomaly T-1 so that this line can be modelled to determine the stratification of lateral brine flow and/or the presence of a structure which may be controlling local fluid movement.
d. Plan to model T-1 as above, and the results (if any) of the line S extension across the north-south projection.

7.0 COMMENTS ON AREAS OF INTEREST IN FIGURE 5.1

The point-form discussion of the areas identified by letters A through Q on Figure 5.1 is intended as a basis for further discussion toward planning the next increments of exploration. Principally resistivity observations are made, but other observations may be noted as well. The suggestions for resistivity work represent possible components of an exploration plan which would require input from geologists and geochemists, and whose final form may or may not include resistivity survey.

Area A

Coverage to Date

Area A has been very superficially tested with resistivity to date.

- 8 to 9 Schlumberger spot measurements (1981).
- one corridor of multiple pole-pole data at east edge (1978).
- a few dipole-dipole measurements on the ends of lines D and K (1974,1975).

Reasons for Interest

- immediately adjacent to the main South Reservoir zone.
- both 2-D models of line K data suggest conductive zones within area A, both as extensions to the South Reservoir in zone and as a possible second zone west of Boundary Creek.
- the limited pole-pole coverage suggest increased conductivity at depth on the upper slopes of eastern area A.
- the five Schlumberger spot measurements between Boundary Creek and No Good Creek support increased conductivity at depth.

Possible Models

Since the location of the geothermal system supplying heat and brine to the South Reservoir zone has not been identified, area A lying immediately adjacent to the west is of more than passing interest. None of the resistivity data obtained to date excludes the possibility of a large geothermal system underlying the zone. There remains physical room for a large geothermal system centred on or northeast of the Devastation Creek valley. The moderately high temperature gradient (125°C/km) may result from lateral heat transfer from the main zone of the South Reservoir, but could equally represent lateral flow from the north or west of area A.

Area B

Coverage to Date

Area B comprises the higher altitude ground to the east and southeast of dipole-dipole line S which follows the Meager and South Fork valleys. No resistivity data has been obtained in Area B.

Reasons for Interest

- reasonably close to the South Reservoir activity, and lying on the strike of a major northwest lineament.
- Area B abuts a long string of geothermal manifestations labelled as the South Fork anomaly system (Figure).
    - Meager Creek Hot Springs waters are of undefined origin and could contain a component originating from area B directly upslope to the southeast.
    - a resistivity anomaly on line S at Hot Springs Creek is interpreted as indicating lateral near-surface flow of conductive waters from within area B downhill towards Meager Creek.
    - the warm seeps observed along the bank of Meager Creek between the Meager Creek Hot Springs and the South Fork issue from the southeast side of the creek, and could contain thermal water from area B.
    - resistivity anomalies in the South Fork area (on lines C, E, S. T, and ELA) could be caused by saline outflow from area B.
    - saline brine under artesian head was observed in test well M12-80D located on a lower slope of area B.
    - a saline surface run-off has been observed on a lower slope of area B, south of test well M12-80D.

Possible Models

The geology of area B is at present only superficially known. Hydrologic principles suggest that saline waters observed in the southern part of the South Fork anomaly system do not originate in the South Reservoir area. The salinity of these waters indicates a geothermal origin. The low temperature of the measured waters indicates that they have travelled sufficient distance to have cooled to local ambient temperatures. The source of the saline waters must lie some distance away from the observed anomalies, in either area B or area C, or in the area to the south. A geothermal reservoir lying in the upper slopes of area B could be supplying the conductive fluids which cause the line S anomalies on the lower slopes. Such a model does not conflict with any existing data; indeed the proposition for a northwest striking major lineament through area B provides an ideal transport mechanism for the brine.

Area C

Coverage to Date

Area C is bounded by dipole-dipole resistivity survey lines F, T, S, and ELA. Survey lines C and E approach the area, with line C entering the area.

Reasons for Interest

- area C lies up the hydrologic gradient from consistent and strong resistivity anomalies lying in the South Fork drainage. (See area B)
- area C contains the intersection of the headwater area of the South Fork and the southward extension of a linear zone proposed to run through the south reservoir area (Ward, 1981).
- saline surface waters have been observed in swampy areas near the headwaters of the South Fork (Openshaw, pers. comm.)

Possible Models

The geology of area C is at present only superficially known. Hydrologic principles suggest that saline waters observed in the southern part of the South Fork anomaly system do not originate in the South Reservoir area. The salinity of these waters indicates a geothermal origin. The low temperature of the measured waters indicates that they have travelled sufficient distance from a geothermal system to have cooled to local ambient temperatures. The source of the saline waters must lie some distance away from the observed anomalies in either area B or area C, or in the area to the south. A major structural zone, possibly a southern extension of the South Reservoir main zone (Ward, 1981) may be a suitable conduit for the local introduction of saline brine. If such brines are travelling at depth along this permeable structure from the South Reservoir area, then perhaps sufficient distance will have been covered to permit their cooling to the low local ambient temperatures in near-surface area C.

The source of the saline waters observed in area C and in parts of the South Fork anomaly system could originate from structures or systems completely independent of the South Reservoir area. Some manifestation of this structure or system is likely to be identified somewhere in area C.

Area D

Coverage to Date

The area around the confluence of Meager Creek with the Lillooet River has been peripherally sampled repeatedly, not as yet has not undergone a systematic survey. 1977 multiple pole-pole array work centered on the area, and yielded highly ambiguous results which nonetheless contained some reasonable indications of anomalous conductivity in the area.

Reasons for Interest

- Line A (1974) terminates near D_1 with indication of strongly anomalous conditions downstream from Pebble Creek.
- Line V (1980) terminates near D_1 with indication of anomalous conditions downstream.
- Testing of 1977 pole-pole array indicated extreme near-surface conductivity near D_3.
- Soundings S-1 through S-4 (1976) indicate conductive alluvium.
- 1978 pole-pole Lillooet Valley Resistivity Anomaly can be projected through point D at the confluence.
- A lack of apparent sediment conductivity at D_4 appears to at least structurally disconnect the area D from the brine systems associated with the Meager Creek Hot Springs.
- Major structures in the Lillooet and Meager Valleys may intersect in the area.
- A volcanic vent has been reported some distance up Pebble Creek.
- The Capricorn Creek watershed drains into area D. This watershed drains a large area involving at least three eruptive centers at or near Pylon Peak, Capricorn Mountain and Meager Mountain, providing an opportunity to supply outflow brine to area D.
- Drainage from the north slopes of Mount Meager and the area toward Plinth Peak enters area D at surface at the point where the

anomalies A-2 and V-4 begin, and where conductive sediments are noted.

Possible Models

The amount of unconnected data yields a large number of speculative models, none of which can be preferred on the basis of present data. Access to the center of the south-north eruptive center trend via Capricorn Creek is perhaps a useable way to obtain mid-complex data, operating a carefully planned resistivity section up the Creek and across the eruptive trend to the west along the south edges of Capricorn Mountain and Mount Job. If the regional north-south suture model of Ward is providing some local control of fluid circulation or displacement, then such a traverse would be possibly diagnostic.

Substantial support information can be had much more easily, however, by completing resistivity measurement coverage of the area marked by D_1 through D_4, using the established network of existing roads. Resistivity measurements up Capricorn and surface water conductivity testing in the Capricorn watershed and on the slopes above and below the Lillooet Valley Resistivity Anomaly would help to indicate the possibility of a geothermal system associated with Meager Mountain being responsible for most of the Area D anomalies.

The limited present data also carries a caution in developing models at this stage. For example, the bulk of the conductive media in Area D sediments could be settled fines and clay particles deposited from Lillooet River and Meager Creek waters over a long period. The map indicates that the anomalous area coincides with the first major decline in stream gradient (except for the area above Salal where conductive, settled sediments also occur) for both watercourses. The low cost of completing valley bottom and lower slope measurements indicates that the data set should be completed before major models are seriously considered.

Area E

Survey Coverage

Area E is bounded on the north by dipole-dipole survey coverage. Line M along Job Creek extends south into the area. At the east edge of the area, the Lillooet Valley Resistivity Anomaly approaches the area.

Reasons for Interest

- The resistivity anomalies of Lines M and N are open into area E.
- The 103°C temperature and high gradient in L1-78D may relate to a system in area E (or F).
- There is a strong and unresolved SP response across lower area E.
- The Lillooet Valley Resistivity Anomaly approaches the area and has not been cut off.
- The area may hold the site of the most recent pyroclastic eruption and in known to contain the vent from which the recent dacite flow issued into the Lillooet Valley.
- Anomalies A-3 and V-3 and nearby Pebble Creek Hot Springs lie to the northeast of the area.

Possible Models

There are numerous possible models for this area, particularly since it sits on the north end of the northerly trend of eruptive centers and contains very recent vent sites. To the present considerations for the area, the resistivity data indicates that further exploration should keep the Ward north-south structure model, with its passage through anomaly L-1, in mind.

The cause of the SP anomaly reported from the fall-line leading down to drillsite L1-78D is not understood at present. It could indicate major fluid upwelling in the area of the letter E on the map, or it could be caused by vigorous drainage of meteoric waters within a permeable layer in the flow sequence on the slope.

Area F

Survey Coverage

Area F is bounded on the north by dipole-dipole survey coverage. Dipole-dipole line X bisects the area. Area F is contiguous with areas E and G.

Reasons for Interest

- Resistivity anomalies on all bounding dipole-dipole lines.
- Visible surface hydrothermal alteration in the area,
- With resistivity anomalies apparently cut off to the north, exploration south into the volcanics is indicated.

Possible Models

There are no specific resistivity-based models to be proposed for testing at this time. Exploration planning for this area is underway at present.

Area G

Survey Coverage

Area G is bounded to the north by Lines N and R. No other resistivity survey has been undertaken in area G.

Reasons for interest

- The anomalies on Line N and R suggest a north-south trending structure.

- Depending on the demonstrated strike of the anomalous structure, area G may demonstrate connection of the structure with area F.

Possible Models

This anomaly could indicate an outflow from a geothermal system to the south contained within a north-south fracture zone. Little is known about area to date.

Area H

Survey Coverage

Area H is bounded to the south by Lines N and R. No other resistivity survey has been undertaken in the area.

Reasons for interest

- The anomalous structure identified on Line N and R to the south. These may extend north to the Area H.

- There is no evidence to date that sediments in Area H will mask or otherwise interfere with survey measurements.

Possible Models

The northwest resistivity anomaly may extend as a structure into and/or across the Lillooet Valley. Investigation would depend on assessment of prior work in area G.

Area J

Survey coverage

There is no previous survey work in area J. The area lies north of the anomaly on lines N and R, and west of the anomaly on line Q at the west edge of area K.

Reasons for interest

- If the structure indicated on Line N and R south extends north, survey in Area J may be effective in mapping its continuation.
- The anomaly mapped on the western end of Line Q may extend into Area J.

Possible models

The area may relate to areas H and K.

Area K

Survey Coverage

Line Q (1979) runs along the south side of area K.

Reasons for Interest

- Area K may contain evidence of the continuation of Ward's (appendix B) north-south major structure (anomaly Q-2)
- Anomaly Q-1 yields a 1-D inversion interpretation indicating extreme conductivity in a thin layer under a probable flow unit.

Possible Models

This is a case of a very limited amount of data providing an interpreted section of large potential ambiguity, both in reliability and exclusivity of the inversion result itself, and in the range of possible models for the interpreted result. The most acceptable model is that of a conductive clay basal till under a flow unit of moderate resistivity, over a basement of high resistivity. Beacuse of the position of the anomaly on the gneral trend of north-south eruptive centers, it is appropriate to also consider a thermal cause for the till conductivity, and to speculate quickly on a vapour-dominated system of resistive cap, conductive condensate layer and resistive hot/dry rock basement.

Such speculation serves best to illustrate the lack of sufficient data in the area on which to eliminate any of this extreme range of models.

Area L

Survey Coverage

Area L is bounded to the south by Line Q.

Reasons for interest

- A moderate anomaly on Line Q (Q-3) is undefined to the north.

Possible Models

Area L lies between the north resistivity anomaly and further at least one center of hydrothermal alteration at the headwaters of Salal Creek, and may lie on the contact between the Fall Creek stock and the local basement rocks. It is also generally in the path of the south-north eruptive center trend. The anomaly Q-3 may be sampling a portion of a more conductive manifestation north or south of Line Q.

Area M

Survey Coverage

Area M is bounded to the south by Line V.

Reasons for interest

- Anomaly V-2 is open to the northwest toward Area M.

Possible Models

Anomaly V-2 could represent outflow from a system located to the north or northwest.

Area P

Survey Coverage

Area P covers much of the central alpine area of the complex, where almost no measurements have been obtained to date.

Reason for Interest

This area is of obvious exploration interest due to the number of volcanic vents within it. The lack of comprehensive measurement coverage to date is caused by the difficulty in operating in this type of terrain, from both an equipment and personnel standpoint. The difficulty in conducting exploration in this area, combined with the probable difficulty in test drilling and exploiting a resource located therein, tends to allow the area to be set aside while other more accessible and reliably exploitable areas are explored.

The deferred status, if it exists, should be reviewed periodically to assure that the conditions supporting it have not changed to allow a cost-effective evaluation at some future date. The changes might occur in exploration technology, exploitation technology, or both.

The largely untested area P contains sufficient area to locate 10 to 12 geothermal systems of 9 km^2 minimum size.

Area Q

Area Q is discussed in 6.1 of this report, and in other reports on the Meager Creek geothermal area. Area Q contains the south reservoir resistivity anomaly.

8.0 COMPUTER-ASSISTED DATA INTERPRETATION

A review of available computer-assisted data interpretation routines was undertaken. A separate report on this subject is in preparation at present, the completion of which is dependent upon the results of three different areas of investigation presently under way.

8.1 Two-dimensional forward modelling program

The application of an advanced two-dimensional forward modelling routine to Meager Creek data and to Mt. Cayley data from the 1981 reconnaissance propgram has provided some initial results which suggest that the method may be useful in the evaluation of drill sites for initial testing of anomalies. Two of the model results are shown in figures 8.1 and 8.2, in which Line K data from the south reservoir area have been used. These are best fits on a first attempt using the IP2D routine of the Earth Sciences Laboratory of the University of Utah Research Institute. Mr. Claron Mackelprang was the program operator. The models show a zone of low (50 ohm-metres) resistivity at the west side of the main anomaly, extending to a depth in excess of the lower limit of model resolution (greater than 1500 m). The highest temperature and steepest gradient, those of test well M7-79D, were obtained directly over this unit. The lapse of initial steep gradients in test well M10-80D into an isothermal state may be explained in this model by the large block of 1000 ohm-metre rock directly below M10. The test well data obtained in the south reservoir support this model substantially. At time of writing, rotary test well MC3 has been targeted to penetrate vertically just east of the 50 ohm-metre zone, turning west-northwest at depth to test the 50 ohm-metre zone at depth. It is anticipated that the 50 ohm-metre zone will provide better permeability than the rock units lying further east.

These models were generated from the a = 610 m (2000 ft) data only, shown in figures 3.6 and 3.7. No further work is in progress on these data at present; Ward (appendix B) recommends further work be done on south reservoir area modelling using both Lines K and D data and expanding to utilize the available seismic, test-well and shallow Schlumberger sounding data over and near the south reservoir. Such information could provide significant information for planning further testing of the area. It will at least define the reliability of the present general model, and test the 50 ohm-metre zone for sensitivity to single data point variables.

8.2 One-dimensional inverse modelling

Work has been going on for several years on the refinement of a non-parametric one-dimensional inversion routine by Dr. Doug Oldenburg of the University of British Columbia. At this time, the routine is being tested on Schlumberger sounding results from the south reservoir area and from a geothermal program in the Anahim volcanic belt in central B.C. (Geological Survey of Canada, Energy, Mines and Resources Canada). This program provides a continuous interpreted resistivity curve for any electrode array configuration, for an assumed one-dimensional (layered) model. It is seen as providing the first useful tool for evaluating the deeper aspects of the 1978 pole-pole survey data, including the anomalous area above the south reservoir where conducyive volcanics overlie crystalline units of unknown resistivity characteristics. The routine could also provide for evaluation of two- or three-point Schlumberger data on a rough scale.

This routine may be available for use by late 1982.

8.3 Availability of routines for in-house operation

The availability of computer routines for outright purchase, operation under licence, or use as a consultant-operated hourly-rate service is under study. Most routines benefit from the experience and understanding accumulated by their creators or present operators, and the obtaining of physical software may not constitute a direct benefit to the exploration program. On the other hand, the development of a degree of competence with the routines by local personnel assures that the full familiarity with the exploration situation is brought to bear on the program operation. Most available routines can be accessed and used on a time-share basis for a yearly fee or a per-use fee, using a local terminal. Substantial savings in cost and time, and in particular in flexibility, can be obtained by implementing programs on owned computer facilities, where access may be easier, and the CPU costs more favourable. The leading modelling technique, the IP2D routine, is written in PRIME Fortran and is available on licence terms for local implementation.

Respectfully submitted,

Greg A. Shore

Michaël G. Schlax

April 27, 1982

Appendix A

References cited:

Edwards, L.S., 1977, A modified pseudosection for resistivity and I.P.: Geophysics; Vol. 42, No. 5, p. 1020-1036.

Roy, A., and Apparao, A., 1971, Depth of investigation in direct current methods: Geophysics, Vol. 36, p. 943-959.

APPENDIX B

Report on Analysis of Dipole-Dipole Resistivity Data, Meager Creek, British Columbia

for

Premier Geophysics Inc.

by

Stanley H. Ward

STANLEY H. WARD
Geophysical Engineer

729 Hilltop Rd.
Salt Lake City, Utah 84103
May 7, 1981

Mr. Greg Shore
President
Premier Geophysics Inc.
134 Abbott Street
Vancouver, B.C.

Dear Greg,

Herewith my report on analysis and interpretation of the dipole-dipole resistivity data at Meager Creek.

Please telephone me should you require clarification on any aspect of the report.

Yours sincerely,

Stanley H. Ward

Report on Analysis of Dipole-Dipole Resistivity Data
Meager Creek, British Columbia
for
Premier Geophysics Inc.

1.0 Introduction

1.1 The Assignment and Data Base

At the request of Greg A. Shore, President, Premier Geophysics Inc., a one day analysis was made (May 6, 1981) of the dipole-dipole resistivity data accumulated at Meager Creek during the interval 1974-80. The results of three Schlumberger soundings were taken into account in interpreting the dipole-dipole data, but the Schlumberger data was not seperately interpreted in a rigorous manner. No study was made of available pole-pole resistivity data since such would have been beyond the scope of the request for consultation.

