UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Airborne Electromagnetic Surveys of the Cascade Range, Western United States

by

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with a preface by

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Preface

For the past 10 years the USGS has been investigating new techniques and the application of old techniques to studies of geothermal areas. In these studies, geophysical techniques (electrical methods in particular) have played a significant role. One aspect of our work has been to look at what exploration strategy might be used effectively in an exploration program. Airborne electromagnetic (AEM) techniques had not been very seriously considered until recently because of their limited exploration depth in spite of their advantages of ease of acquisition, and high-density data coverage.

Recently however we have begun to reexamine the potential for airborne AGM methods as exploration tools for geothermal systems. This has come as a result of extensive work by the USGS in the use of audio-magnetotelluric, AMT, techniques in a large number of potential geothermal areas (Hoover and others 1978). Most of the areas in which AMT studies were made are Known Geothermal Resource Areas, (KGRA's), regions where geothermal commercial interest was high. In many of the KGRA's there is a close correlation between the location of resistivity lows, as mapped by AMT, and the known surface manifestations of hot spring activity. This is true even in low resistivity unconsolidated sediments in the valleys of the Basin and Range Province. Often these resistivity lows extend between two or more hot springs or they may follow the trend of apparent fault zones away from a hot spring. The cause of the resistivity lows is not known with certainty but is probably a result of hot water and/or alteration of the sediments or rocks by thermal waters. In some cases thermal water may no longer be present, but its past existence is recorded by hydrothermal alteration patterns and low resistivities in the alteration zone. In any case, the areal extent of the resistivity lows is greater than that of the surface manifestations which can be mapped by geological techniques. Therefore, shallow probing techniques, such as AMT, are useful for locating the near surface expression of geothermal systems which may have no surface manifestation and for delineating the extent in the near surface of such systems. Shallow probing techniques are not, of course, adequate for delineation of the deeper parts of a geothermal reservoir.

Typically the resistivity lows which correlate with known geothermal activity do not vary much with frequency which indicates that locally the resistivity does not vary much as a function of depth. This suggests the possibility that AEM systems might be used for rapid reconnaissance of large areas.

To assess the use of AEM surveys for geothermal exploration, an INPUT* survey was flown in late 1979 in five areas of the Basin and Range province where AMT and other data were available. This was done under a grant from the U.S. Department of Energy. The areas flown were Wabuska and Steamboat Hot Springs, Nev., Long Valley and Surprise Valley, Calif. and Raft River, Idaho. The results of this work were encouraging enough (Christopherson and others 1980A and Christopherson and others 1980B) that further evaluation of deep-looking AEM methods was considered worthwhile.

The area chosen for further work was the Cascade physiographic province where the U.S. Geological Survey has a large ongoing geothermal program. As topography in the Cascades precluded the use of a fixed-wing aircraft for AEM surveying, a helicopter-based system was required. In September 1980 a contract was issued to DIGHEM LIMITED, Toronto, Canada to fly five areas of geothermal interest in the Cascade province with their DIGHEM II AEM system. Much of the flying was again supported by the U.S. Department of Energy's

*Trade mark of Barringer Resources. See Keller and Frischknecht 1966 for details of the system.

Office of Advanced Technology Projects. Under the same contract two other areas were flown with funding from the Bureau of Indian Affairs (BIA). The BIA work was flown for evaluation of mineral potential rather than for geothermal investigations and will be reported on in another report. The following is the report submitted by DIGHEM LIMITED on the results of their AEM work in the Cascade Range. Preliminary evaluation of the results presented, again confirmed our belief in the utility of AEM surveys for geothermal exploration (Christopherson and Hoover, 1981).

References for Preface

Christopherson, K. R., Long, C. L., and Hoover, D. B., 1980A, Airborne electromagnetic surveys as a reconnaissance technique for geothermal exploration: Geothermal Resources Council Ann. Meeting Trans. v. 4.

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Hoover, D. B., Long, C. L., and Senterfit, R. M., 1978, Some results from audio-magnetotelluric investigations in geothermal areas: Geophysics, v. 43, no. 7.

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REPORT NO. 140

DIGHEM^{II} SURVEYS

OF

THE CASCADE RANGE
WESTERN U.S.A.

