DEEP GRID ANALYSIS, LIMITED
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MINING, GEOTHERMAL AND PETROLEUM EXPLORATION GEOPHYSICS

Report on

DEEP RESISTIVITY SURVEYS

and Supplementary Geophysics

at MEAGER CREEK SELECTED AREA,

PEMBERTON, B.C.

for

NEVIN SADLIER-BROWN GOODBRAND, LTD.

GEOTHERMAL INVESTIGATION

(1975)

by

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1. INTRODUCTION

DGA Geophysics division of Deep Grid Analysis Limited has completed a program of reconnaissance and extended depth penetration resistivity profiles over a large area of the south valley of Meager Creek.

The purpose of the survey was to locate and dimensionally define the low resistivity materials whose presence was indicated on several reconnaissance survey lines operated by McPhar Geophysics in 1974. Operating from a comprehensive grid system laid out in the valley, the present survey has clearly identified a three-part anomaly system, dimensionally very large, displaying apparent resistivities from low to extremely low in magnitude, and bounded and contained by higher resistivity granites.

2. RELATIONSHIP OF RESISTIVITY TO GEOLOGY: MEAGER CREEK AREA

Because the present survey was operated exclusively in a known granitic environment, variations in observed apparent resistivity may reliably be attributed to two primary factors: the depth and electrical nature of the overburden, and variations in the physical, chemical and mechanical state of the granite itself.

Most dried rock samples, including granites, exhibit an extremely high resistivity. Thus, the primary factor controlling the resistivity of an in situ, non-metallic rock medium is water content. As rock porosity increases, available groundwater fills the pore spaces to form connected ionic conduction paths, and hence a decreased observable resistivity. An increase in the salinity of the water also reduces resistivity, as does an increase in system temperature.

In an active geothermal occurrence, all of these factors of porosity, degree of saturation, water salinity and system temperature combine in varying degrees to produce a decrease in electrical resistivity across the system. Levels of one-third to one-tenth of background resistivity may be expected.

Factors expected to produce anomalous resistivities within the Meager Creek granodiorites are as follows:

a. Porosity: The fracturing of the granites by local and regional tectonic stresses, and possible rock alteration represent the dominant mechanisms in establishing a high porosity. Substantial fracturing is observed in situ near the 79-D hot springs, and in core from research well H-74-1.

On a regional basis, a major fault zone is known to exist in the north-flowing section of the Meager Creek valley, and another fault is thought to lie in the east-west portion of the valley. These structures may contain quantities of fault gouge, clays, and other finely sheared and fractured materials, water saturated and potentially very conductive electrically.

The organic and alluvial overburden overlying much of the

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valley in varying thicknesses, in the river bed and on the slopes, represents a highly porous medium, whose conductivity has to potential to be high, dependent upon the degree of water saturation and the presence of clays, silts and other ion-supplying components.

b. Water Saturation: The abundance of meteoric waters on a year-round basis ensures effective saturation of most porous media. Vertical percolation (and upwelling) may be deflected horizontally by layers of impermeable clays in some of the thicker overburden areas (varved clays have been logged in the overburden of research well H-74-1) but the net availability of regional water indicates an effective saturation of the rocks to a great depth.

c. Water Salinity: Meteoric waters entering the groundwater flow systems in this area are relatively non-saline, due to the large and consistent annual rainfall and well-developed drainage. The opportunity for surface evaporative concentration of salts is almost nil. A geothermal system at Meager Creek would be supplied therefore with relatively fresh waters, the salinity of which would be increased primarily as a result of convective circulation within the system itself.

The observed resistivities of such a relatively pure water system would be expected to be substantially higher than those measured, for instance, in the Imperial Valley of California. In the Imperial Valley, the environment through which meteoric waters must pass is one of arid, saline soils, and brackish ponds and lakes, dried or partially dried and lined with evaporitic salts. Concentration of salinity within the deep geothermal systems to as much as 250,000 part per million (25% solids) is largely responsible for the extremely low resistivities of less than 4 ohm-metres, and as low as 0.5 ohm-metres.

d. Temperature: An increase in temperature within a geothermal system almost always results in a decrease in absolute resistivity levels. Initial, unrefined temperature gradient data from research well H-75-1 implies a rapid increase in temperature with depth. A component of any observed resistivity low in the Meager Creek area can, by virtue of H-75-1 implications and knowledge of the regional geology and other thermal manifestations, be ascribed to an increase in temperature.

3. DISCUSSION OF SURVEY RESULTS

A. Types of Measurement: The detailed DC resistivity surveys at Meager Creek made use of the Dipole-Dipole A = 1000 feet, N = 1, 2, 3, 4 array used in reconnaissance by McPhar in 1974, to maintain continuity of data, and in agreement with the suitability of the array in the environment. While different equipment and frequencies were used, the data is theoretically interchangeable; a re-survey of some 16 McPhar readings on Line D with the DGA Geophysics equipment showed an acceptable convergence of data.