In interpreting the dipole-dipole resistivity data I benefitted from extensive discussions with Greg A. Shore and from brief discussions with Brian Fairbank of Nevin Sadlier-Brown Goodbrand Ltd. Account was taken of current knowledge of topography, geology, drill hole information, brine chemistry, tectonic history, ages of extrusive rocks, and preliminary quantitative interpretation of a single profile of dipole-dipole data (interpretation of Line K by Claron Makelprang of the Earth Science Laboratory of the University of Utah Research Institute). My previous knowledge of the Meager Creek geothermal prospect was acquired through discussions with personnel of Nevin Sadlier-Brown Goodbrand Ltd., through a one day visit to the property, courtesy of the latter firm, and through study of the literature referenced herein.

1.2 Presentation of Analysis

A plan map at a scale of 1:20,000 to be overlayed on the geologic map (GSC Open File 603) of Peter B. Read, is used herein to present the significant resistivity lows found in the analysis. The correlation between geology, geophysics, and thermal springs is thereby afforded.

2.0 Pertinent Geologic Features

2.1 Regional and Local Trends of Eruptive Centres

Figure 1 (Lewis and Souther, 1978) illustrates the NNW trend of the Garibaldi belt of Quaternary volcanism. Locally, between Meager Creek and the Lillooet River and possibly beyond to the Bridge River, the trend lies almost due north as shown in Figure 2 (from Roddick and Woodsworth, 1975). These authors state that "This belt thus appears to be the locus of a major fracture system that persisted from a least Miocene to Recent time." Potassium-Argon dates of extrusives are shown to the right of this figure. Figure 3 (from Read, 1978) shows the locations and ages of volcanic vents between Meager Creek and the Lillooet River. The axis of the vent system and the eastern and western bounds of it are superposed on this latter figure.

2.2 Mapped Local Faults

Souther (1980), in reporting on the Central Garibaldi Belt, notes that "The only basement structures that appear to be related to the volcanic belt are north-northwesterly trending, gouge-filled fractures." Read (1978) observes that "Springs and volcanic vents trend northerly and are spatially associated, particularly if the estimated position to the subcrop of Meager hot springs is considered." ...."Fracturing during rhyodacite volcanism in these vent areas probably produced the necessary premeability to depth in the basement, which permits deep circulation of the spring waters in this area of abnormally high

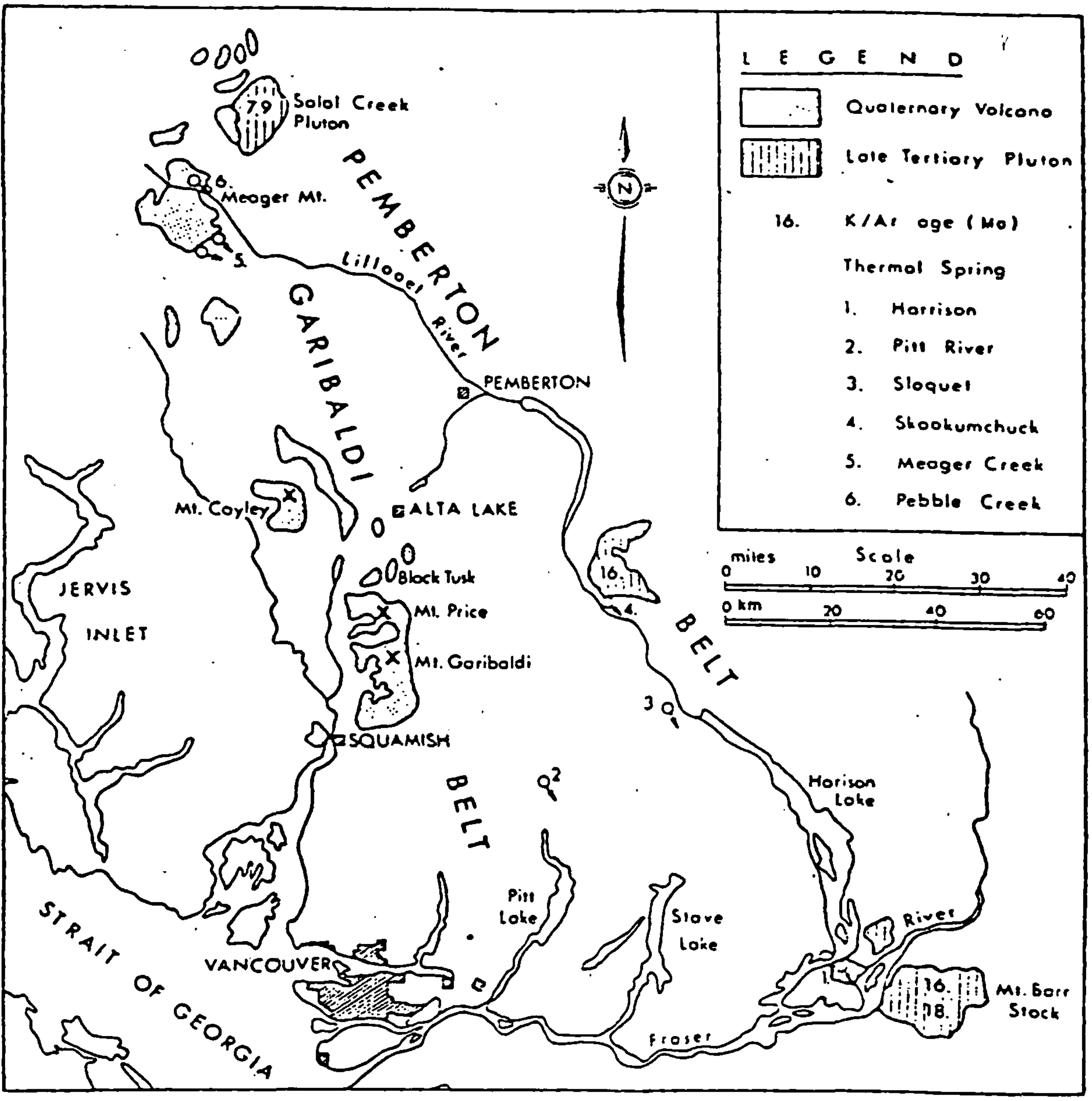


FIG. 1 The Pemberton belt of late Tertiary plutons and the Garibaldi belt of Quaternary volcanoes (from Lewis and Souther 1978).

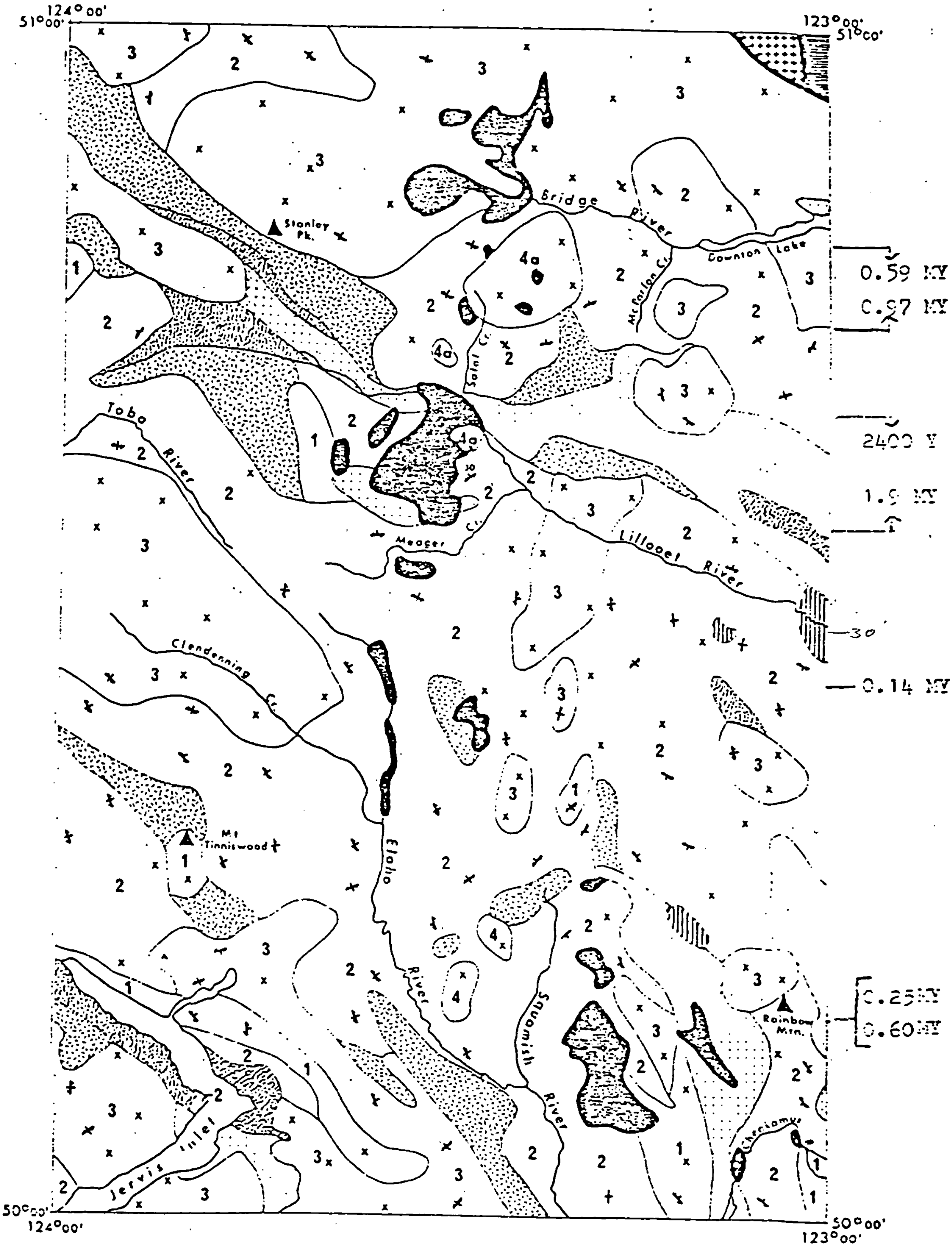


Fig. 2 Distribution of Quaternary rocks (dark areas) and their age distributions. (After Roddick and Woodsworth (1975).

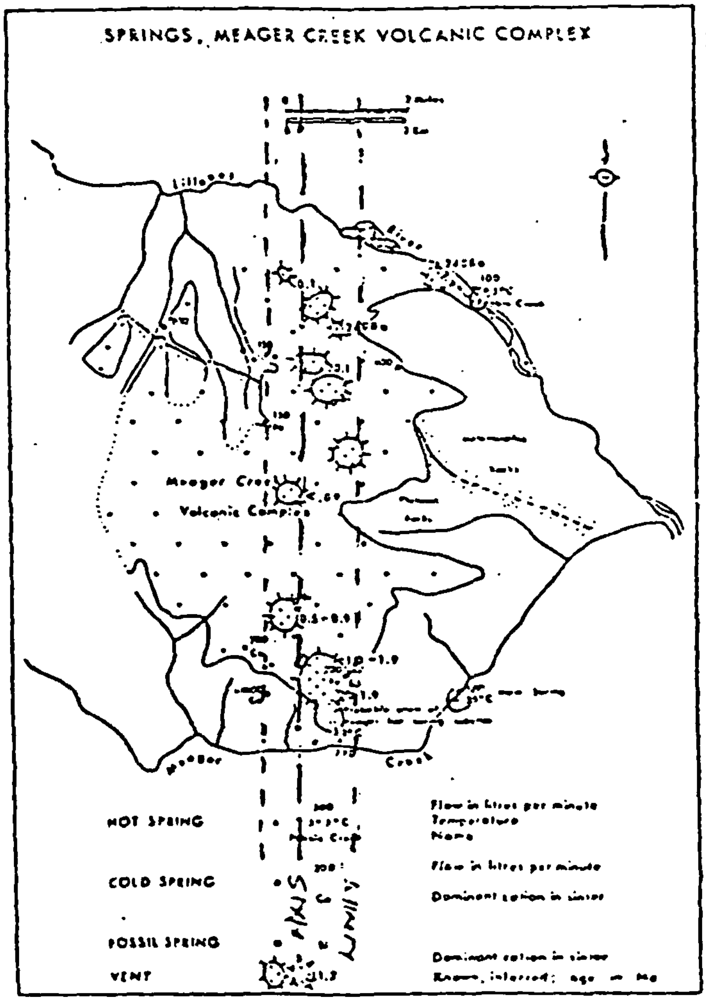


Fig. 3. Meager Creek volcanic vents (after Read, 1978)

2.2 Mapped Local Faults (cont'd)

heat flow." Fairbank (personal communication) observes a dominant 130° fracture set dipping 60° SW and a secondary 20° fracture set dipping vertically. He observes some faults parallel to these trends. North-South fractures are strong and consistent. Fractures radial to the Meager Creek volcanic complex are not observed. Meager Creek appears to lie along an East-West fault dipping 45° to the north.

2.3 The Conceptual Model Implied by Local Volcanic and Structural Trends

The heat source would appear to be a linear NS trend of intrusives associated with the volcanic vents of Figure 3. Pulses of magma evidently introduced heat and fracturing along this NS trend. Where the topography has been deeply disected, as at Meager Creek and the east-west segment of the Lillooet River to the north, access to high temperature regimes ($\sim 200^{\circ}C$) is afforded. The south fork of Meager Creek may afford the same deep access, although the potential source of heat south of Meager Creek is currently unknown. Barr Creek and Hot Spring Creek may also afford access to warm or hot fluids. Hot springs vent along fractures associated with the deeply disecting valleys but the waters so vented are not intimately connected with the deep high temperature convective hydrothermal system (Hammerstrom and Brown, 1977). The drilling target would appear to be a fracture or preferably an intersection of fractures, of any orientation, at a depth sufficient to penetrate the deep high temperature part of this convective hydrothermal system. The system is conceptually bounded on the east and west by the dotted lines shown in Figure 3.

2.4 The Dipping Sheet Model (South Reservoir) of Nevin Sadlier-Brown Goodbrand Ltd.

Quoting Nevin et al (1978), "The South or Meager Creek Reservoir as it is presently known, is a tabular body which

2.4 The Dipping Sheet Model (South Reservoir) of Nevin Sadlier-Brown Goodbrand Ltd. (cont'd)

occupies about 5 sq. km. and dips to the north under the volcanics edifice. The leading hypothesis is that it consists of a slow discharge-plume from a presumably permeable feeder pipe for the southermost volcanics...."

2.5 Sources of Low Resistivity near a Convective Hydrothermal System

Brine satruated alluvium will exhibit resistivities in the 1 to 10 ohm metre range. Brines and associated clay alteration of feldspars will lower the resistivity in the close vicinity of a fracture in rock. The otherwise impermeable quartz diorite basement at Meager Creek will only possess low resistivity where highly fractured; the resistivities of such reservoir rocks ought to lie in the range 10 to 100 ohm metres.

3.0 Depth of Exploration and the "Lateral Range" of Dipole-Dipole Resistivity Surveys

The depth of exploration, d, of dipole-dipole resistivity surveys is conventionally given as

$$d = 0.2\ (n + 2)\ a$$

where n is the spacing (n = 1,2,3,4,5, and 6) and a is the dipole length. Thus for n = 6 and a = 1000 ft., it is 1200 ft. Recent work suggests that this formula is slightly pessimistic and that the simpler formula

$$d = 2a \text{ to } 3a \text{ (for } n = 6)$$

is more appropriate. This would increase the depth of exploration for 1000 ft., dipoles to 2000 ft to 3000 ft.

The lateral range of the method is the same, numerically, as the depth of exploration. Hence resistivity contrasts within about 2000 ft. on either side of a 1000 ft. dipole-dipole traverse line will affect the data and, unless great care is taken, may be interpreted to lie vertically below the traverse line.

PROPOSED WELL SITES FOR GEOTHERMAL DEVELOPMENT:

SOUTH MEAGER MOUNTAIN

Prepared for

Pacific Geopower
4599 Tillicum St.
Burnaby, B.C.
Canada V5J 3J9

by

University of Utah Research Institute
Earth Science Laboratory
Salt Lake City, Utah

Earth Science Laboratory

University of Utah Research Institute
391 Chipeta Way, Suite C
Salt Lake City, Utah 84108
(801) 524-3422

June, 1994

PROPOSED WELL SITES FOR GEOTHERMAL DEVELOPMENT:

SOUTH MEAGER MOUNTAIN

Prepared for

Pacific Geopower
4599 Tillicum St.
Burnaby, B.C.
Canada V5J 3J9

by

University of Utah Research Institute
Earth Science Laboratory
Salt Lake City, Utah

June, 1994

EXECUTIVE SUMMARY

Geologic, geophysical, and geochemical investigations have been conducted at Meager Mountain to characterize the geothermal system it hosts. The results of this work suggests that the geothermal system on the southern side of Meager Mountain has a complex geometry and involves several different fluid types and possibly multiple reservoirs. We suggest that two distinct thermal reservoirs are present. The shallower of these reservoirs discharge from the deep production well MC-1 and from hot springs located mainly along the southern bank of Meager Creek. This reservoir is characterized by moderately saline fluids with total dissolved solids contents of 4000 ppm and temperatures up to about 200°C. Fluids discharged from the hot springs show dilution by groundwaters which results in a salinity of approximately 2000 ppm and a temperature of 60°C. The outflow plume from this reservoir manifests itself as a shallow, low resistivity zone within the central part of the prospect area. Cation geothermometry suggests that the maximum temperatures attained by these fluids is about 225°C. Isotopic relationships indicate that the fluids from this reservoir are mixtures of magmatic and ground waters.

In contrast to these thermal waters, water characterized by higher salinities and low temperatures are found to the south of Meager Creek. The chemistry of these fluids do not appear to be related to geothermal activity, but rather they may represent connate fluids with some component of hot spring water.

A second, deeper and hotter reservoir is implied by the maximum measured temperatures recorded in the deep production wells. These temperatures reach 265° to 275°C in wells MC-2 and MC-3 respectfully. The geometry of this reservoir is, at this point, poorly characterized. The trajectories of these wells indicate that high temperatures will be found in both the northern and western parts of the prospect area at depth. No fluid has yet been produced from these higher temperature zones, and consequently, it is not possible to estimate the maximum temperatures of the deeper reservoir or its composition.

Faults within the crystalline basement rocks that host the geothermal reservoir are dominantly north trending although northeast- and northwest-trending faults have been identified (Fig. 1). The north trending fault appear to be regional in origin, whereas the other fault directions may be controlled by local tectonics. Both the northerly alignment of volcanic vents across Meager Mountain and the wide zone of northerly-trending fractures south of Meager Creek are indicative of the fundamental nature of this trend. The most significant of the north-trending faults parallel No Good Creek and define a zone that is approximately 600 m in width. This zone can be traced intermittently across Meager Mountain on satellite images and is represented at its southern end near Meager Creek by strong resistivity contrasts in the basement rocks. Field mapping, lineament analyses of these images and the electrical conductivities of the basement rocks indicate that the No Good zone contains the highest density of fracturing yet recognized in the southern part of Meager Mountain.