FOR

UNITED STATES GEOLOGICAL SURVEY

BY

DIGHEM LIMITED

TORONTO, CANADA
AUGUST 20, 1981

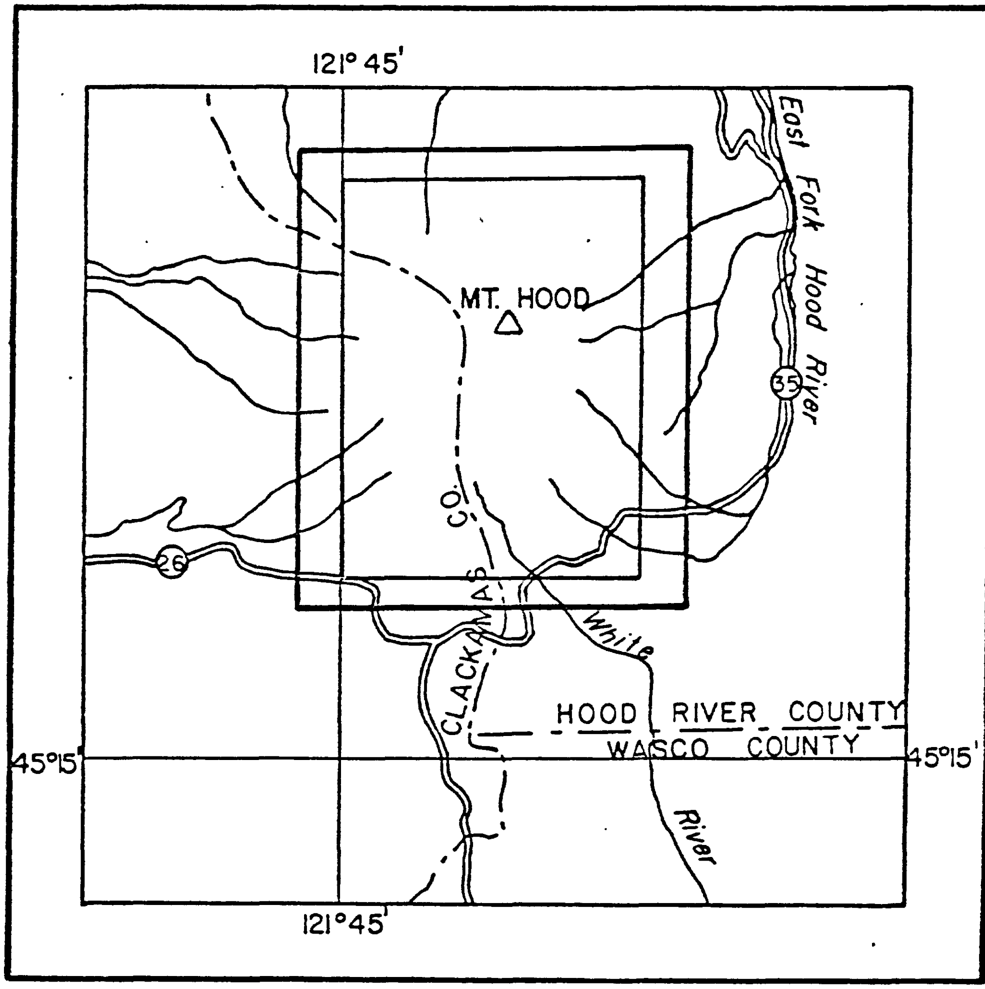
D.C. FRASER
PRESIDENT

SUMMARY

Dighem^{II} airborne electromagnetic/resistivity/ magnetic surveys totalling 2,125 line-km were flown in seven areas in Oregon, Washington and California, for the United States Geological Survey.

The geologic environments in the survey areas vary from very conductive to very resistive. In most cases, the magnetic field is quite active, often reflecting magnetite in volcanic flows. EM anomalies were due to bedrock conductivity as well as to locally conductive overburden and culture.