To extend the knowledge of near-surface resistivity to greater depths, major lines D and K were also surveyed with a 2000 foot dipole array, N = 1, 2, 3, 4, 5, 6, 7, effectively tripling depth penetration.

A shallow vertical resistivity profile was measured on Meager Creek bed sediments near research well H-74-1 using highly portable battery operated resistivity equipment, as an interpretation assist in dealing with the extremely low resistivity measured there with the larger arrays.

A Self-Potential (SP) data component was extracted concurrently with the resistivity measurements, as a possible interpretation assist.

Shallow refraction seismics were used in three locations for overburden depth information at proposed drill sites. The seismic data provides some possibly useful correlation of rock velocities with apparent resistivities.

B. The Interpreted Geophysical Overview: It is useful to consider the geophysically defined units in their regional context before examining the discrete data components in detail. Drawing # 1 is a plan map showing the location of survey lines. Apparent resistivity anomalies are shown as solid bars, the wider bar representing deeper measurements obtained using the larger 2000 foot array. The shaded area indicates the interpreted horizontal dimensions of the anomaly.

Where extremes of topography have prevented the location of additional survey lines to further delineate lateral extent, the possible continuance of the anomaly is denoted by an arrow accompanied by a question mark.

Reference to interpreted sectional dimensions across various parts of the system indicate two basic geometrical configurations, identified on the plan map as "A" and "B", the latter comprised of two sections "B_1" and "B_2".

System "A" is a broad area of low resistivity, porous granodiorite approximately 5000 feet wide, lying between 55W and 110W on line D and between 10W and 62W on line K. It abuts against higher resistivity rocks to the west, and is similarly confined in the vicinity of line K to the east.

This porous unit extends to near surface at line D, where it has an estimated depth of approximately 2500 feet, but further north it appears to be capped by a resistive layer observed on line K as being perhaps 500 feet thick, overlying the low resistivity medium which here appears to have a thickness of up to 3500 feet. The interpretation of the thickness and apparent resistivity of this cap layer is necessarily substantially qualitative, as there is not sufficient shallow detail to resolve the difference between a thin, high resistivity layer and a thicker layer (up to 1000 feet) of lower resistivity, both of which models could fit the available data. A granite upper-surface seismic velocity obtained on the "cap" at 53W, line K is at 14,000 ft/sec identical to that obtained over known high resistivity granite near the intersection of lines K and H, a tenuous piece of evidence suggesting at best that the upper-slope granites enclosing the system are uniformly fractured. A velocity obtained just east of 60W on line D does, however, indicate, at 10,000 ft/sec, a far greater degree of fracturing in this area where no resistive cap is inferred.

The northern extent of anomaly "A" is unknown. Steep topography prevents the acquisition of further resistivity data to the north. The observation at line K is of a gradually thickening porous unit extending into the mountain, nearly horizontal on its upper interface and dipping at an angle at its lower surface toward the center of the mountain.

Interpreted resistivities for this system indicate a mode of 20 to 30 ohm-metres with the strong possibility of areas of 6 to 10 ohm-metres. In the Meager Creek environment, with background granodiorite resistivities observed in the 2000 to 6000 ohm-metres range, anomalies of the order of 20 to 30 ohm-metres or less should be considered as important manifestations of strong geothermal activity.

The southern boundary of anomaly "A" is also undefined. A large fault can be identified from air photographs as lying along the valley; its confirmed presence would support a theory that the "A" anomaly terminates low in the valley.

Geophysical evidence suggesting the existence of a fault structure is found in anomaly B_1, extending from anomaly A east along the valley toward the northward bend near station 5E, line D. Profiling on line D, considered with data from three lines extending northward at nearly right angles (G, H, J) indicates a narrow, linear structure, probably 1000 to 2000 feet wide and of similar depth dimension, of very low apparent resistivity. This structure could be fault-controlled, as could its northward extension (B_2) along Meager Creek past line K. A regional fault is known to strike northwest up this valley, trending to the west side of the river.

Data from line K crossing of Meager Creek, and parallel McPhar line C confirms a narrow, highly conductive structure for anomaly B_2. Line K shows an extremely low resistivity (apparent, 5.7 ohm-metres) near research well H-74-1 on and west of Meager Creek. There is incomplete evidence from McPhar line A , running parallel to the Lillooet River several miles north suggesting that the northward extension of this fault carries a similarly low resistivity signature with it. The hypothesis can be raised that the low observed resistivities within this fault are continuous along its length, and due primarily to high porosity and water saturation. On the other hand, just such a porous unit in the geothermally active environment at Maeger Creek could serve as a major conduit for thermal fluids, both laterally and in the vertical, convective mode, the strike length of several miles possibly containing a number of discrete systems and flow patterns along its length. In this case, the low observed resistivities would contain components of elevated temperature, increased salinity and possibly chemical precipitate as causative factors. The flow of thermal fluids in research well H-74-1 supports this model locally at least, while the annular distribution of hot springs coincident with possible and known fault zones around the mountain complex adds some weight to the hypothesis.