Meager Creek follows a major east-trending structure on the south side of Meager

Mountain. The linearity of this structure across rugged terrain suggests that it is steeply dipping. We have mapped a parallel group of faults to the north of Meager Creek. Together these faults and the Meager Creek fault appear to define an east-trending graben that is centered approximately on well M5. The northern edge of this graben lies close to M7 and the pad for the MC wells. Temperature profiles of these wells suggest that this fault zone may have channeled fluids upward.

The north-trending structures appear to have exerted a dominant control on the circulation of fluids within the basement rocks. The most pronounced zones of surficial hydrothermal alteration on the south side of Meager Mountain are found on the upper canyon walls of No Good Creek and in the upper reaches of Boundary Creek to the west. Lesser amounts of hydrothermal alteration are found in the Angel Creek area. Additional areas of hydrothermal alteration or thermal fluids to depths of 1000 m are suggested by the resistivity contrasts in the basement rocks. These regions are concentrated near the southern end of No Good fault zone. A second large area of low resistivities occurs to the west near Boundary Creek and smaller scattered areas of low resistivity are found to the east near Angel Creek.

Circulation losses within the production wells show good correlation with mapped structures. MC-1 may have encountered northeast-trending faults that can be projected from the Angel Creek area. Two zones of lost circulation occur in MC-2. The shallower of these zones correlates with a north-south fault along Angel Creek; the deeper zone is in an area where north- and northeast- trending faults intersect. MC-3 encountered circulation losses where it crossed the northern margin of the Meager Creek graben and again just west of the No Good fault in an area of strong fracturing.

Inspection of subsurface temperature data suggests that unusually cool temperatures in MC-2 and MC-3 are related to mechanical problems in the wells that are allowing relatively cool water to enter at shallow depths. Therefore, the temperature profiles of these wells are misleading. Temperatures measured following airlift suggest that MC-3 has intersected the hottest geothermal zones and that the fluid was produced from the No Good fault zone. Temperatures measured in MC-2 were nearly as hot as MC-3, suggesting that temperatures may increase to the north and west of the MC production pad.

In summary, the data suggest that the highest permeabilities and potential for future production lies within the north-trending fault zones located along No Good and Angel Creek faults. We propose three wells to test targets in these zones (heavy arrows in Fig. 1). In order of decreasing priority, these are:

1) Drill a production-scale well from the existing pad MC-4 to test the No Good fault zone. The well should be drilled to intersect as much of the zone as is practical and be drilled deep enough to intersect the permeable zone encountered near the bottom of MC-3. Drilling from this pad will require the building of a bridge over No Good Creek and perhaps strengthening other bridges between Pemberton and Meager Mountain.

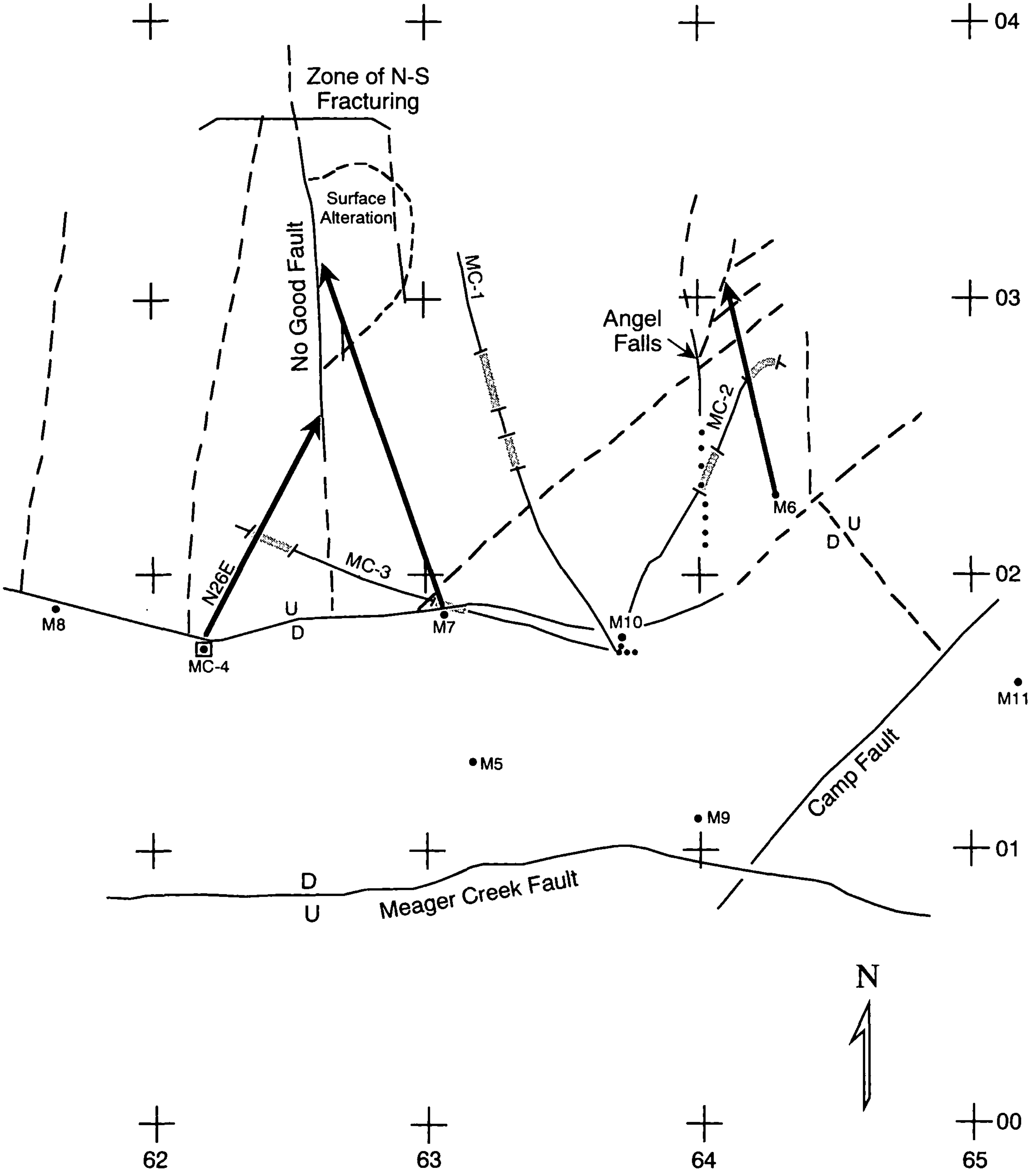


Figure 1. Map of the southern part of Meager Mountain showing the locations of mapped structures, existing thermal gradient and large diameter wells, and the locations of the proposed drill holes (heavy arrows). Crosses are 1 km apart.

2) Drill a production-scale well from a pad near M6 to into the Angel Creek Falls area. This well would target the fault intersections immediately east of Angel Falls. This well is necessary to define the minimum east-west extent of the reservoir.

3) Drill a production-scale well from M7 through the altered zone on the east side of No Good Creek to the No Good Creek Fault. This well would test the accessible northern end of the No Good zone.

GEOLOGIC INVESTIGATIONS

Reconnaissance structural mapping on air photos was completed during the week of 23 May, 1994. The purpose of this mapping was to identify structural trends and place previous drilling results into that framework. During the field work, access was limited to the area east of No Good Creek because the bridge was out and water levels high.

The field reconnaissance was done on a 1:40,000 scale black and white air photo base. Previous geologic mapping was used to guide the effort, but our work concentrated on mapping structural elements. Reed (1979) mapped the lithologies present in the project area, but his map identifies few faults. Fairbank (1993) summarizes the structural geology as it was developed during previous exploration work.

STRUCTURAL GEOLOGY

The Meager Creek geothermal system is hosted by crystalline rocks and therefore will rely exclusively on faults and fractures for production. In other geothermal systems hosted by similar rocks where geologic mapping and drilling have been done in sufficient detail such as Roosevelt Hot Springs, Utah, Coso, California, Steamboat Springs, Nevada, and Zunil, Guatemala, geothermal production can be assigned to specific fault trends.

Previous field mapping at Meager Mountain had identified three principal fault trends in the project area. These trends are east-west, associated with the Meager Creek fault; northeast, associated with the Camp fault; and north-south, associated with the No Good fault. The compiled structural map is shown in Figure 2. The present work expands significantly on our understanding of these structural trends, and has resulted in the recognition of a number of additional faults on the southern side of Meager Mountain.

Meager Creek Fault

The Meager Creek fault was proposed by NSBG (1980) and confirmed by field work the next year (NSBG, 1981). The fault orientation was based on outcrop mapping, fracture analysis, core and temperature results from M9-80D, and geophysical surveys. An average dip of 40-50°

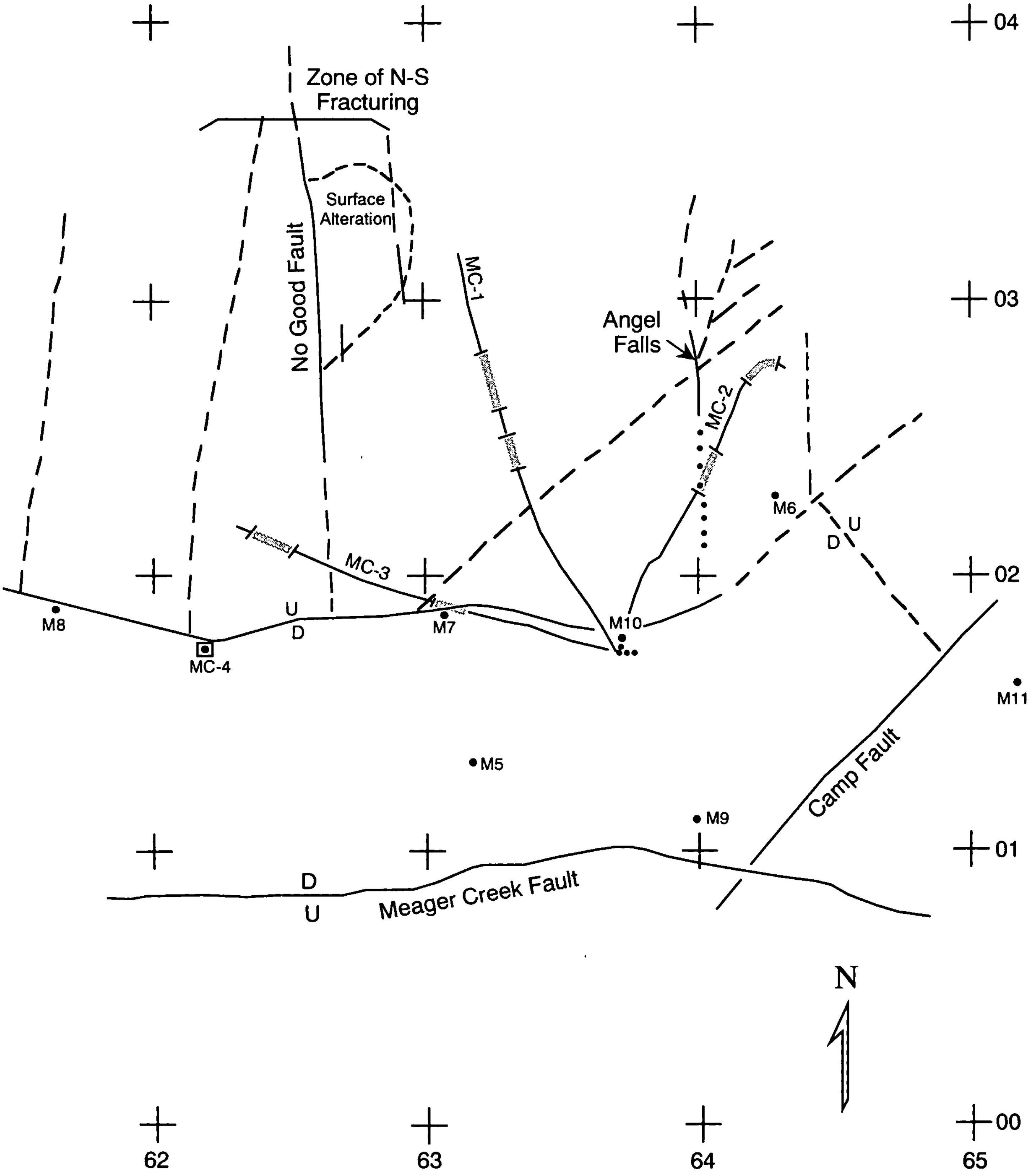


Figure 2. Map showing the location of faults mapped in the field during this study and the locations of existing wells. Crosses are 1 km apart.

N was interpreted from "geomorphic and fracture attitude data". The critical piece of data on the dip of the fault was the compilation of fracture orientations that showed dip angle maxima of 20-50° N. Based on these postulated dips, KRTA geological reports on the production wells subsequently interpreted intersected fracture zones as being the Meager Creek fault. Fairbank (1993) more recently suggested that the Meager Creek fault is a collapse structure with a dip of 50° N.

We have mapped the Meager Creek fault as being a normal fault that forms the southern boundary of an east-west graben (Fig. 2). The northern boundary fault of the graben is represented by the break in slope immediately north of the pad of the deep MC wells. In contrast to previous reports, we suggest that the Meager Creek fault itself is a very steeply dipping structure since the trend of the fault is linear through an area of very rugged topography. Similarly, the northern boundary fault of the graben, which was identified on the basis of morphology, appears to dip at high angles to the south.

Camp Fault

The Camp fault was identified by NSBG (1981) as striking N35°E and dipping vertically. We agree with their interpretation of its geometry. The Camp fault is part of a family of northeast-trending faults that define another graben structure controlling the northeast trend of Meager Creek between the project area and the Lillooet River. Northeast-trending faults were also mapped at Angel Falls where one of the faults hosts a dike of hornblende dacite. The dike has itself been sheared, demonstrating fault movement following the dike emplacement. The lack of alteration and its composition suggest that the dike is related to the Meager Mountain Volcanic Complex.

No Good Fault

The No Good fault was located on the basis of "sharp resistivity contrasts, changes in the subsurface temperature regime and an EM anomaly across the zone" (NSBG, 1980). Fairbank et al. (1981) attempted to verify the structure on outcrops south of Meager Creek and observed a set of north-south trending vertical fractures. Apparently failing to find more concrete evidence, they proposed the term "No Good Discontinuity". Fairbank (1993) interprets the feature as a fault and suggested that it is a major control on fluid flow.

Aerial photographs and observations of the cliffs along No Good Creek clearly show faulting within this zone. The creek appears to occupy the center of a zone of north-south faulting that is approximately 600 m in width. An area of hydrothermal alteration of the volcanic rocks can also be observed within the canyon, principally along the eastern wall. This altered rocks apparently contain abundant pyrite which is manifested by a strong limonitic color.

Another north-trending fault was observed at Angel Falls, although the zone here does not seem to be as wide as that at No Good Creek. In addition, north-trending faulting can be observed along Boundary Creek, to the west of No Good canyon.

Ryan River Lineation

The Ryan River lineation is a northwest-trending feature (Fairbank, 1993), roughly parallel to the trend of the Lillooet River. We were not able to confirm the geothermal significance of this feature or map specific faults that could be related to this lineation.

SUBSURFACE TEMPERATURES

There is an abundance of subsurface temperature information at Meager Mountain, including data from three deep production wells. We reviewed this information in the context of the structural geologic mapping described above in order to better rank potential target zones for future drilling.

Temperature gradient wells, drilled largely within the Meager Creek graben, show anomalously high temperatures generally between the No Good fault and the Angel Creek area, and in the northern part of the graben structure (holes M5, M6, M7 and M10; Fig. 2). Well M10, drilled to an approximate depth of 935 m is isothermal at a temperature of 160° C from approximately 300 m to total depth. This suggests the potential for an intermediate temperature resource that may be controlled by the northern boundary fault of the Meager Creek graben. Note, however, that the relatively cool temperatures recorded in gradient hole M9 suggest that the southern boundary fault (the Meager Creek fault of previous reports) does not function in a similar manner, and may in fact represent a zone of recharge.

The following paragraphs discuss the deep temperature surveys recorded in the production wells MC-1,2, and 3. These wells were drilled between 1981 and 1982, and the principal sources of information are reports prepared by KRTA for BC Hydro. Numerous temperature surveys were run in association with the drilling and testing of these wells. Temperature surveys were also run in 1983-84, but although we have the profiles, there was no supporting information available.

MC-1

Well MC-1 was drilled to the north-northwest to a total depth of 3039 m. The upper portions of the well were drilled with water to about 2350 m, after which mud was used. At 3039 m, attempting to displace mud to water, it was found that circulation was not possible because of mud baked in the collars. A fish with a top at 2511 m was subsequently lost in the hole, and 178 mm perforated liner was run into the well to the top of the fish. Since mud set up in the collars, one can assume that the drilling damaged geothermal entries present below a depth of 2350 m, although the extent of any damage cannot be ascertained. Subsequent testing (KRTA, 1983) suggested fluid in this well was being produced from permeable zones between

1300 and 1400 m and 1550-1650 m and that no entries were present below 1700 m. Several attempts were required to flow the well before it was able to sustain discharge. KRTA states that the source fluid was single phase with a temperature of 194° C.

Figure 3 is a cross section along MC-1 that extends across the Meager Creek graben to M9. The collar for M10 is plotted in the same location as that of MC-1. The contours show the temperature distributions in the upper parts of the wells. The 200°C contour is consistent with the location of the entry that was thought to be sustaining flow.

When the well is plotted on Figure 2 it can be seen that it traverses zones where we have few surface indications of faulting. This may be due to our lack of access and detailed mapping in this area. We suspect that the well intersected permeable zones associated with the northeast-trending faults mapped above Angel Falls. However, the well does appear to be east of the zone of high density fracturing associated with the No Good zone.

MC-2

Production well MC-2 was drilled to the north-northeast from the same pad as MC-1. The well was completed at 3502 m, and 7" slotted liner was run in the well. The well was gradually mudded up between 2200 and 2600 m to reduce drag. A hole in the 9-5/8" production casing was detected, resulting in a 178 mm production tie-back string being set between 915 m and the surface. Efforts to produce the well using air and nitrogen lifts were unsuccessful.

Even the latest temperature surveys (KT2-62,63,64) show a change in gradient at 200 m, and it is probable that 130° C water is entering the well at that point and flowing down the annulus between the production casing and the tie-back string. The KT2-64 temperature survey shows a depressed gradient to a depth of 3450 m, after which the temperature increases rapidly to about 265° C at bottom hole.