The vertically plotted apparent resistivity pseudosections also give some indication of the nature of the deeper rock underlying the the low resistivity materials. However, as the array expands to provide deeper penetration, resolution decreases and in an area of such severe topographic relief as Meager Creek, the varying influences of mountains, valleys, rivers and faults strongly affects measurement relevance and permits only a very carefully derived, general interpretation of the resistivities at great depth. Beneath the low resistivity material of anomaly A could be interpreted a discrete layer of moderately low resistivity of 60 to 150 ohm-metres. While this feature could simply be the normal transition gradient between the 20-30 ohm-metre mode and a more resistive deep basement in a hot-water dominated reservoir, the case for a distinct layer of resistivity values consistent with those of the dry steam zone of a vapor-dominated system can be made and in general reconciled with the data. Neither possibility can be ruled out on the basis of available geophysical data at this time.

Overburden has been demonstrated to play little part in the electrical measurements over anomaly A. Refraction seismic operated by DGA Geophysics showed only 50 feet of cover on line K near 53W, and similarly only 38 feet (subsequently confirmed by drilling) near the intersection of lines K and H.. In the more critical area of line D, where an estimate by eye from the creek gorge placed cover thickness at 175 feet, seismic measurement some 300 to 400 feet back from the gorge near 57W on line D indicates a thickness of 55 feet.
These depths of overburden are thought to have had negligible effect on measurement accuracy.

The case of anomaly B, particularly B_2 is different. Bedrock is observed in the creek gorge near 50W of line D, but gives way to large observed depths of clay materials just east of 50 W, and bedrock is no longer seen on the downstream extent of anomaly B. A seismic profile along B_2, centered at research well H-74-1, indicates a depth of overburden below creek level at the research well of 380 feet (confirmed in drilling to be 95% accurate), becoming shallower 1000 feet downstream (to the north) to about 230 feet, and deepening slightly 1000 feet upstream (south) to over 400 feet. The extremely low apparent resistivity on line K occurs very near the center of this seismic spread, near the research well, in these deep sediments. The shallow resistivity profile oriented along the valley, on mid-stream gravels only 500 feet north of the research well and 100 feet north of line K crossing showed a nearly homogenous single earth medium of 17 to 19 ohm-metres over a vertical 200 to 300 foot sample. (Dipole-dipole, A = 50 feet, N = 1,2,3,4,5,6,7) The anomaly at line K is thought to be largely caused by the conductive creekbed medium, but there is suggestion that the anomaly is not limited to the narrow few hundred feet of existing river channel, but extends, particularly west, to a total width of perhaps 2000 feet to 2500 feet. The existing stream channel may be a post-glacial downcut in a wider, debris-filled valley.

Self-potential (SP) data is shown on plan map 2. Extracted during resistivity operations, the SP represents a measurement of the relative voltage distribution over the ground, such voltage being due to a net surplus or deficiency of ions. Of the many causes of SP voltages, the most common occurrence, utilized in metals explorations, originates with the ozidation and chemical deterioration of sulphide minerals, liberating quantities of anions and cations which migrate under electric pressure to establish a polarized field around the source sulphides. By measuring the voltage of a series of points passing over this field, referencing to a single point in distant, electrically quiet rocks, the polarity and magnitude of the SP anomaly can be measured. In the Meager Creek SP survey, an anomaly of such great areal extent and substantial magnitude has been mapped, that the possibility of a sulphide deterioration source of ions is effectively ruled out. It has been demonstrated (E. Poldini, 1938, 1939) that ascending waters confined within a column undergo a process of cation enrichment by the selective adsorption of anions by the conduit rock, and that the net surplus of cations tends to accumulate near the top of the flow, producing a positive SP effect. It is this effect, which has been observed over numerous geothermal systems, which is thought to be responsible for the large SP anomaly at Meager Creek.

The magnitude of the Meager anomaly compares favourably with other observed anomalies:

Meager Creek:	250 - 350 millivolts
Mud Volcano Geothermal Reservoir, Yellowstone:	65 millivolts
Dunes Geothermal Anomaly, Imperial Valley, California:	250 millivolts
Observed geothermal system in north-central Nevada:	70 millivolts
Kilauea Volcano, extremely hot environment:	up to 1600 mV/Km.

The position of the anomaly, peaking over the line K - B_2 extremely low resistivity anomaly and surrounding B anomaly generally, leads to several possible models of water flow patterns which are best considered in the context of a complete geological/ geophysical/geochemical overview. *(See Appendix 6: Self-Potential Survey)*

To summarize, Anomaly A is identified as a prime target, with dimensions and resistivity characteristics typical of a major geothermal system. Anomalies B_1 and B_2 are of a lower degree of interest because they are dimensionally smaller, and their resistivity signatures are possibly due in large measure to fault material. The possibility of smaller, active geothermal systems within the fault zones must be considered.