Figure 4 shows a profile of MC-2 with M6 projected onto the section. The 100° C temperature contour is relatively consistent between the two wells, whereas the 140°C contour is somewhat depressed in MC-2. The 200° C contour is also depressed, given the relatively high near-surface temperatures.

Permeable zones are marked on the well path on Figure 2. Note that the upper permeable area defined by KRTA is probably developed along the mapped extension of the north-south fault passing through Angel Falls. The lower permeable zone is in an area north-south and northeast-trending faults intersect.

MC-3

Well MC-3 was deviated to the west-northwest, and passed nearly beneath M7, the hottest of the temperature gradient holes. The target for this well was the No Good zone. The

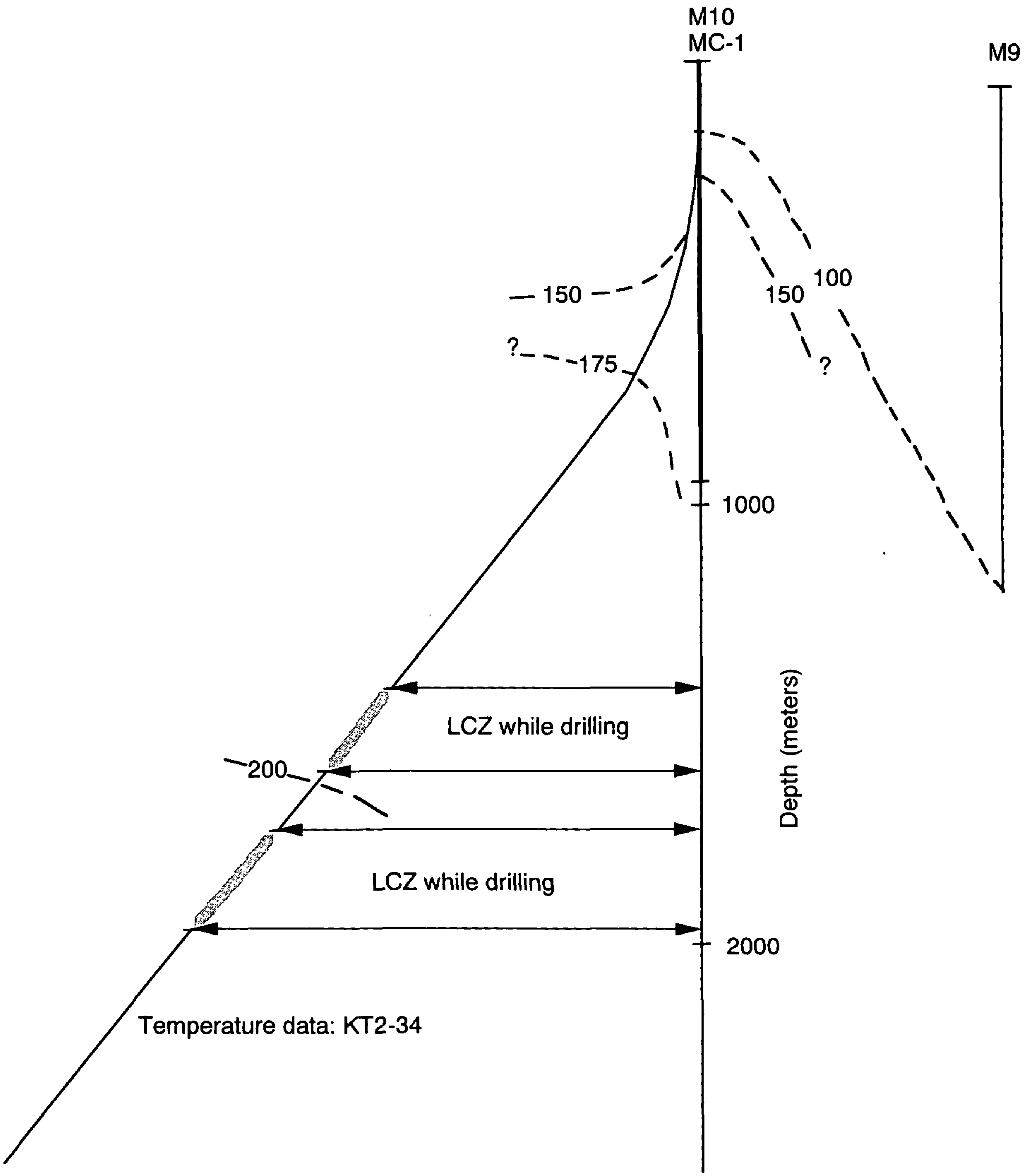

MC-1 Section

Figure 3. Cross section showing the locations of lost circulation zones (LCZ) in MC-1 and the distribution of isotherms between MC-1, M10, and M9.

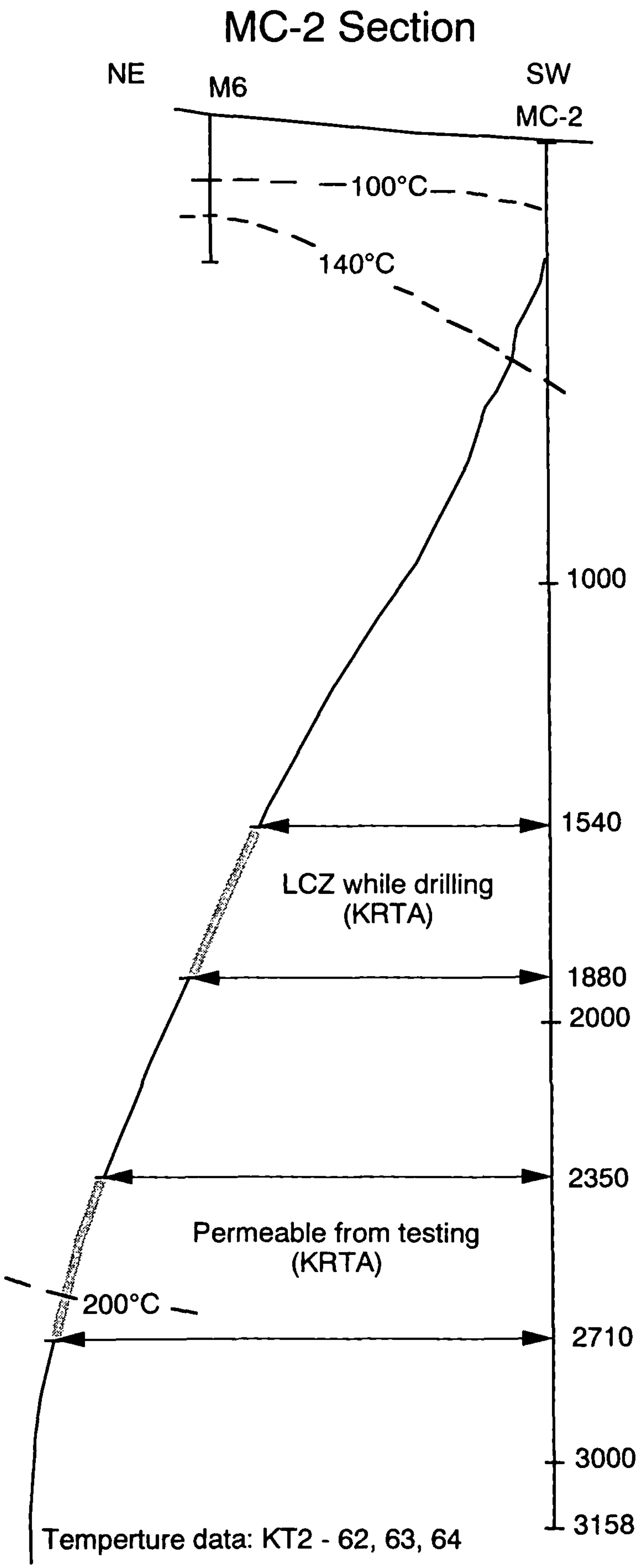


Figure 4. Cross section showing the locations of lost circulation zones (LCZ) in MC-2 and the distribution of isotherms between MC-2 and M6.

well was drilled to a total depth of 3503 m. Drilling below the production casing at 1211 m used a high-temperature sepiolite mud. A 216 mm perforated liner was hung from the production casing to TD. It is notable that the 244 mm production casing was landed at 1189 m and then cemented to the surface in two stages. L. Capuano (personal communication, 1994) indicates that this was done through a cement sleave set at 580 m. Complete displacement was not achieved and it was necessary to do a top job on the casing string.

Efforts to flow the well were not successful. However, a temperature profile run following airlift (ELT-15; KRTA, 1983) shows a maximum measured temperature at 3250 m of 275° C. This plot also shows a rapid decrease in temperature above 580 m. Temperature profiles measured in 1983-84 show that the well is isothermal at a temperature of 160° between 300-400 m and a depth of about 2000 m. Below this depth, the temperature begins to increase gradually. The temperature at this time was 233°C at 3500 m (KT3-35).

Figure 5 is a cross section of MC-3 and M7. Note that the 100 and 150°C isotherms are reasonably consistent between the two wells, but that the 200°C isotherm is extremely depressed in MC-3. One explanation for this could be that the well was drilled under an outflow plume. However, given the mechanical problems with the well, it is more likely that the temperature profile reflects cold water in-flow in the upper portions of the well and drainage of this cooler, denser fluid into the lower portions of the well.

Plots of the identified permeable zones on the structural map (Fig. 2) show that the upper permeable zone could have been related to either the northern boundary fault of the Meager Creek graben, northeast-trending faults, or the intersection of these zones. The lower permeable zone is probably in fractures related to the No Good fault zone.

REMOTE SENSING

Remotely sensed data has long been used for the interpretation of certain geologic features. Their principal usage in geology is to map hydrothermal alteration, structure, lithology, and mineralogy. Geobotanical anomalies are also detectable with the proper data. Remote sensing platforms range from satellite, to airborne, to hand-held. These platforms carry a variety of instruments covering a spectral range from ultraviolet to microwave. Their spatial resolution varies from millimeters to kilometers. Small and medium scale remote sensing data sets, derived from satellite platforms, are especially useful for preliminary exploration reconnaissance on a regional scale, and can aid in the siting of local targets. The importance of this type of data increases in areas with incomplete geologic data coverage.

Since the regional geology of Meager Mountain is incompletely understood and mapped, it was determined that satellite remote sensing data would be useful in gaining a better understanding of the regional structural characteristics, through lineament mapping, and the distribution of hydrothermally altered areas. The data set chosen for this project was from the

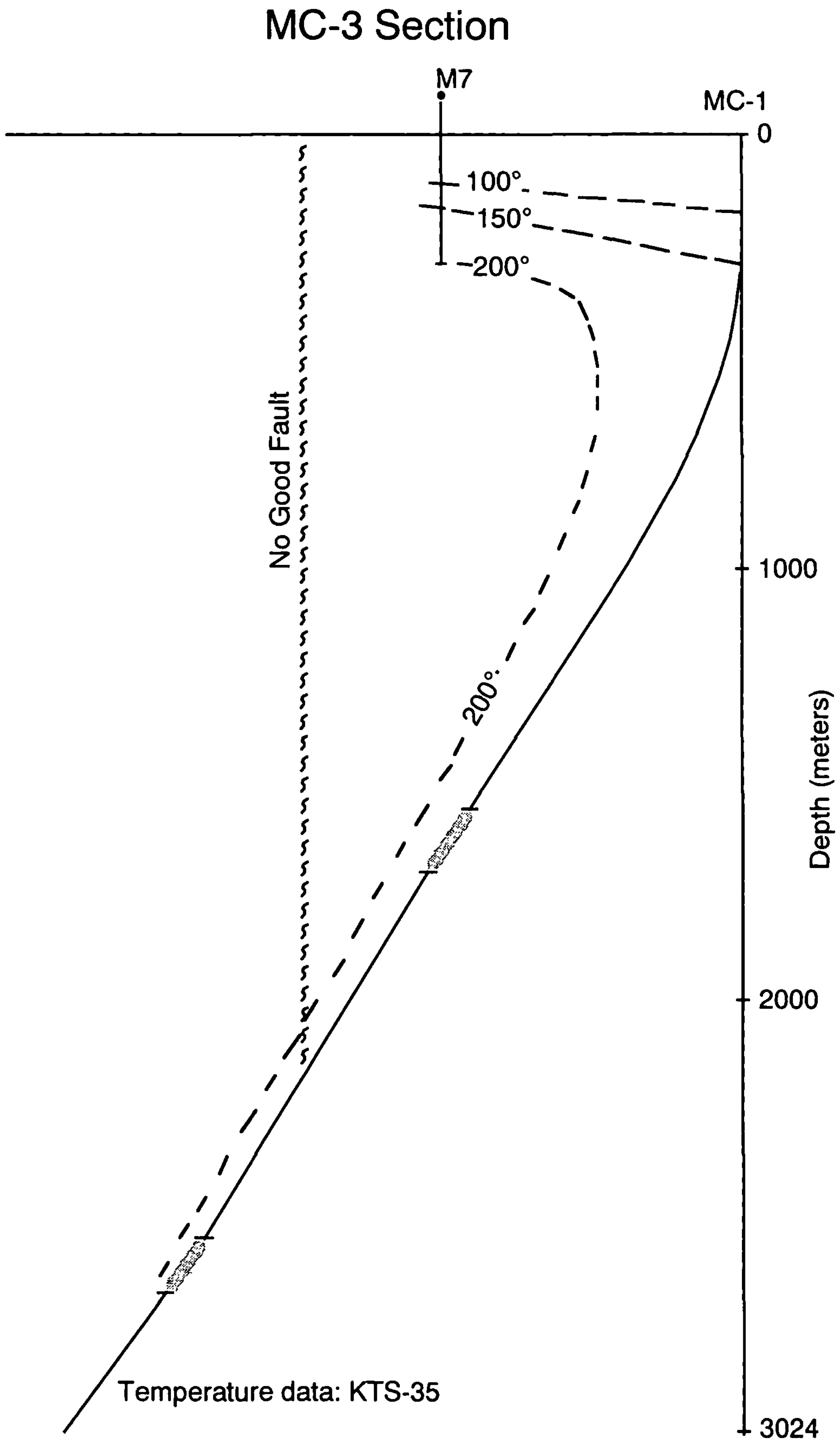


Figure 5. Cross section showing the locations of lost circulation zones (LCZ) in MC-3 and the distribution of isotherms between MC-3 and M7.

Landsat 5 satellite. This data was generated by the Thematic Mapper (TM) imaging spectrometer, which has a broad spectral resolution covering a range from visible blue to thermal infrared, with a spatial resolution of 28.5 meters. This data is best suited for regional reconnaissance investigations. TM data was chosen for this project because: 1) it was the most expedient data to acquire on short notice; 2) it was cost effective; and 3) it had an appropriate spatial resolution.

TM Processing

The remote sensing investigations were performed on a 1° x 0.5° TM scene obtained from EOSAT. The scene was generated on September 28, 1993. This date was chosen because the area is relatively free of snow cover this time of year, and the image was recent enough to show the new clear-cutting that has taken place.

The data was obtained on a 9-track tape and downloaded into our image processing system. Two preprocessing steps were taken to assure optimal quality. The data were first atmospherically corrected using the dark object subtraction method. Secondly, they were rectified, using the nearest neighbor technique, to UTM ground coordinates. This assured true map orientation. The resultant atmospherically corrected, geocoded data, were used for all further processing.

Interpretation

In order to conduct a regional structural interpretation of the scene, the corrected data were used to generate near-photographic quality hard copy images using TM band 7 (mid-infrared), band 4 (near-infrared), and band 1 (visible-blue) assigned as red, green, and blue, respectively, to make a false color composite. The hard copies that were derived from this image included 8.5 x 11 inch prints of the TM scene, and close up shots of Meager Mountain and the adjoining areas. Two of these images, one produced at a small scale showing a region surrounding the Meager Mountain area, and the other at a larger scale are shown in Figures 6 and 7 respectively. A larger scale mosaic was also produced covering nearly the entire TM scene. These images were used to help determine the regional geologic structural relationships.

Surface lineaments were mapped on the images. Although the exact nature of the lineaments cannot be determined from the images, they have been found to have a positive correlation with both mapped structures and the targeting of successful wells in geothermal and groundwater exploration. This is especially true in areas of areas that have high lineament densities with a high occurrence of lineament intersections (Brown, 1994; Bryan, 1990).

Lineaments were mapped for this project using the corrected TM data as a false color composite with the same band assignments used for hard copy generation (Fig. 8). Lineaments were determined from geomorphic properties such as stream morphology. The minimum lineament length mapped was approximately 350 meters.

Lineaments were also mapped from enhanced data. These data were generated by the use of principal component (PC) analysis and convolution filtering. To accomplish this task, the TM image was first reduced to a PC image of which PC 1 represented a near-albedo image. The near-albedo image, which had nearly all of the noise removed (it is placed into a higher principal component), approximates a high quality panchromatic image. This image was convolution filtered with specific kernels for all of the cardinal directions, thus producing eight new filtered images. The new images were then merged, using PC analysis once again. PC 1 of the new image produced a high quality directionally filtered image with enhanced linears. As the possibility increases of mapping nongeologic linears from enhanced data, the lineaments mapped from this data were examined for error by overlaying them on the original image. Lineaments thought to be in error were removed.

The highest density of lineaments on the image are located just to the south-southwest of Meager Creek hot springs. These are generally trending north-northeasterly, and may be caused by jointing in crystalline rock that lies within a zone of extension. The area to the north of Meager Creek also had a relatively high density of lineaments, with the highest density occurring in the No Good Creek area. The longest lineaments are generally north-trending, with shorter lineaments trending to the east, northeast, or northwest. This could indicate the potential for intersections of lineaments in this area, especially if mapped lineaments are projected beyond what could be seen on the imagery. We suspect that the generally north-trending lineaments are related to regional east-west extension, while the east-trending lineaments appear to be local structural features related to the east-striking fault along Meager Creek.

Hydrothermal alteration mapping was also conducted using the TM data. This type of mapping can be accomplished on multispectral data using several different techniques. Two well documented methods include the use of band ratios (Drury, 1987; Ebel, et al., 1993) and the use of feature oriented principal component selection (FPCS) (Crosta and Moore, 1989).

The band ratio method allows the highlighting of certain features by using the ratio of an extremely bright portion of the spectrum, with that of an absorptive part of the spectrum. The ratios used in hydrothermal alteration highlight hydrous minerals, and iron. For the Meager Mountain image, band ratios were only partially successful. This is due to the fact that the images contain extensive areas of vegetation, snow fields and glaciers. The TM band ratio that is used to highlight clay alteration also highlights water absorption. Vegetation and water are typically masked out before the ratio is initiated to reduce confusion. The vegetation and snow in this image were found to be impossible to mask adequately, using conventional techniques. Therefore, the FPCS method was attempted.