C. Detailed Examination of Resistivity Pseudosections:

The plotting of resistivity data in vertical pseudosection (drawings 3, 4, 5, 6, 7) is a convenient way of representing data for purposes of separating the effects of lateral changes of resistivity from those of vertical changes. They can not normally, and especially in this complex environment, be considered as cross sectional representations of resistivity data, each apparent resistivity value being subject to substantial modification both in magnitude and vertical and/or horizontal position in the process of sorting the field distortions produced by the positioning of the array relative to resistivity features.

Line D: At the east end of Line D can be seen evidence of the higher resistivity granite closing off the anomaly to the east. This closure is confirmed on McPhar line C. From 15E to approximately 50W can be seen a narrow, very low apparent resistivity unit, probably a fault under or near the line. From 50W to 110W is the broad low resistivity manifestation of the A anomaly. Under the entire system from 15E to 110W lie rocks whose resistivity value could be interpreted to show an interim layer of 60 to 150 ohm meters underlain by substantially higher resistivity materials. To the west of 100W apparent resistivities are moderately high for 4000 to 5000 feet, with indication at 160W of a much higher resistivity unit appearing.

Line K: Line K shows an abrupt drop from high background resistivities at the east end to the narrow, extremely low resistivity unit on and west of the river. This unit is considered to be the major fault known to strike northeast through the valley. The sides of the anomaly are vertical or near vertical, and its depth is limited to an estimated 2000 to 2500 feet. The strong apparent trend 45^{o} to the west is primarily an array response to a narrow and shallow conductor. Between 50E and 5E there is a block of high resistivity granite, the vertical dimension of which is very unclear due to a severe distortion of of the electric fields caused by the position of anomalies A and B_2. It is unclear whether the resistive unit extends to depth or is underlain by a low resistivity material perhaps connecting the two anomalies. Some apparent compression of equipotential lines may be responsible for the 2300 reading adjacent to the low. Certainly strong consideration has to be given to the existence of a resistive block of between 250 and 500 ohm-metres apparent resistivity extending to substantial depth in the area between 10E and 50E. Cross-lines G and H support such a position, indicating that the front face of the unit (parallel with line K) terminates in a vertical interface with the fault identified on line D. Between 10W and 60W is the broad, low apparent resistivity expression of anomaly A, involving very low resistivities with a mode of about 20 to 30, and probable areas of substantially lower resistivity, 6 to 10 ohm-metres not appearing unreasonable. There is evidence of a resistive cap of perhaps 500 feet in thickness, with a gap at 35W where the low resistivity extends to near surface. On either sied are marginal areas of increasing apparent resistivity, grading into a moderately high granite in each case. Though a westerly dipping trend may exist beneath 60W, the pseudosection manifestation is thought to be a further field distortion due to shallow conductive zones and may be largely discounted.

Line G: Line G shows a clear interface of nearly vertical nature between a resistive unit of a mode of 600 to 700 ohm-metres, grading higher to the north, and the low resistivity materials of the line D identified fault. The pattern distortion on the pseudosection is due in its 45^{o} angular component to the abrupt change in resistivity along the line, and the apparent undercutting of lower values is simply a side-look at the parallel very low resistivity in the creek at lineK crossing near the research well H-74-1. The discontinuation of the apparent low manifested in the N = 3 and 4 measurements is to some extent evidence that the B_2 anomaly does not continue north up the valley for a substantial distance or at great magnitude.

Line H: Line H is a simple example of a near-vertical contact between highly resistive rock and highly conductive media, the interface positioned probably at 10N to 15N. Note the high apparent resistivities to the north on the center of the resistive unit which separates anomalies A and B_2.

Line J: Line J is very short, and is influenced both by the interface of higher resistivity granite with the B_1 low to the south, and by side-looking influence from A anomaly as the array increases and distance-from-line effectiveness increases. Little can be read from line J except to position the side of the resistive unit noted on lines G and H between 0 and 10W on line K.

Respectfully submitted,

G. Shore,
Deep Grid Analysis, Limited.
DGA Geophysics.

September 16, 1975

Project 0275

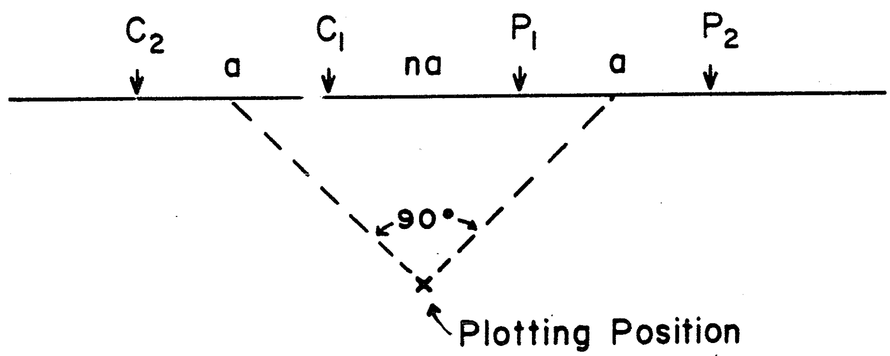
APPENDICES

APPENDIX 1

Method of plotting data in pseudosection

The convention for plotting resistivity data in pseudosection is:

DIPOLE - DIPOLE ARRAY



C_1 - C_2 represents current dipole, length "a"; P_1 - P_2 represents potential (measurement) dipole, length "a". Inter-dipole distance "na" is increased to provide larger volumetric sampling of the measured media.