In FPCS analysis, eigen vectors produced from principal component analysis are used as a guide to hydrothermal alteration. TM bands are selected to achieve optimal probability that at least one principal component will be produced that contains the desired information. This process will also often result in the placement of unwanted features, such as vegetation and water, into a different principal component. This process was also found to be only partially successful for the Meager Mountain image.

Band ratioing was successful in producing the desired results for ferric iron using the TM 3/1 ratio. FPCS produced the desired results for OH^--bearing (hydrous) minerals and limonite. This included the subduing of vegetation. Therefore, the ratioed TM 3/1 image and the FPCS results were combined into a three band composite. Snow was still a problem in this image, but it was mostly remove by using a mask produced from a TM 5/1 ratio. In the resultant image, shown in Figure 9, areas of potential hydrothermal alteration are bright yellow or bright white. These colors resulted from the combination of OH^--bearing minerals being represented by red, ferric iron being represented by green, and limonitic material being represented as blue. Hydrothermally altered areas generally contain a combination of the above minerals and therefore appear as yellow (OH^--bearing minerals + ferric iron) or white (OH^--bearing minerals + ferric iron + limonite). The most abundant hydrothermal alteration in the area north of Meager Creek occurs in the No Good Creek area.

GEOPHYSICAL DATA

Aeromagnetic Data

Aeromagnetic data are often useful in defining major structural features such as faults and fault zones, and the location of discordant igneous bodies, in geothermal environments. Inquiries by Pacific Geopower to the Geological Survey of Canada revealed that no detailed or even quality reconnaissance aeromagnetic survey data that included the Meager Mountain area were available. There did not appear to be time to fly new surveys, and the potential geological value of new data versus cost was uncertain, so UURI did not request that new surveys be flown. No additional effort was expended upon this proposed interpretation task.

Gravity Data

Regional gravity data are sometimes useful in defining regional structures that control fluid flow within geothermal systems, although extreme terrain variations at Meager Mountain could preclude the recognition and interpretation of subtle density contrasts. Inquires to the Geological Survey of Canada indicated that reconnaissance gravity data were available for the Vancouver, British Columbia 4 by 6 degree quadrangle (scale:1:1,000,000). Inspection of Free Air and Bouguer Gravity maps for the quadrangle show that the Meager Mountain lies within the southern lobe of a large Bouguer gravity low (-30 to -70 mGals, 45 km (N-S) by 10 to 20 km (E-W)) within the Coast Mountains. The entire gravity low may indicate that the Meager Creek area is only part of a much larger igneous-volcanic complex. Unfortunately, the contoured map only has about 5 gravity stations within the 400 sq km area that includes Meager Mountain. Thus the data density, and map scale are not appropriate for any detailed studies.

Magnetotelluric Survey

In the magnetotelluric (MT) method, natural electrical and magnetic fields are measured as a function of frequency to determine electrical resistivities from near surface to crustal depths. Although some data has been collected from the Meager Mountain area, it is sparse and limited to 13 stations within an area of about 600 sq km (Ngoc, 1978, 1980). The distribution of these stations are shown in Figure 10. Unfortunately, these data are far too limited to be useful in developing a detailed resistivity model of the prospect area. Figure 11 reproduces a regional-scale interpretation by Ngoc (1980) which does infer fracture zones, but with a resolution on the order of kilometers.

Electrical Resistivity Data

Electrical resistivity is the most important physical property of geothermal systems which can be readily measured. The wide range of resistivity variations in many geothermal systems, often from <1 to >10,000 ohm-m in fractured crystalline host rocks, provides a basis for the detection of conductive fault and fracture zones, conductive thermal fluids, and low resistivity alteration zones.

An extensive electrical resistivity database was acquired at Meager Mountain between 1974 and 1980, often with helicopter support, and presumably at considerable expense. All the resistivity work completed at Meager Creek is discussed in considerable detail by Shore and Schlax (1982). The data available are of two different types:1) in-line dipole-dipole profiles; and 2) pole-pole survey data in which one current electrode and one potential electrode are located a substantial distance away from the area being surveyed. The geometries and generalized data reduction formulae for these resistivity arrays are shown in Figure 12. Only those data relating to PGP's lease holdings and the immediately adjacent terrain are discussed in this report.

Dipole-dipole survey data.

As indicated in Figure 12, dipole-dipole resistivity data are obtained in an in-line configuration which results in a relatively dense data plot. Larger separations between the transmitting and receiving (potential) electrodes correspond to increasing depth of current penetration, and to greater lateral sampling. Figure 13 (after Shore, in NSBG, Ltd., 1979) identifies dipole-dipole line locations and indicates the pole-pole resistivity corridors (i.e. C615) in the surveyed areas. Figure 14 summarizes anomalous (low apparent electrical resistivity) areas interpreted by Premier Geophysics, McPhar, and others (NSBG, Ltd.,1979). Most significant to the present study are Lines D and K which trend east-west in the Meager Creek drainage, north of the creek.

A principal goal of the present study was to improve on the resolution of anomalous areas shown in Figure 14, to identify those anomalous areas which may have low resistivity zones at depth and distinguish them from areas with only superficial low resistivity layers, and to locate possible geologic structures that are expressed in the data. We have reviewed data for Lines K, J, H, G, and T whose locations are shown on Plate 1. Our interpretative results are summarized on

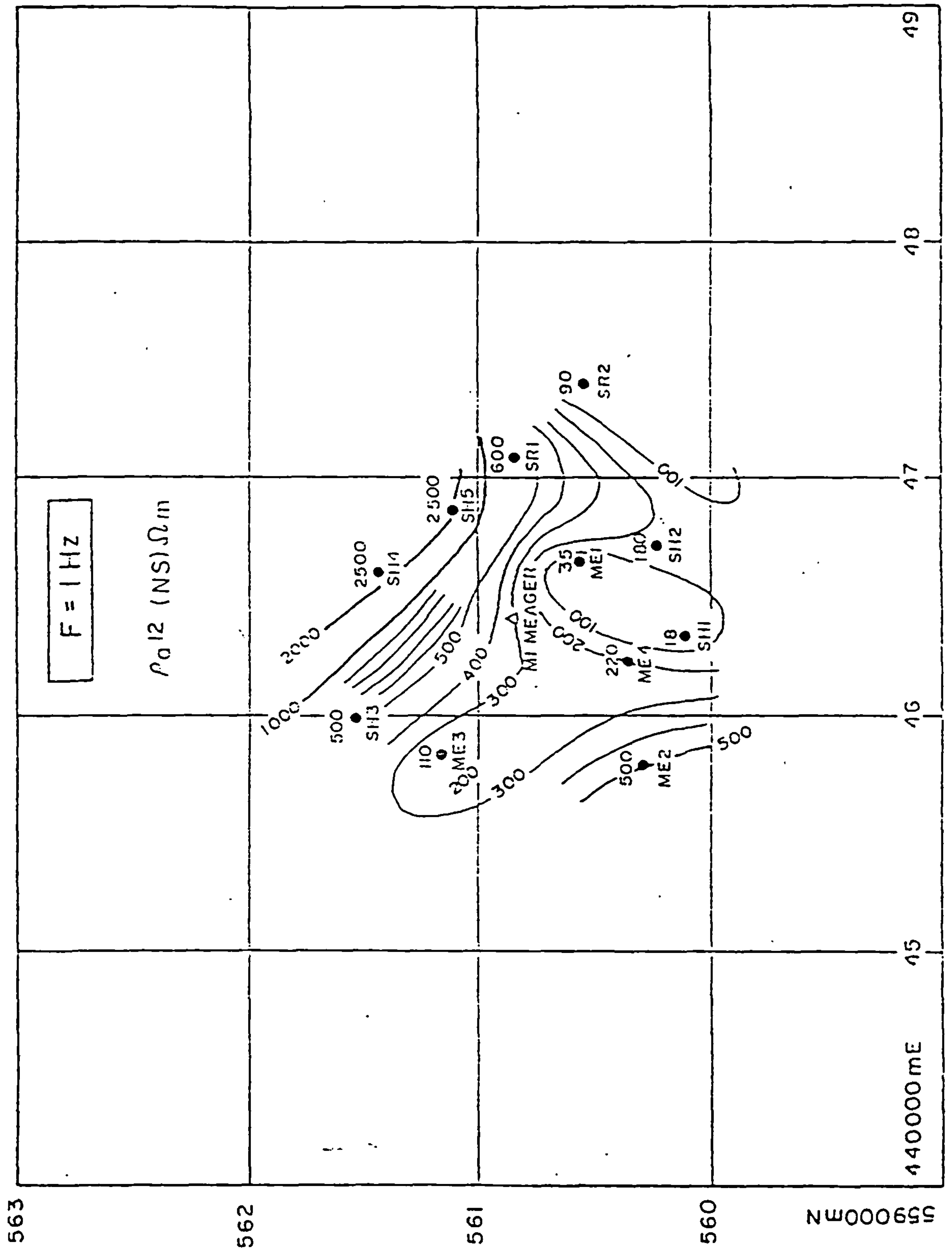


Figure 10. Location of magnetotelluric (MT) stations in the Mt. Meager area, British Columbia. Station identification (ME2) and apparent resistivity (500) in ohm-m for 1 Hz are shown. From Pham Van Ngoc, 1980.

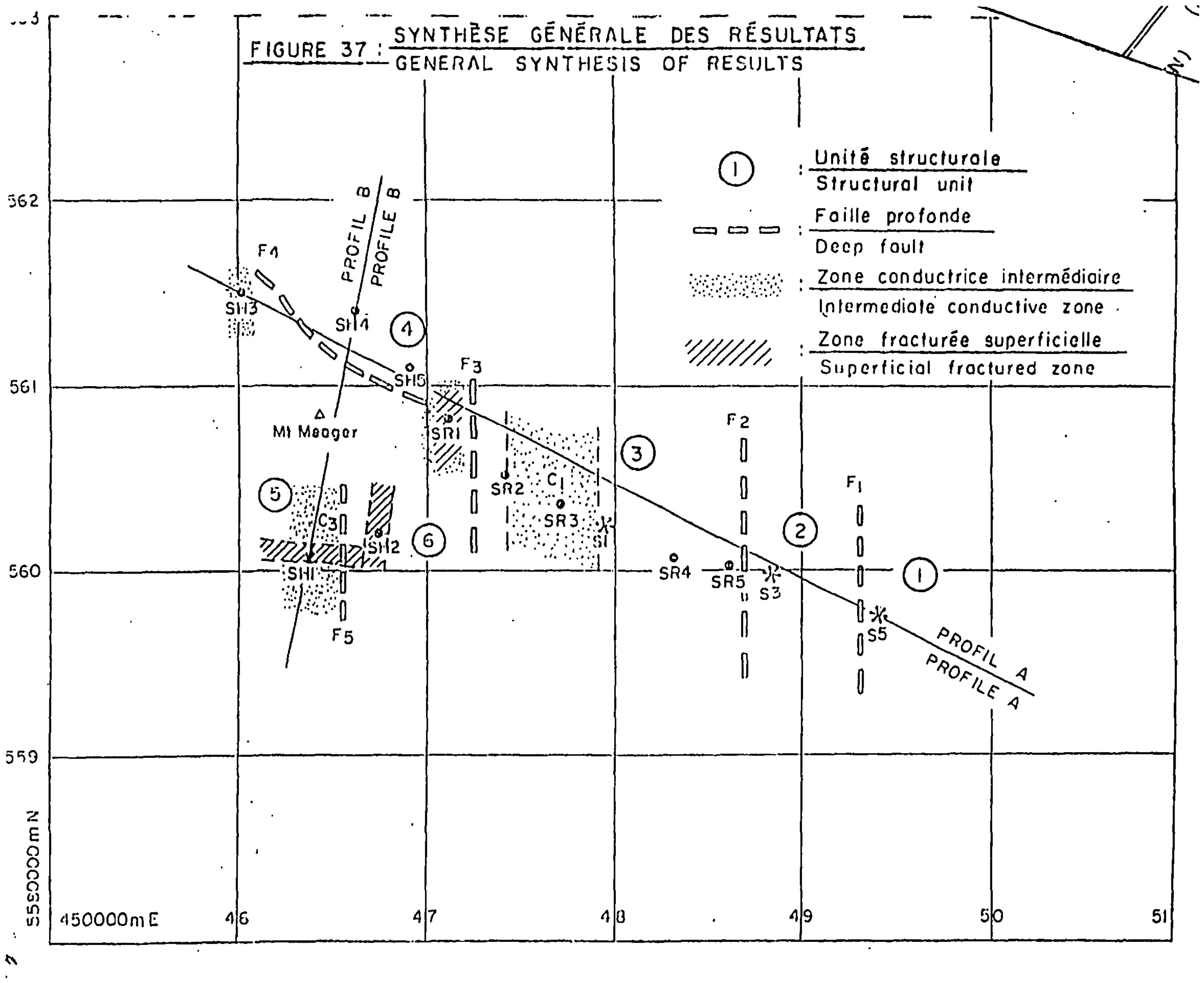
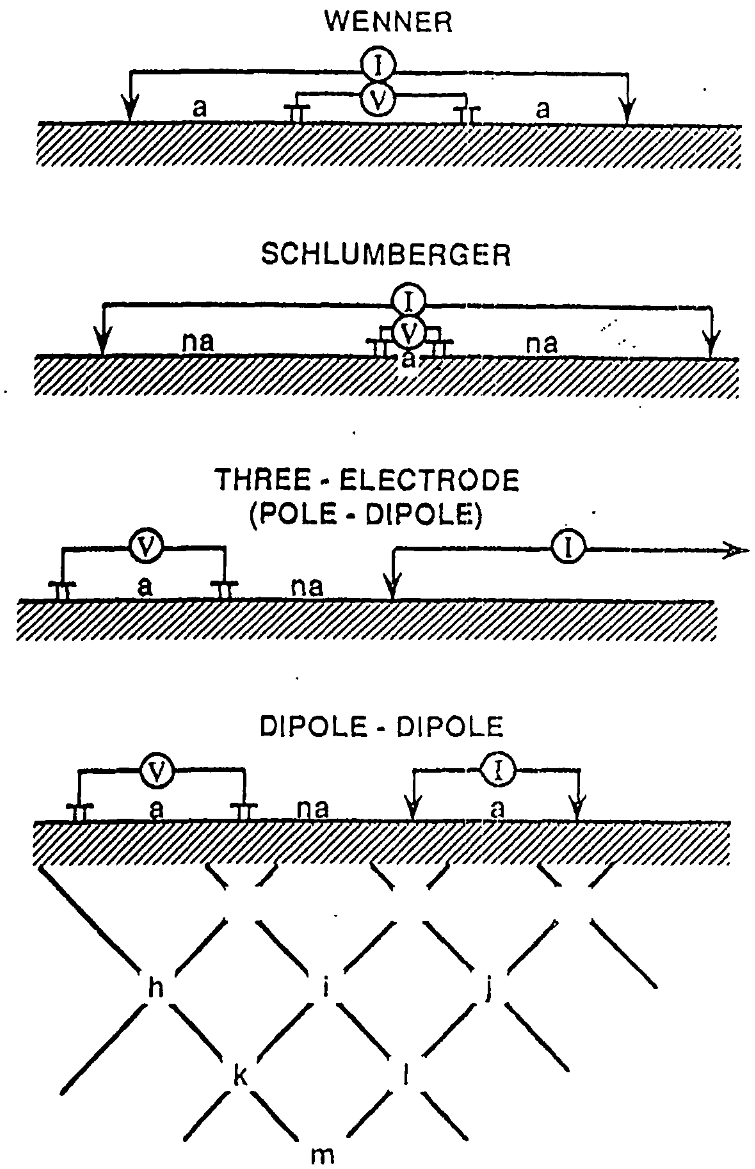


Figure 11. General synthesis of MT results for the regional Mt. Meager area, British Columbia. From Pham Van Ngoc, 1980.



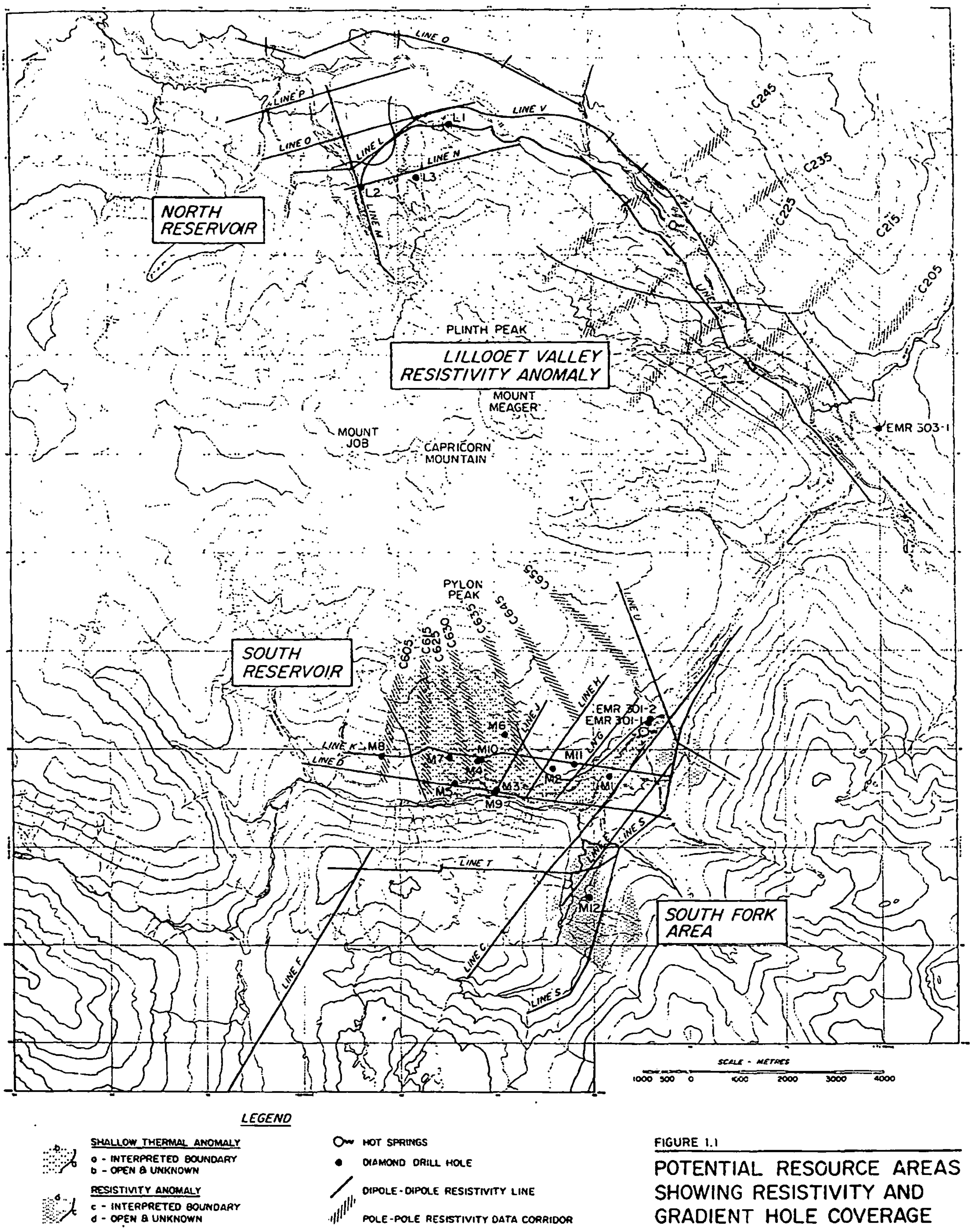
$$\rho = 2\pi \frac{V}{I} a$$

$$\rho = \pi \frac{V}{I} n(n+1) a$$

$$\rho = 2\pi \frac{V}{I} n(n+1) a$$

$$\rho = \pi \frac{V}{I} n(n+1)(n+2) a$$

Figure 12. Electrode alignment and apparent resistivity formulation for common resistivity arrays. The pole-pole array used by Premier Geophysics, Ltd. may be considered a special case of the Three-electrode (pole-dipole) array in which one potential (V) electrode is removed a great distance and remains a constant reference voltage for a given resistivity line or corridor.



Fiure. 13. Location of dipole-dipole resistivity lines (C, D, F, G, H, J, K) pole-pole resistivity corridors (C605, C615, etc.), and drill holes at Meager Creek, British Columbia. From NSBG, Ltd., 1979.

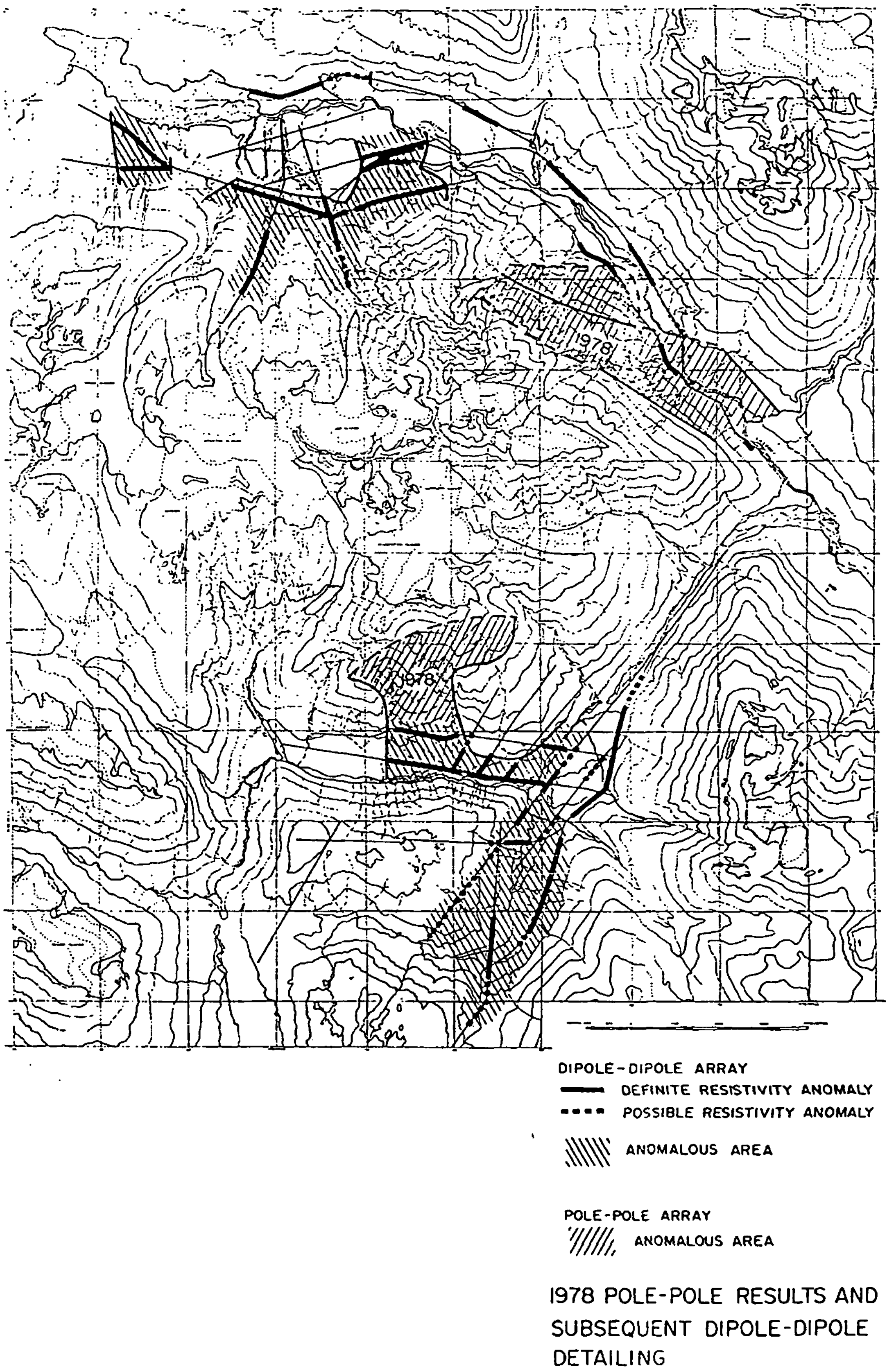


Figure 14. Anomalous areas based on resistivity surveys as summarized in NSBG, Ltd., 1979.

Plate 2 which shows the distribution of high and low resistivity areas and the locations of possible structures indicated by the data.

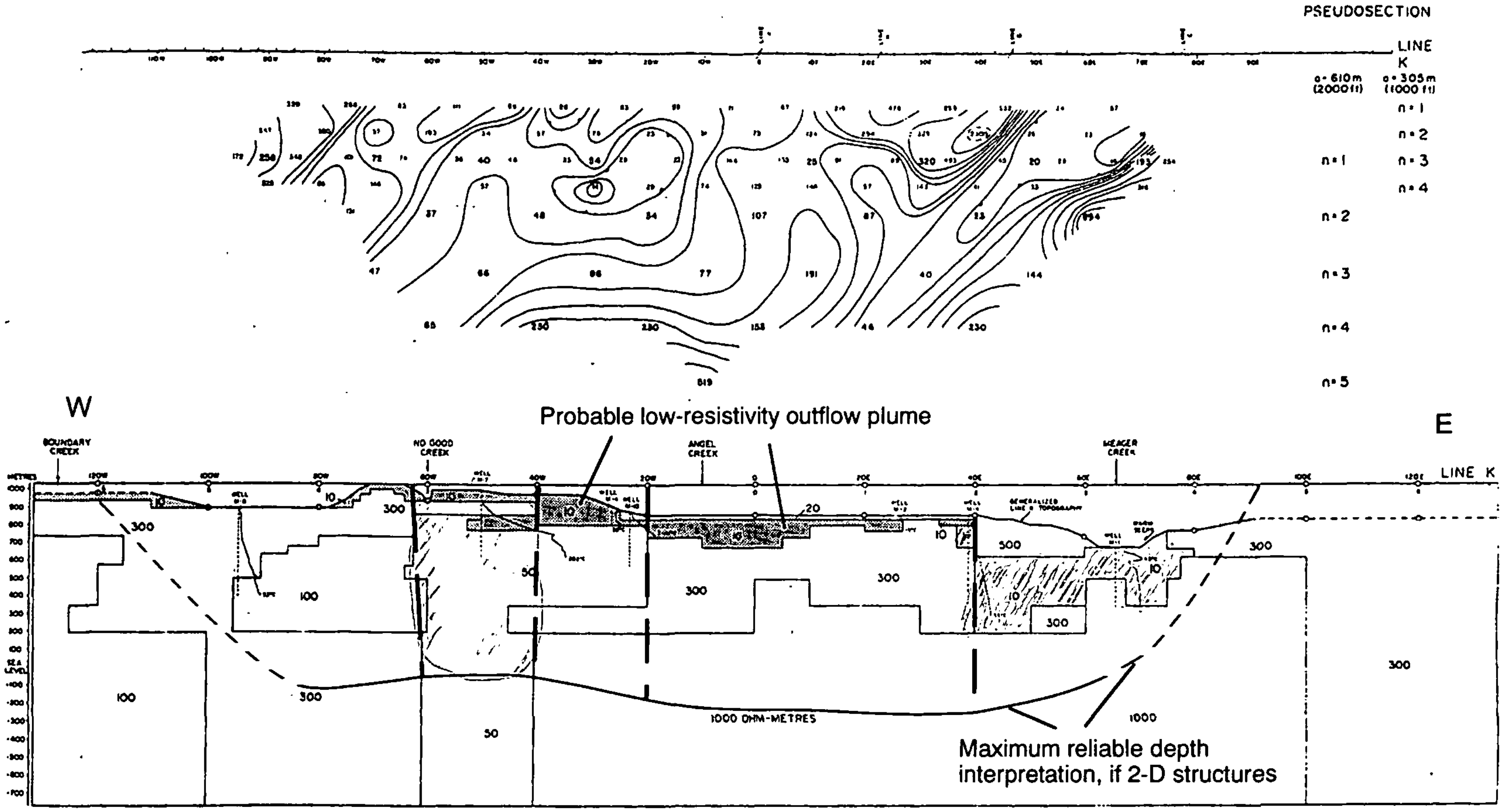
Line K was selected for numerical modeling at UURI in 1981. We are not familiar with the details of the goodness-of-fit match between observed and modeled data, but express confidence in the model results. The numerical modeling results offer much greater resolution of resistivity contrasts and resistive bodies than any qualitative or inspection method. In addition two alternate models were offered, and the primary features of the resistivity distribution are similar. Model A, Line K is reproduced as Figure 15, with clarifying comments and interpretation from this review. The maximum reliable depth to which the data can be interpreted for a two-dimensional resistivity distribution perpendicular to the line is approximately 1000 m. The spatial resolution of interpreted resistivity bodies is about 100 m near the surface and 150-200 m at depth. The model shows geometric blocks with interpreted resistivities that range from 10 to 1000 ohm-m. The 10 ohm-m near-surface layer was interpreted by Shore and Schlax (1982) to be an outflow zone of thermal waters. This is a reasonable interpretation of the data, and we find no evidence to dispute it. Sharp resistivity contrasts extending to depth are modeled at Stations 60W (No Good Creek), 40W, 20W, and 40E. We interpret these discontinuities as near-vertical faults which trend nearly normal (north-south) to the survey profile.

Data were not available for Line D which contains evidence for a shallow low resistivity layer, but we have reviewed interpretative comments by a consultant, Dr. Stanley H. Ward, and the data appears similar to, and consistent with, those of line K just to the north. These observations were used to establish the resistivity distributions in the No Good Creek area.

Line J is a partial line which trends northeast from drill hole M3. These data may have been cited as evidence for a conductive zone dipping to the north. Our interpretation, supported by reference to standard numerical models, is that a sharp resistivity contrast occurs between Stations 20N and 30N, with higher resistivities to the north. The apparent dip of the low resistivity values is typical for that of a vertical or near-vertical resistivity contrast, and does not necessarily indicate a dipping conductive zone.

Line H is a partial line which trends northeast near drill hole M2. It indicates a major resistivity contrast just south of Station 20N, with very high resistivities to the north. South of 20N low resistivities occur within 150 m of the surface, and probably continue to at least 305 m depth. Line G is also a partial line which trends northeast, east of drill hole M11. High resistivities occur north of Station 20N, quite similar to Line H.

We have inspected data for lines C, F, S, and T, to better understand the regional resistivity variations. In general, resistivities along these lines are relatively high and provide no indication of significant thermal fluids or alteration south of Meager Creek. The resistivity distributions along these lines cannot be meaningfully projected into the prospect area, and as a result the data are not reported here.



MODEL A One result of "IP-2D" (University of Utah Research Institute) forward two-dimensional modelling program. A•610 m data only were used. Test well collar elevations are adjusted to fit Line K topography in order to compare temperature profiles with interpreted resistivities

Computer Modelling of Resistivity Data - Line K South Reservoir Area

/ Probable north-trending faults or fault zones.

Lateral resolution < 150 m.

Figure 15. Computer modeling of resistivity data, dipole-dipole line K. Note the probable maximum limit of resolution, and interpreted structures, suggested by this review.

Pole-pole survey data.

The pole-pole data were acquired by Premier Geophysics Inc. and have been reported in detail in NSBG, Ltd. (1979). The details of the method, the array geometry, and data reduction are reported in that document and are not repeated here. The logistics and geometry of the dipole-dipole array restricted this method to terrain of low-moderate relief and reasonable access. Thus, the survey was restricted primarily to the Meager Creek drainage. The pole-pole array was employed by Premier Geophysics as perhaps the only electrical resistivity array which could provide survey coverage over the imposing terrain and difficult logistics on the south side of Meager Mountain

In the pole-pole array, the current return electrode is located some remote distance from the area to be surveyed, as is the reference potential electrode. Variations in the observed apparent resistivity are due to the position of the roving current and potential electrodes, and the electrical resistivity variations along the corresponding (and ill-defined) current path. In our review of these data, we seek to define any areas of lower apparent resistivity that could be identified from the pole-pole data plots presented by Premier Geophysics, Ltd. in NSBG, Ltd. (1979), Appendix B-2.

Our approach has been to examine the pseudo section plots for the relevant pole-pole corridors presented in NSNG, Ltd (1979). Each corridor (Fig. 13) is the terrain between roving current and potential electrode positions for a large number (50-70) of variations of electrode placements, each of which results in an apparent resistivity value. In studying the pseudosections C605, C615, C625, C630, C635, C645, C655, we identified a number of apparent resistivity values that appear anomalously low (10-40 percent) compared to other resistivity values, and which are not obviously related to either the conductive volcanics identified to the north, or to the shallow conductive layer to the south. Using the tabulated data printouts in Appendix B-1 (NSBG, Ltd. 1979), we have replotted the position of electrode midpoint (MD) at depth (Appendix B-3) and tied this to the corresponding current (CE) and potential electrode (PE) positions. We plotted this path (CE-MD-PE) as a line on maps overlying the survey map. Separate maps were constructed for low- and high-resistivity CE-MD-PE paths. Low resistivity values were arbitrarily taken as those that were 20% or more less than background values. The maps were then compared to determine areas of consistent low and high resistivity.

Our rationale for this technique is that much of the southern part of Meager Mountain has high apparent resistivity (400-4000 ohm-m). Small volumes of fractured rock with alteration and low-resistivity fluids may substantially decrease the observed apparent resistivity when aligned along certain current-potential electrode paths in contrast to other areas. Thus, a reduction of 20% apparent resistivity for the bulk sampling pole-pole array could well indicate a significant volume of lower (<100 ohm-m) rock.

Table 1 presents some statistics regarding the pole-pole resistivity data, and our plotting of selected CE-MD-PE resistivity paths. Additional higher resistivity current paths could have

Table 1. Pole-Pole Resistivity Data Analysis.

Pole-Pole Corridor	Lower Apparent Resistivity	Higher Apparent Resistivity	Not Plotted	Total
605	16	21	22	59
615	21	25	19	65
625	13	21	31	65
630	13	12	44	69
635	9	13	44	66
645	14	10	36	60
655	6	13	46	65
Totals	92	115	242	449

been plotted, but not in the vicinity of the lower resistivity current paths. Note that 207 of the 449 pole-pole apparent resistivity values, about 46 percent, are represented in our analysis.

The results of the resistivity analysis are shown on Plate 2. Most of the lower apparent resistivity zones are elongate north-south, especially near the No Good Fault area. Northwest- and northeast- trending zones are also mapped in this area. The range of apparent resistivities is indicated for the lower resistivity zones, and these are often 20 to 50 percent the values for the background. Note however, that these are apparent resistivities rather than true resistivities, and that the distribution of low resistivity areas could have been influenced by topographic effects and near surface alteration effects. None-the-less we believe that Plate 2 represents the best attempt at resolving low and high resistivity areas from the pole-pole data. Even after this effort, the areas including lower apparent resistivity zones represent only about 50 percent of the total area. However, the correspondence with low resistivity zones from the dipole-dipole data to the south is good, and as discussed in the Summary, there is a general correlation between the resistivity structure and the results of geologic and remote sensing studies.

FLUID GEOCHEMISTRY

The compositions of the thermal waters found on and near Meager Mountain have been examined by Ghomshei et al. (1986), Adams and Moore (1987), Ghomshei and Clark (unpublished manuscript), and Clark et al. (1993). The data discussed in this report were taken from the tables published in these works.

The Meager Mountain thermal waters can be grouped into categories (Table 2), as was done by Adams and Moore (1987). Waters from the hot springs and some of the shallow wells (EMR 301-1, EMR 301-2, and M-1) are all relatively homogeneous, with salinities of approximately 2000 ppm and maximum measured temperatures of 50 to 60°C. A group of waters that are lower in temperature than the hot springs but higher in their salinities have been found around Meager Mountain, and will be referred to as the saline thermal waters. These waters discharge from M-12 and springs on the south side of Meager Creek. The highest temperature water was found in the deep well MC-1. This fluid has a salinity twice that of the hot spring fluids and a measured temperature of approximately 200°C.