APPENDIX 2-1

Survey Operating Specifications:

A. Resistivity Survey

Array:	Dipole - dipole, A = 1000 feet, N = 1, 2,3,4 and A = 2000 feet, N = 1,2,3,4,5,6,7.
Current Electrodes:	½" diameter 110,000 PSI tensile superior ground rod, 4 foot lengths, 4 to 6 per station, supplemented with aluminum foil on occasion.
Potential Electrodes:	Scintrex porous porcelain pots, $CuSO_4$ electrolyte.
Current Wire:	40,000 feet of combined 16 and 18 guage copper stranded single conductor TFF high voltage insulation.
Potential Wire:	McPhar type steel reinforced, double insulated copper wire, in unbroken lengths equal to dipole dimension.
Transmitter:	Deep Grid Analysis 40 kilowatt system in high voltage configuration.
Frequency:	Effective DC. Frequency of .0166 hertz selected after examination of response to wide spectrum.
Waveform:	DC pulse, maximum 6% transmitted ripple, polarity reversed each successive pulse with equal duration relaxation (off pulse) between each pulse.
Current Control:	Continuously adjustable to maintain steady current level throughout measurement, even while electrode resistance varies with heat buildup.
Receiver:	Hewlett-Packard 970A multimeter, autoranging, autopolarity, digital readout.
Data Components Recorded:	Continuous notation of successive DC pulses and polarities, drift trends, and pre-, intra- and post-pulse sequence background levels, polarities and drift trends

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Data Checks Applied:	Data reported by radio for each station to permit a calculator-assisted test of pulse symmetry about the plotted background drift, resulting in acceptance or immediate repeat of reading with extended sampling. The interference effects of excessively high electrode contact impedance or dry porous pots can be detected in this manner and problem source corrected before repeating the reading.
Data Components Extracted:	The observed DC pulse amplitude in volts is extracted from the averaged, digitally reconstructed waveform, and used with recorded transmitted current and an array constant to calculate apparent resistivity. From the reconstructed waveform, a reliable self-potential (SP) value was extracted.
Receiver Backup:	Maintained in camp for specific measurement problems were one Huntec M-3 IP/resistivity receiver, and a TOA Electronics EPR2-T continuous chart recorder-receiver. The M-3 was used on a first-day calibration check on the Hewlett-Packard receiver. None of the possible problems which would have demanded use of either machine were encountered.

B. Self-Potential Survey

As noted aboven self-potential data component measured and extracted from resistivity data. Available SP component was one consideration in selecting the Hewlett Packard receiver for use. (The TOA receiver would have provided it as well, but was reserved for somewhat slower, less accurate emergency application if a rapidly fluctuating, strong SP component was encountered and could not be tracked by the digital equipment.)

C. Refraction Seismics

Instrument:	Huntec FS-3 facsimile seismic, paper recoding of all arrivals, single print channel, two-geophone variable-gate "and" logic filtering for directional elimination of noise.

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Energy Source:	Hammer. Single and multiple placements of seismic caps were ineffective even at close distances. 12 pound hammer striking 10" diameter by 1¼" thick steel plate placed in contact with C soil horizon where available.
Data Repeatability:	All shots repeated at least twice, some in the presence of noise repeated 5 times to assure identification of first arrival.
Accuracy:	Readings unambiguous, expected to be very reliable.

D. Shallow Resistivity Profile

Instruments	Huntec M-3 LOPO transmitter, 47 pounds weight, battery operated. Huntec M-3 IP/Resistivity receiver.
Accessories	2 x 50 feet wire, porous pots, steel current electrodes.

APPENDIX 3-1

Description of Deep Grid Analysis Resistivity Systems

The resistivity equipment suite utilized in the Meager Creek surveys represents the industry's most comprehensive field exploration system in terms of power availability and mode, portability, frequency and waveform options, available receiver and waveform analysis capability and high efficiency, high productivity operational survey subsystems.

The core of the system is the DGA proprietary transmitter system, designed and built as a modular system, both for maximum portability and maximum flexibility in assembling power components to exactly match field conditions.In addition, recognizing the wide variation in ground and signal conditions, and array requirements, four complete field receiver systems are maintained, permitting the operators to duplicate virtually any equipment performance characteristics ever applied in world geothermal exploration.