The relationships between these fluids are illustrated in the enthalpy-chloride diagrams shown in Figures 16 and 17. The Na/K (Fournier, 1981) temperatures, which generally record the highest temperatures, were used to define the enthalpy of the fluids in Figure 16. This plot shows that the hot spring fluids record original temperatures slightly higher than those of the deep thermal MC-1 fluid, but not significantly so. Although there is considerable scatter among the data points, the nearly linear relationship they display suggests that the fluids could be related to each other by mixing and that MC-1 fluid could be a mixture of the thermal and saline thermal waters. Such an origin for the MC-1 fluid, however, is not supported by the isotope data. Irrespective of the actual mixing relationships among the fluids, the enthalpy-chloride data

	1	2		3	4
	Low TDS NaCl fluid	Moderate TDS NaCl fluid		High TDS NaCl fluid	Low TDS $NaHCO_3$ (-SO_4) fluid
		Flashed	Reservoir		
Na	435	1385	1132	3600	423
K	56	103	84	136	17
Ca	85	39	58	490	33
Mg	26	0.8	0.65	240	5
SiO_2	189	326	266	164	85
B	3.3	9.0	7.35	38	2.4
Li	1.2	3.19	2.61	7.6	0.7
HCO_3*	330	85	2660	3535	724
SO_4	152	117	96	1820	329
Cl	661	2130	1740	4230	82
F	0.3	2.1	1.72	0.32	8.8
TDS	1938	4160	4745	12463	1695
pH (20°C)	6.6	8.4	5.9**	7.1	6.9
Temp. (°C)	57	97	194	22	60
$\delta^{18}O$(SMOW)	–16.4	–7.7	–8.7	–14.2	–19.6
δD(SMOW)	–126	–86	–91.7	–120	–141

Table 2. Representative chemical and isotopic compositions of thermal fluids

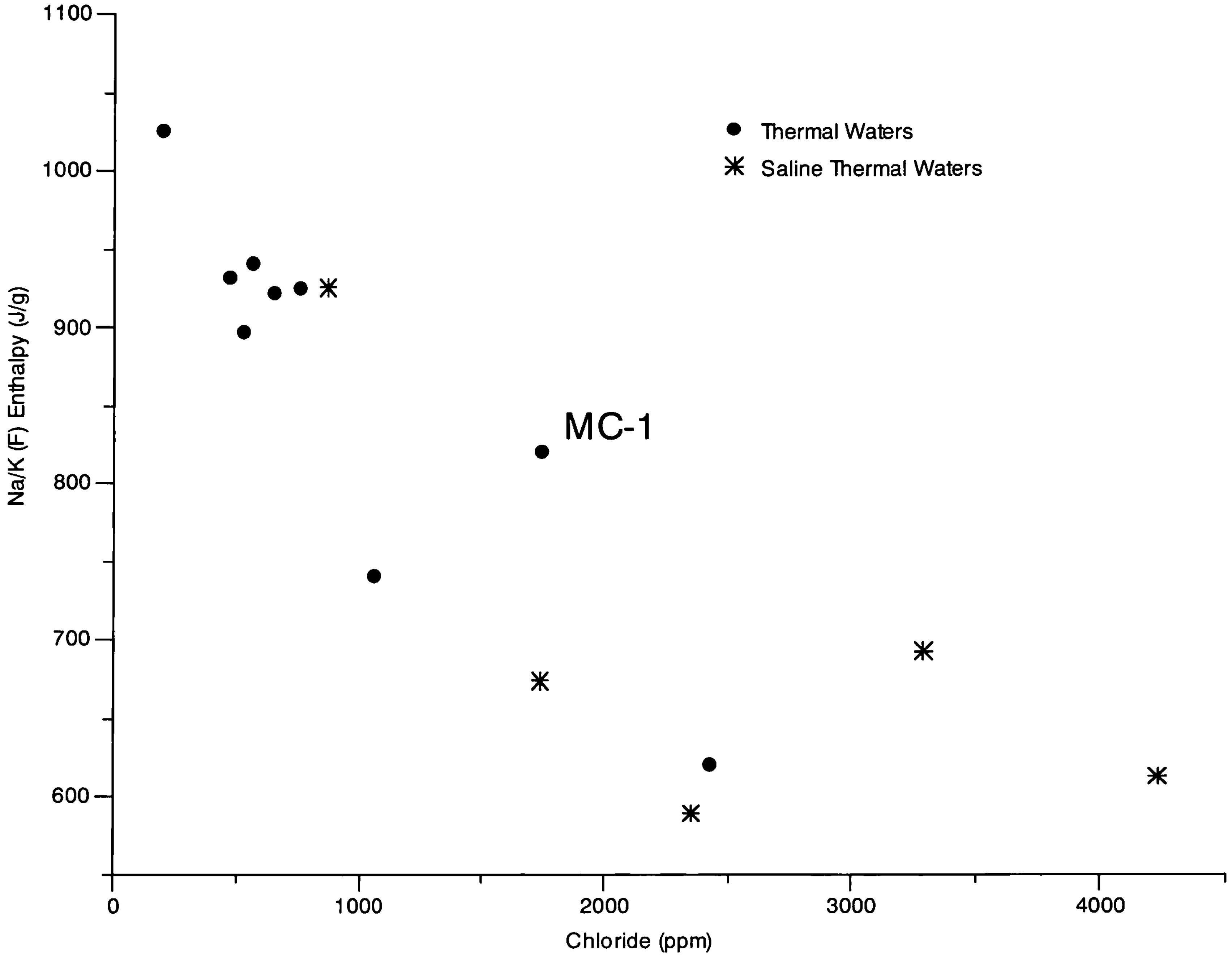


Figure 16. Enthalpy-chloride diagram of thermal and saline thermal waters. Enthalpies in Joules/gram (J/g) were determined from the Na/K geothermometer of Fournier (1981).

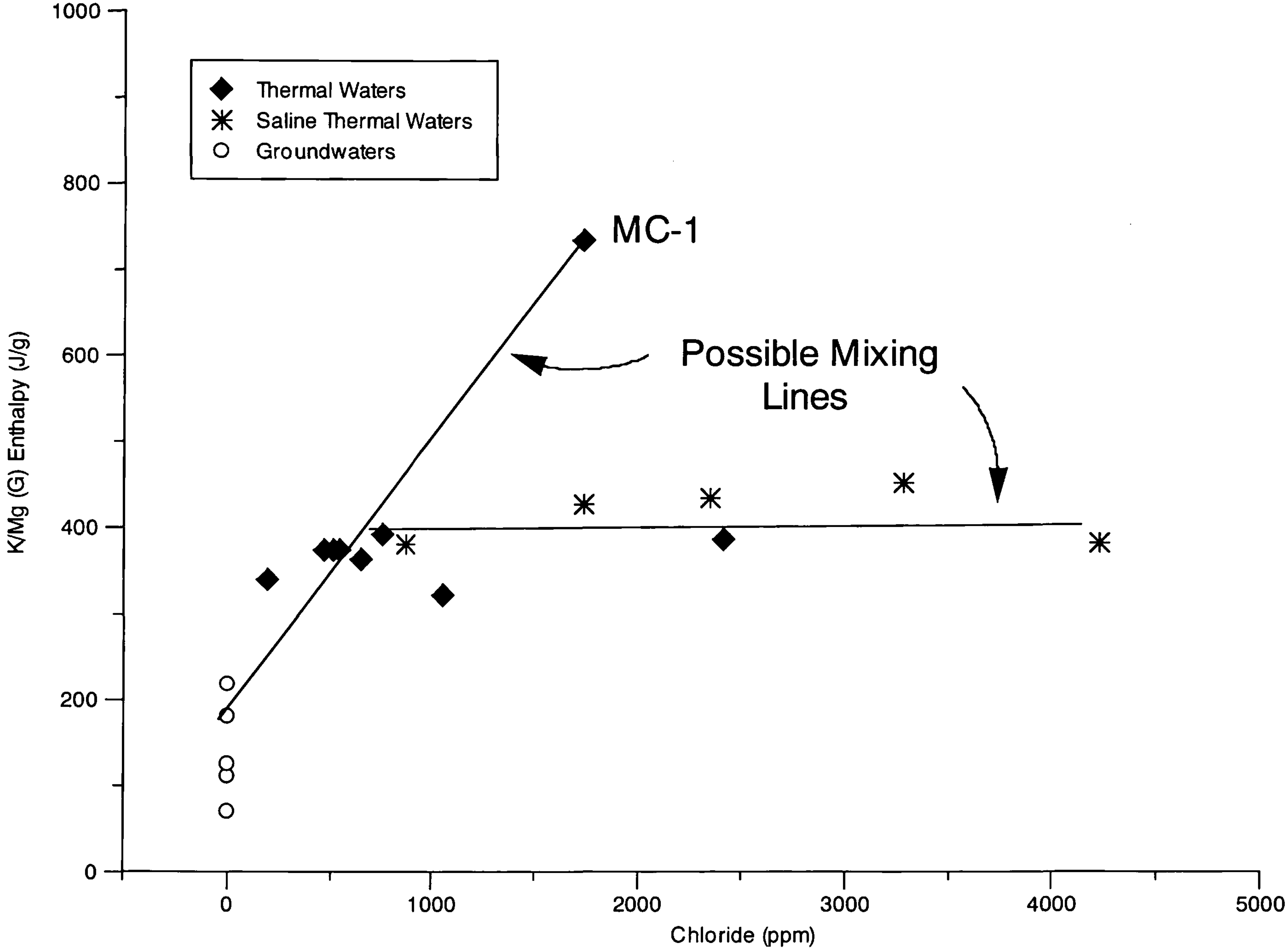


Figure 17. Enthalpy-chloride diagram showing relationships between the thermal waters, saline thermal waters and groundwaters. Enthalpies in Joules/gram (J/g) were calculated from the K/Mg geothermometer (Giggenbach, 1988).

nevertheless allow the possibility that the parent of the hot spring waters was hotter than that of the fluid discharged by MC-1.

Figure 17 shows the same fluid variables, except that the geothermometer used to calculate the enthalpies of the fluids is based on the K/Mg ratio of the fluids (Giggenbach, 1988). Unlike the Na/K geothermometer, the K/Mg geothermometer continues to record equilibrium temperatures as a fluid cools. The relationships shown in this diagram indicate that the hot spring fluids could be mixtures of MC-1-type fluid and groundwater. This mixing relationship is consistent with the stable isotope compositions of the fluids. In addition, the thermal saline waters appear to be a mixture of a low-temperature saline end member and the hot spring waters. However, the stable isotopes compositions are too scattered to substantiate any mixing trends involving the saline thermal waters.

The silica concentrations of the hot spring fluids are anomalously high for a low-temperature geothermal fluid. Plotting the silica concentrations versus measured temperature reveals that the hot spring fluids lie along the amorphous silica solubility curve, while groundwaters and MC-1 fluid lie along the of the quartz solubility curve (Fig. 18). This is unusual because the silica concentrations of the thermal waters, which appear to be mixtures of unboiled MC-1 water (see below) and groundwater (Fig. 17), should lie between the these two end members. An example of silica-enthalpy relationships which are more characteristic of mixing is shown in Figure 19. The data are from the Steamboat, Nevada geothermal system which is hosted in silicic crystalline rock similar to that found at Meager Mountain.

There are several possible mechanisms that can lead to the high silica contents of the thermal waters. These include conductive cooling of a high temperature fluid, concentration by boiling, the increased solubility of silica in an acid fluid, or equilibration at moderate temperatures with rock containing amorphous silica that was readily available for leaching. Such a source of silica would be found in fresh extrusive or hypabyssal volcanics rich in glass. The chemistries of the hot spring fluids show no signs of high acidity or evidence of a high temperature origin (above 300°C), so boiling or equilibration with fresh volcanic rock is the most likely possibility. However, if the parent fluid boiled from the temperature indicated by the Na/K geothermometer, it would have had to boil to near-atmospheric temperatures from about 200°C. The effects of boiling on the silica concentration of fluid from MC-1 are shown in Figure 19. The lack of fumarolic activity near the hot springs on the south side of Meager Mountain, suggests that boiling is not the cause of the high silica contents. Based on these observations, we suggest that the most probable mechanism for producing the high silica contents of the thermal waters is through interactions with glassy volcanic rocks.

Geothermometry

Chemical geothermometry of the Meager Mountain thermal fluids indicates that the maximum temperature that these fluids have achieved is within the range of 200° to 220°C. The calculated temperatures of the MC-1 quartz (Fournier and Potter, 1982), Na-K-Ca-Mg (Fournier

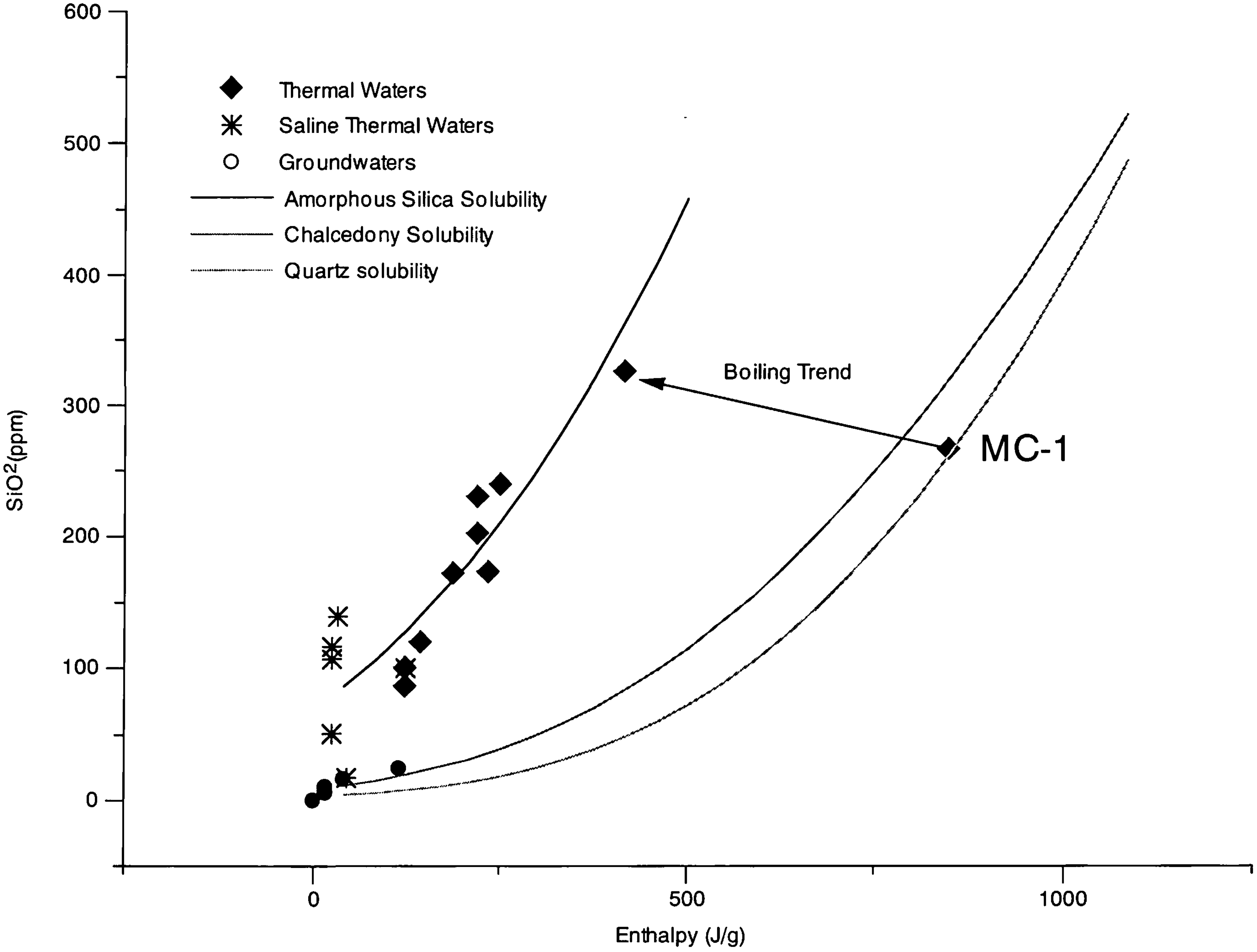


Figure 18. Silica contents vs. enthalpy (Joules/gram) of waters from Meager Mountain. Solubility curves for quartz, chalcedony and amorphous silica are shown. See text for discussion of figure.

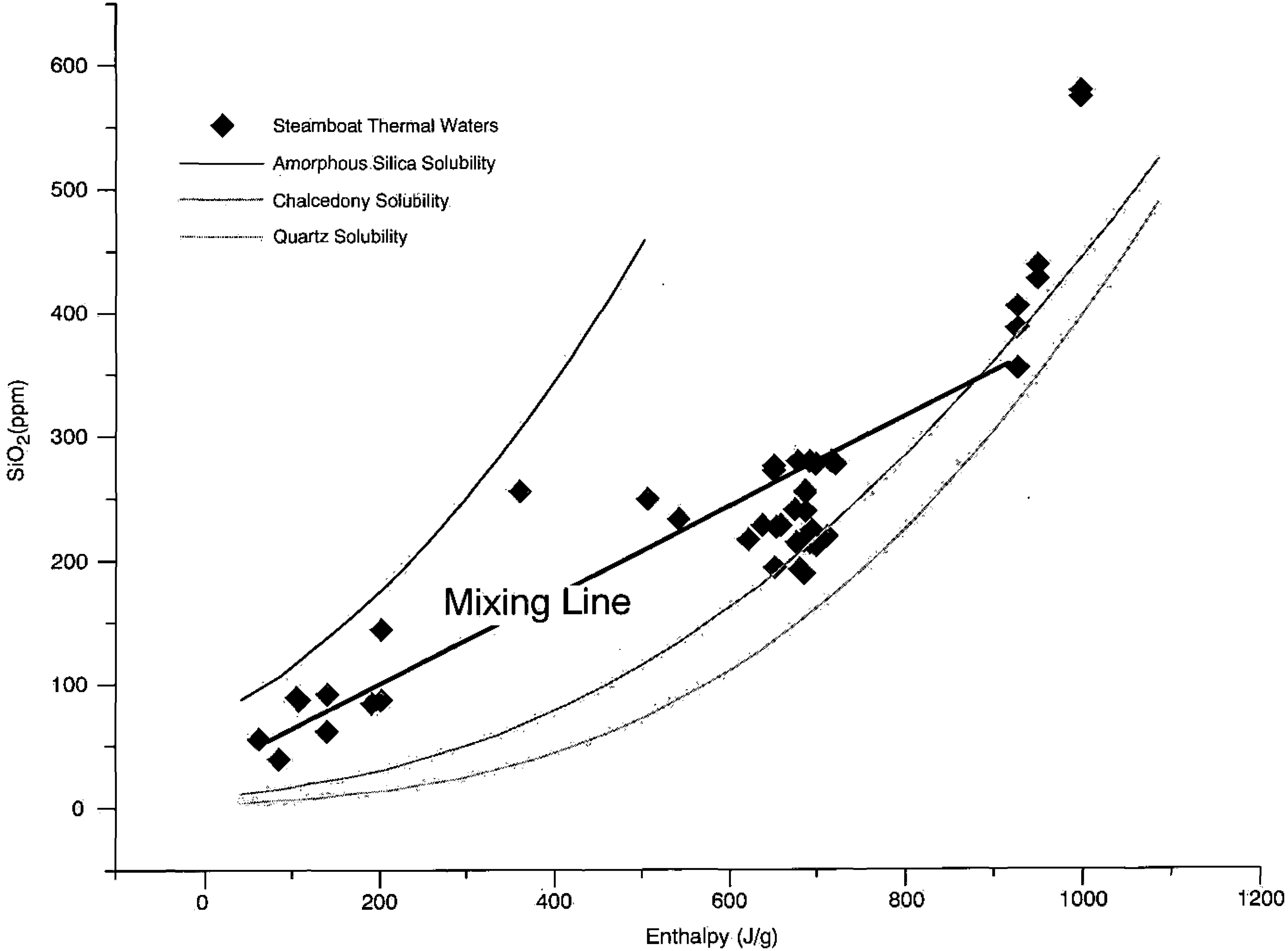


Figure 19. Silica contents vs. enthalpy (Joules/gram) of waters from the Steamboat, Nevada geothermal system. Mixing relationships are shown by the solid line. The solubilities of the various silica polymorphs are shown by the curved lines.

and Truesdell, 1973; Fournier, 1981), and Na/K (Fournier, 1981) geothermometers are all within 15°C (Table 3). This is a good indication that the chemical geothermometry is reliable for the MC-1 waters, i.e., that no unusual circumstances or disequilibrium exists, and that the fluids are mature and have either existed at these temperatures for a long period of time, or have never existed at temperatures above the present temperatures. The Na/Li (Fouillac and Michard, 1981) geothermometer, used by Ghomshei et al. (1986) to predict reservoir temperatures of >280°C, is not commonly used and has not been found to be as reliable as those using Na and K.