Transmitters: DGA maintains a lightweight, battery powered IP/resistivity transmitter (Huntec M-3) which was used in a shallow profile on this job. The main transmitter is the DGA modular 40 kilowatt unit which uses interchangeable high voltage transformer units (kept lightweight by use of a 560 Hz operating frequency), main rectifier banks and polarity switching. The configuration used at Meager Creek involved the highest voltage available components (transformers, rectifiers and vacuum relays) to provide up to 5000 volts DC and up to 15 amperes DC. Other configurations involve a lower voltage set of transformers for southwest USA operation at up to 2800 volts DC and up to 75 amperes DC, using sealed high-current

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polarity switching relays and the same high voltage rectifiers. For sea-encroachment and salt lake areas, the low voltage transformers may be used or bypassed to direct alternator coupling for up to 300 amperes of DC current (600 amperes peak to peak in a reversing polarity sequence) using open-type heavy duty silver relays for polarity switching. All current commutation is solid state, permitting the polarity relays to transfer under no-current conditions, prolonging life and preventing the introduction of unnecessary transients to the ground. Further, the power level is completely variable over a stepless range of 0 to 100% in any transformer tap range, permitting selection of any desired current level within the impedance and total power limitations.

The transformerless, 300 ampere configuration is used in a marine sub-bottom profiling system developed* by Deep Grid Analysis in which a continuous resistivity profile of the ocean floor is generated for petroleum exploration in coral-dominated seas or in older, silt and mud lined seas where conventional seismics is ineffective, and for the determination of the extent and continuity of sub-bottom permafrost components in pre-pipeline engineering studies of northern shelf environments. Data is obtained from a three to five mile long floating string of potential electrodes, connected to a high-speed scanner which records dipole voltages, current data, sonar data and radar derived positioning data on a 24 channel tape recorder for direct computer analysis.

** Instrumentation system and hardware developed by G. Shore at Deep Grid Analysis, Limited; computer programming and electrical studies leading to concept developed by Dr. N.R.Paterson of Paterson, Grant & Watson, Ltd., Toronto, for joint contract operation.*

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APPENDIX 3-3

The DGA transmitter can operate in either the time or frequency domain, with virtually any timing configuration from a crystal controlled high precision timing to a manually switched operator-timed signal. Complex coded waveforms using asymmetrically timed sequence components can be programmed. Two current dipoles can be operated from the transmitter, either in an interlocked, alternating sequence or simultaneously at a maximum of 20 kilowatts for each dipole, with timing and current control of each dipole independent of the other.

The DGA system consists of two, independent, self-contained 20 kilowatt systems, operating in parallel mechanical configuration from the alternators, through control circuits, transformers, rectifier banks and polarity switching, to be terminated in separate or common output to the current dipole(s). With this design, one system can be used in a moderate demand (up to 20 kilowatts) program, with the second system on standby as a backup. A component failure in one system need not interrupt what may be a logistically complex day of operation; the defective system may be switched off and the survey continued on the backup, repairs to the first system being made later at a convenient time.

A full complement of spares is maintained for the entire system, further minimizing the possibility of severe time/cost disruption of a program due to equipment failure.

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APPENDIX 3-4

Power supply for all multiple kilowatt operation is a twin 20 KVA alternator system mounted on a single shaft-driven gearbox. Commercial avaiation equipment is used because of its high reliability and high operating frequency which permits tremendous savings in weight in all inductive components. Periodically maintained to Commercial Aviation standards, this equipment has proven 100% reliable under wide extremes of temperature and humidity. Although the unit may be fitted to a cradle for operation fromtthe DGA truck engine, most projects demand air portability. A Porsche industrial engine developing 75 BHP at 4000 RPM is used to power the alternators in a configuration which produces 40 kilowatts in a package of less than 600 pounds. A comparable output system commercially available represents 2500 to 3000 pounds, plus an additional 600 to 1000 pounds for transformers, as opposed to a maximum of 200 pounds for transformers with the DGA system. Further, the DGA generator system disassembles into four components, the heaviest of which is the engine at 275 pounds, by the removal of 14 large bolts.

High reliability is maintained with the selection of the Porsche engine, which carries a West Germany military specification for continuous-duty, unattended applications.

Other power supplies include, of course, the rechargeable battery packs for the M-3 portable transmitter, and an alternative marine resistivity supply consisting of a high momentary current demand lead-acid battery bank maintained by twin 110 ampere DC rechargers, permitting a draw of up to 400 amperes DC on a 50% duty cycle, from a comparatively small, lightweight source suitable for a small skiff.

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APPENDIX 3-5

At the signal reception end, DGA maintains four receivers:

1. Huntec M-3 IP/resistivity receiver. This is an extremely sensitive programmed unit which continuously samples transmitted signals as small as a few tens of microvolts, integrating successive measurements and providing a continuous digital display of the average measurement. Varying SP is tracked and subtracted from the individual measurements, leaving a relatively noise-free, highly accurate measurement of the resistivity signal. This is the unit which would be used in the rapid vertical sounding followup to any regional SP survey, operating from the portable M-3 transmitter.