The Na and K geothermometers are similar for MC-1 and the hot spring waters, indicating a fairly recent mixing of deep, hot water with groundwater that has not allowed time for re-equilibration. In contrast, the geothermometers that are faster to re-equilibrate display temperatures closer to the measured temperatures of the hot springs.

Isotopes

The isotopic composition of the fluids found in the vicinity of Meager Mountain are shown in Figure 20. These data can be used to infer the source of the fluids and to establish possible mixing relationships among them.

During the early years of isotope geochemistry, correlations of the stable isotope compositions of geothermal fluids with nearby meteoric waters indicated that their deuterium concentrations were identical, although the oxygen-18 concentrations were heavier in the geothermal waters (Craig, 1961, 1963). The interpretation of this correlation was that geothermal water is derived from meteoric water, and subsequent reactions with rock alter the oxygen isotopic composition but do not alter the hydrogen composition of the fluid (Craig, 1963). This relationship is called the geothermal oxygen shift. According to this theory, geothermal fluids will plot to the right of the meteoric fluids on a graph of oxygen-18 vs. deuterium fluid concentrations, and the fluid composition trends for a given field will be horizontal.

It can be seen on Figure 20 that the MC-1 thermal water is heavier in deuterium (less negative) than the groundwaters or hot spring waters. Thus, the local groundwaters cannot recharge the reservoir MC-1 water was derived from, if it is assumed that only the oxygen isotope compositions have been altered by water-rock interactions. Ghomshei and Clark (unpublished manuscript) speculated that the recharge must be from an area west or south of Meager Mountain where waters with heavier deuterium values are found. This is unlikely in a region of extreme topography, where no regional aquifers exist. Adams et al. (1987) also noted this discrepancy in the isotopic compositions of the local groundwaters and thermal fluids. They concluded that the enrichment was due to water-rock interaction. Recent research on the origin of the isotopic compositions of water near active volcanoes has provided a more rational explanation.

Using data collected by several researchers who have investigated geothermal systems

Table 3. Geothermometry of the Meager Mountain geothermal fluids.

Sample	Chal-cedony	Quartz	Na-K-Ca-Mg	Na-K-Ca	K/Mg (G)	K/Mg (G)	Na/K (T)	Na/K (F)
MC-1[1]	201	216	199	197	210	173	158	193
MC-1[2]	213	226	204	209	225	169	178	210
Meager Hot Springs No. 1	170	190	58	185	234	89	190	219
Meager Hot Springs No. 2	160	181	77	177	226	89	179	210
EMR-301-1	174	193	46	183	231	86	185	215
EMR-301-2	102	130	62	154	193	76	136	175
M1-74D	148	171	64	151	167	92	104	148
Placid Springs	148	170	67	184	231	93	186	215
No Good No. 1	122	148	87	179	232	89	188	217
No Good No. 12	111	138	85	181	251	81	214	237
M12-80D	24	56	29	155	165	91	102	146
South Fork SF-44	73	103	45	174	182	107	123	164
Upper South Fork Swamp	115	142	61	155	160	103	96	140
South Fork Conductivity Swamp	120	146	71	164	178	101	118	160
West Meager WM-35	133	157	73	181	231	90	186	216

[1] Adams and Moore (1987); [2] Ghomshei et al. (1986)

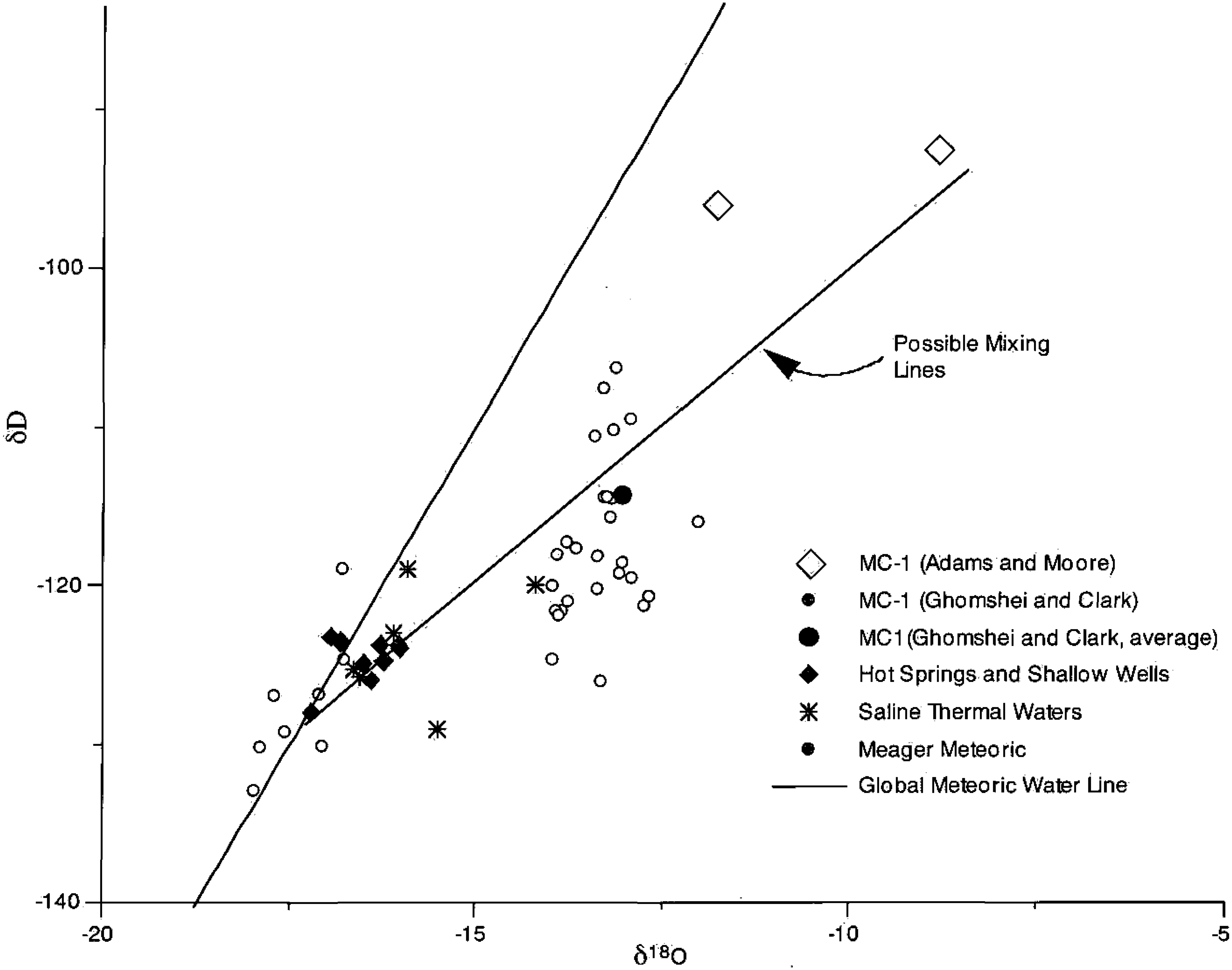


Figure 20. Deuterium (D) and oxygen-18 (18 O) isotopic compositions of waters from Meager Mountain.

lying near active volcanoes along convergent plate boundaries, Giggenbach (1992) has convincingly shown that these systems have a significant proportion of andesitic water (Fig. 21). The term "andesitic water" is used by Giggenbach (1992) rather than magmatic water because the isotopic trends of the geothermal systems that he investigated converge on a composition that is significantly lighter in deuterium than primary magmatic water. The composition of primary magmatic water was defined and first calculated by Taylor (1974) from mineral fractionation factors and the compositions of unaltered igneous rocks.

Figure 21 shows the isotopic compositions of waters from geothermal systems compiled by Giggenbach (1992), the data from Meager Mountain, and the range of isotopic compositions believed to be representative of andesitic water (Giggenbach, 1992) . Note that the slopes of lines connecting the data points for individual systems are positive and that most lines terminate at the global meteoric water line. This implies that recharge for these systems could be locally derived groundwaters. Although there is significant scatter in the data from Meager Mountain, it is apparent that a line drawn from the isotopic composition of the local meteoric waters through the MC-1 compositions of Adams and Moore (1987) and Ghomshei and Clark (unpublished manuscript) will intersect the andesitic water box. This suggests that the thermal waters at Meager Mountain could be mixtures of andesitic and meteoric water. This is a very plausible explanation for the origin of these waters considering the historical volcanic activity of Meager Mountain. If the andesite box is taken as a mixing end member, then the fluid from MC-1 would contain between 20 and 30% andesitic water. The isotopic compositions of the thermal waters from the hot springs lie closer to the meteoric water line indicating that they are dominated by local groundwater. This relationship is compatible with the mixing model derived from the K/Mg geothermometer shown in Figure 17 which indicates that the thermal waters are mixtures of a fluid similar to MC-1 and meteoric water. The compositions of the saline thermal waters are too scattered to draw any conclusions from. This scatter may be due to the existence of multiple mixing end members or to poor analytical precision.

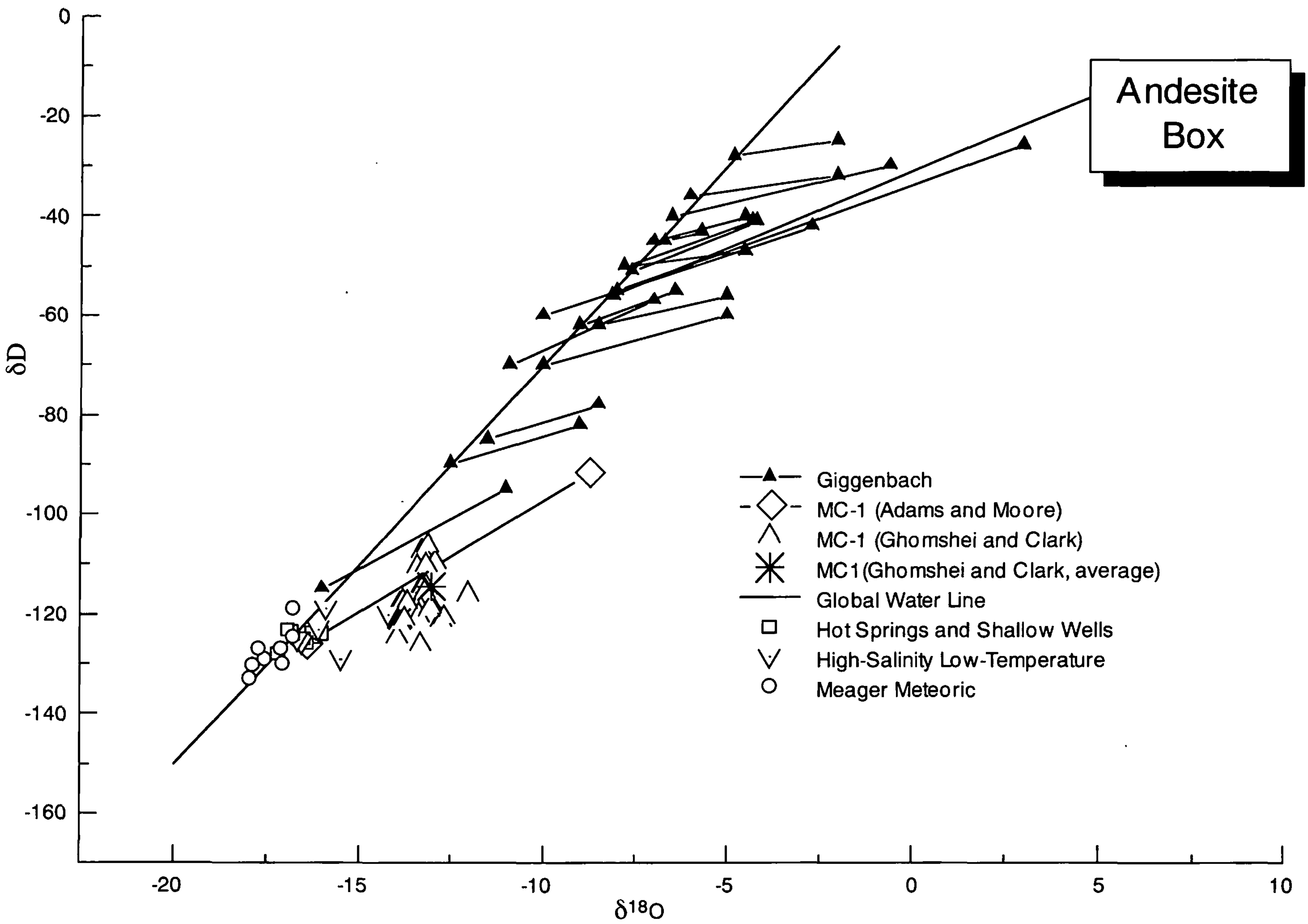


Figure 21. Deuterium (D) and oxygen-18 (18 O) isotopic compositions of waters from geothermal systems associated with volcanic activity. For comparison, the data from Meager Mountain is also shown.

REFERENCES

Adams, M. C., and Moore, J. N., 1987, Hydrothermal alteration and fluid geochemistry of the Meager Mountain geothermal system, British Columbia: American Journal of Science: v. 287, p. 720-755.

Brown, N. N., 1994, Integrating structural geology with remote sensing in hydrogeological resource evaluation and exploration, Proceedings of the Tenth Thematic Conference on Geologic Remote Sensing, 9-12 May 1994, San Antonio, TX, pp. 144-154.

Bryan, J. G., Baumgartner, E. P., and Austin, W., 1990, Remotely sensed structural controls on heat flow within the COSO geothermal area: Implications for Future Exploration, COSO Field Trip, AAPG EMD #1, pp. 41-60.

Clark, I. D., 1993, Isotope hydrogeology and geothermometry of the Mount Meager geothermal area: Geol. Survey of Canada, Open File 1015.

Craig, H., 1961, Isotopic variations in meteoric waters: Science, v. 133, p. 1702.

Crosta, A. P., and Moore, J., 1989. Enhancement of landsat thematic mapper imagery for residue soil mapping in SW Minas Gerais State, Brazil: a prospecting case history in Greenstone Belt Terrain, Seventh Thematic Conference: Remote Sensing for Exploration Geology, Colorado Springs, CO, ERIM Proceedings, pp. 1173-1187.

Drury, S. A., 1987. Digital processing of images in the visible and near infrared, Image Interpretation in Geology, Allen & Unwin:London, pp.188-148.

Ebel, P., Nash, G., Hill, B., and Hauff. P., 1993. Developing the use of AVIRIS, TIMS, and TM data to evaluate hydrothermal alteration types as related to geologic structures in the Cuprite, Nevada Region, VIP Report: Technical applications DivisLaboratory, National Aeronautics and Space Administration. 25 p.ion, Science and Technology.

Fairbank, B. D., 1993, Overview report on geothermal drilling targets at Meager Creek geothermal project, British Columbia: Consulting report for Commonwealth Construction Company by Firbank Engineering, Ltd., 17 p.

Fairbank, B. D., Reader, J. F., Openshaw, R. E., Sadlier-Brown, T. L., 1981, 1980 Drilling and exploration program Meager Creek geothermal area upper Lillooet River, British Columbia: report for B. C. Hydro and power Authority by Nevin/Sadlier-Brown/Goodbrand, Ltd., 123 p.

KRTA, 1983, Report on Meager Creek geothermal project for British Columbia Hydro & Power Authority, 214 p.

Fouillac, C., and Michard, G., 1981, Sodium/lithium ratio in water applied to geothermometry of geothermal reservoirs: Geothermics, v. 10, p. 55-70.

Fournier, R. O., and Potter, R. W., II, 1982, A revised and expanded silica (quartz) geothermometer: Geothermal Resources Council Bulletin, Nov., pp. 3-12.

Fournier, R. O., 1981, Application of water geochemistry to geothermal exploration and reservoir engineering, in Rybach, L., and Muffler, L. J. P., eds., Geothermal Systems: Principles and Case Histories: New York, John Wiley & Sons, p. 109-143.

Fournier, R. O., and Truesdell, A. H., 1973, An empirical Na-K-Ca geothermometer for natural waters: Geochimica et Cosmochimica Acta, v. 37, p. 1255-1275.

Ghomshei, M. M., and Clark, I. D., Oxygen and hydrogen isotopes in deep thermal waters from the south Meager Creek geothermal area, British Columbia, Canada: unpublished manuscript.

Ghomshei, M. M., Croft, S. A. S., and Stauder, J. J., 1986, Geochemical evidence of chemical equilibria in the south Meager Creek geothermal system, British Colombia, Canada: Geothermics, v. 15, p. 49-61.

Giggenbach, W. F., 1988, Geothermal solute equilibria. Derivation of Na-K-MG-Ca geoindicators: Geochimica et Cosmochimica Acta, v. 52, p. 2749-2765.

Nevin, Sadlier-Brown, Goodbrand, Ltd., 1979, Report on 1978 field work, Meager Creek Geothermal Area, Upper Lillooet River, British Columbia.

Ngoc, Pham Van, 1980, Magneto-telluric survey of the Mount Meager region of the Squamish Valley (British Columbia), Earth Physics Branch Rept. OsQ79-00045, 77 p.

Ngoc, Pham Van, 1978, Magneto-telluric prospecting in the Mount Meager geothermal region (British Columbia), Earth Physics Branch Open File Rept. 78-6E, 31 p.

Reed, P. B., 1979, Geology Meager Creek geothermal area, British Columbia: Geological Survey of Canada, Open File Report 603.

Shore, G.A., and Schlax, M.G., 1982, Co-ordination and review of resistivity survey results from the Meager Creek geothermal area, 1974 to Present, Premier Geophysics, Inc. Rept. to B.C. Hydro and Power Authority, 68 p.

Taylor, H. P., Jr., 1974, The application of oxygen and hydrogen isotope studies to problems of hydrothermal alteration and ore deposition: Econ. Geology, v. 69, p. 843-883.

EARTH SCIENCE LABORATORY
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108
(801) 524-3422