2. Hewlett-Packard 970A multimeter. This compact digital millivoltmeter has a high input impedance of 10 megohms, with autoranging and autopolarity features which eliminate potential operator reading errors since no scales or switch setting are used. Sampling and display rate of 3 per second permits close monitoring of drift patterns and the observation of relatively high frequency transmitted signals. It is useful as an SP receiver as well.

3. TOA Electronics EPR2-T polyrecorder. This is a standard chart recording millivoltmeter used by the major resistivity contractors in the southwest USA. It is particularly useful in areas where dipoles of one mile and more are used, because of the potential for large, varying SP components which are best tracked by hand digitization of a permanent record. It is also necessary in the roving dipole method of survey where the array may become so distorted geometrically that measurement polarity cannot be assumed and a coded polarity signal must be transmitted with the signal. DGA uses an asymmetrical "off" pulse to identify polarity in the recorded signal.

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4. Tektronix Dual Channel, Dual Beam, Recording Oscilloscope.

This AC operated instrument is generally left in an accessible location out of the field for emergency application. Any geoelectric occurrence which cannot be resolved by the three on-site receivers, and which is considered to be potentially significant, may well be analysed and controlled with this instrument. With a readability of .1 microvolt, its sensitivity is far beyond the requirements of the field; however, the ability to observe and record multiple waveforms simultaneously, with selected components independently extracted and amplified, represents an important backup capability. It has not yet been required in the field; use to date has been according to its original purpose, that of system design and servicing.

In keeping with the equipment and system design philosophy aimed at rapid, efficient acquisition of relevant data, operational subsystems have been similarly specified for maximum productivity. The DGA power transmitter system allows coverage of vast areas of grid from a single setup, having sufficient power to overcome the series resistance of long current wires. Therefore, complementary capabilities are specified: 40,000 feet of current wire was in use at Meager Creek, for instance. The use of only Motorola high power police-type FM assigned-frequency business band tone-coded squelch communications radios eliminates the most common limitation in survey areas, lack of radio range (and incidentally opens up the opportunity for reliable field data reporting on a continuous basis to permit the base operator to run mathematical checks and analyses for accuracy and possible interference patterns, as well as observation

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of the developing data pattern to determine whether the line should productively be extended to resolve an inflection or terminated as planned, with data clear and unambiguous).

At Meager Creek, an area of 5 miles in length and 2 miles in width, in rough terrain, was reliably operated from one central transmitter position, without day-to-day helicopter support.

APPENDIX 4

Logistics and operational notes

Access to the program site was by truck from Vancouver to Pemberton, thence by logging road some 25 miles northwest from Pemberton. At this point equipment and personnel were transported by helicopter 15 air miles to the site.

A completely equipped and staffed tent camp was located near the center of the property, and the main transmitter base was established here. Current lines were extended in all directions from this base along survey lines. A 3 db gain ¼ wave antenna was placed some 50 feet up in a cedar tree for maximum range from the base radio station.

Crew advanced the survey array in daily increments, accessing the required line portions daily on foot and returning to camp each evening. Work period varied from 8 hours daily to 14 hours, with one notable exception of 17 hours spent on difficult access logistics and measurement on the far side of Meager Creek. A rope bridge permitted access to the east side near station 0 of line D.

Essentially, survey operations were without serious delays, and predicted production rates were achieved. The importance of a well-organized camp and abundant food cannot be overemphasized in a physically exhausting exercise such as resistivity surveying. The existence of such a camp facility was appreciated and contributed substantially to effective operations.

A crew averaging 5 to 6 operational men was employed for the duration of field work, the sixth man operating as an array and equipment expediter for the five array-operating personnel.

APPENDIX 5

Operational recommendations for future resistivity work

The use of a dipole-dipole array, A = 1000 feet, N = 1, 2, 3, 4 for reconnaissance and early lateral detailing of anomalies is recommended. This array has shown its usefulness in the present program, and no improvement can be suggested. The continued use of wider arrays for resolution at depth is recommended.

The use of a high density of parallel and cross lines in the area of an observed low-resistivity anomaly is endorsed as essential to the conceptualization of the dimensional geometry of the anomalous media. The high frequency of topographic discontinuity in the BC operating environment introduces large components of array-geometry error into the data, and cross-reference to adjacent data is useful in sorting these effects and building a useful three-dimensional model. Those parallel and cross lines such as could be placed in the steep valley of Meager Creek provided key information in interpreting array behaviour in this topographically complex area.

No improvements can be suggested in the areas of preparation of the property or in support procedures.

APPENDIX 6-1

Self-potential (SP) survey

The observed existence of a strong positive SP anomaly over the "B" resistivity anomaly at Meager Creek suggests that the SP tool may find application as a fast regional reconnaissance method intended to locate potential geothermal activity centers in areas lacking the traditional guides of surface thermal manifestations (hot springs, infra-red imagery response).

An observed SP anomaly in a region of inferred geothermal potential, or even in an area of unconfirmed, or rumored hot spring activity, would guide the location of reconnaissance resistivity lines.

A high speed, highly portable follow-up instrumentation package might be maintained, consisting of a battery operated resistivity system capable of several thousand feet penetration, and a shallow seismic unit. Having defined the extent and magnitude of the anomaly in the field, three or four vertical electrical soundings could be made in selected positions on or near the SP anomaly, in an attempt to resolve an anomalously low resistivity feature against a higher background. A shallow seismic station over the feature would then permit a close estimation of both depth to bedrock, and the electrical nature of the overburden and its effect on the resistivity values.

Essentially no cut lines are required for this type of operation, and any size program can be operated and maintained with a minimum of daily support and logistical backup, at comparatively low cost.

Applied in principle to the known Meager Creek environment, an SP traverse in the valley would have picked up the major anomaly at "B"

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and its peak located by occasional vector analysis of a set of radial measurements. Electrical sounding on the floodplain and on the hillsides would resolve a local anomaly, which would then require resistivity profile lines to determine its full geometry.

The full potential of the SP method as an additional geophysical tool working in concert with resistivity should be examined in detail, as the preliminary evidence as reported on pages 11, 12 of this report, and the experience at Meager Creek to date, are encouraging.

REFRACTION SEISMIC

PROPOSED DRILLSITE NEAR LINES K & H

Description	Velocity	Depth (FEET)
		surface
7 feet.of dry unconsolidated material	V_1 = 2500 ft/sec	-10
6 feet compact clays or water-saturated material	V_2 = 4450 ft/sec	-20
25 feet possibly compacted clays or till, or blocky well-settled rockslide material, or heavily fractured granite layer	V_3 = 7900 ft/sec	-30
		-40
At 38 feet, top of granite	V = 14,000 ft/sec	-50

REFRACTION SEISMIC

GEOPHONE NEAR 57+00 W, LINE D, ARRAY EAST

Description	Velocity	Depth (FEET)
		surface
15 feet of dry, loose material	V_1 = 1420 ft/sec	-10
		-20
		-30
40 foot thickness of probably clays and compacted till materials, possibly water-saturated	V_2 = 5200 ft/sec	-40
		-50
		-60
At 55 feet, top of granite. Relatively low velocity suggests extensive fracturing.	V_3 = 10,000 ft/sec	-70

REFRACTION SEISMIC

POSSIBLE DRILL SITE NEAR 53W LINE K

		FEET
		surface
		-10
50 foot thickness of clays and compacted till materials. Evidence of perched aquifer between 20 and 30 feet, disappearing to the east.	V_1 = 4500 ft/sec	-20
		-30
		-40
		-50
At 50 feet, top of granite.	V = 14,000 ft/sec	-60

APPENDIX 8

Data plans and pseudosections

Drawing # 1 - Plan map showing location of lines and topography, lateral limits of interpreted resistivity anomaly, and position of anomalies observed on array traverses, brought to surface.

Drawing # 2 - Plan map showing self-potential data distribution and magnitudes.

Drawing # 3 -	Pseudosection,	line D
4 -	"	line K
5 -	"	line G
6 -	"	line H
7 -	"	line J

APPENDIX 9

Bibliography

Abstracts from the Second United Nations Symposium on the Development and Use of Geothermal Resources:

III-14 Self-Potential Exploration for Geothermal Reservoirs, Corwin, Robert F., University of California, Berkeley, California 94720.

III-68 Critique of Geothermal Exploration Technology, Meidav, Tsvi, Geonomics Inc., 3165 Adeline Street, Berkeley, California 94703, and others.

III-94 Telluric Mapping, Telluric Profiling and Self-Potential Surveys of the Dunes Geothermal Anomaly, Imperial Valley, California. Wilt, Mike, and Combs, Jim, Institute for Geosciences, Univ. of Texas at Dallas, P.O.Box 688, Richardson, Texas 75080.

III-97 Mapping Thermal Anomalies on an Active Volcano by the Self-Potential Method, Kilauea, Hawaii. Zablocki, Charles J., U.S. Geological Survey, Hawaii National Park, Hawaii 96718.

Zohdy, Anderson, Muffler. Resistivity, Self-Potential, and Induced Polarization of a Vapor-Dominated Geothermal System. Geophysics, Vol.38, No. 6, 1973.

White, Muffler, Truesdell. Vapor-Dominated Hydrothermal Systems Compared with Hot-Water Systems. Economic Geology, Vol. 66, 1971.

Dieter, Paterson, Grant. IP and Resistivity Curves for Three-Dimensional Bodies. Geophysics, Vol. XXXIV, No. 4, 1969.

McPhar Memorandum on the Dipole-Dipole Resistivity Results over the East Mesa Geothermal Aanomaly, Imperial Valley, California.