LOCATION MAP



SCALE 1:250,000

FIGURE 1b THE SURVEY AREA
AREA 2
MT. HOOD

LOCATION MAP

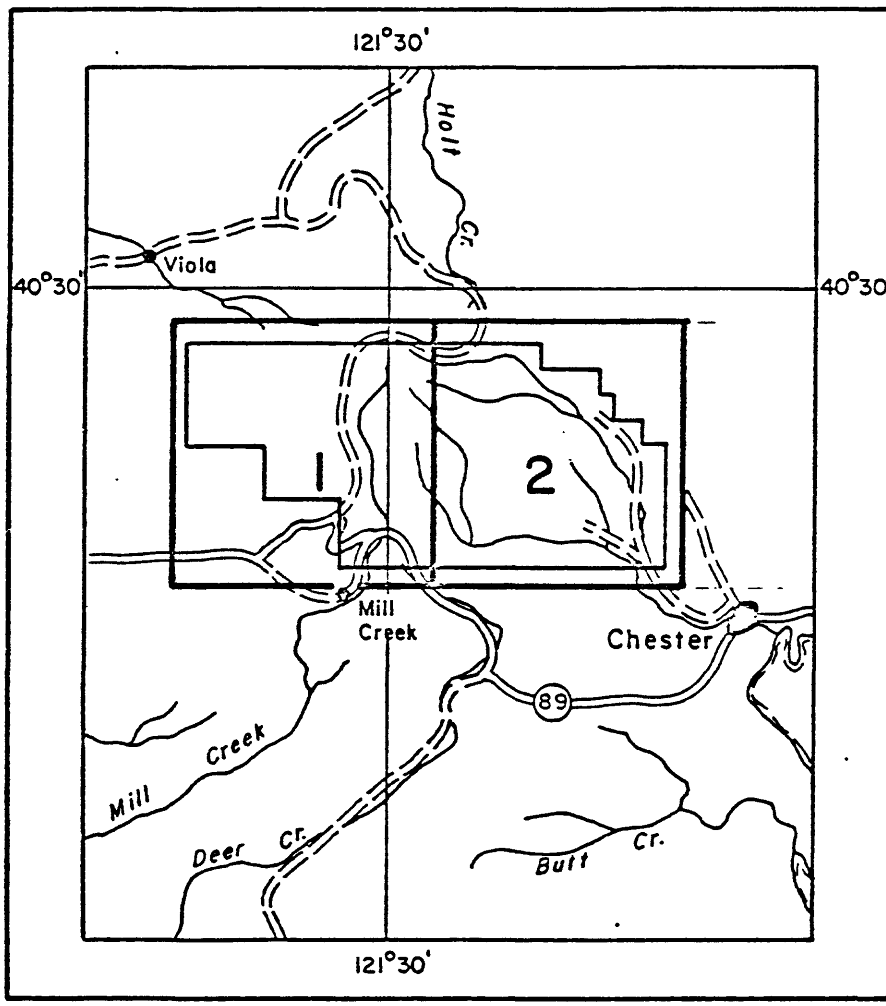


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FIGURE 1c THE SURVEY AREA
AREA 3
LASSEN

LOCATION MAP

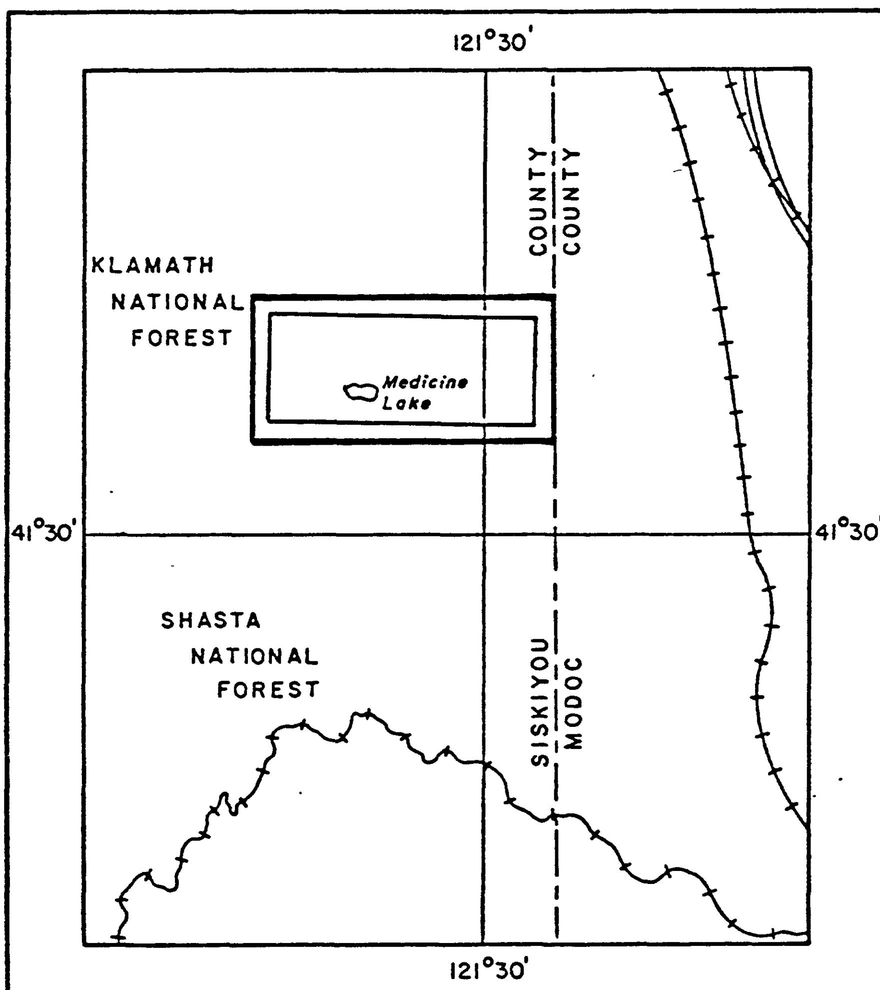

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FIGURE 1d THE SURVEY AREA
AREA 4
MEDICINE LAKE

LOCATION MAP

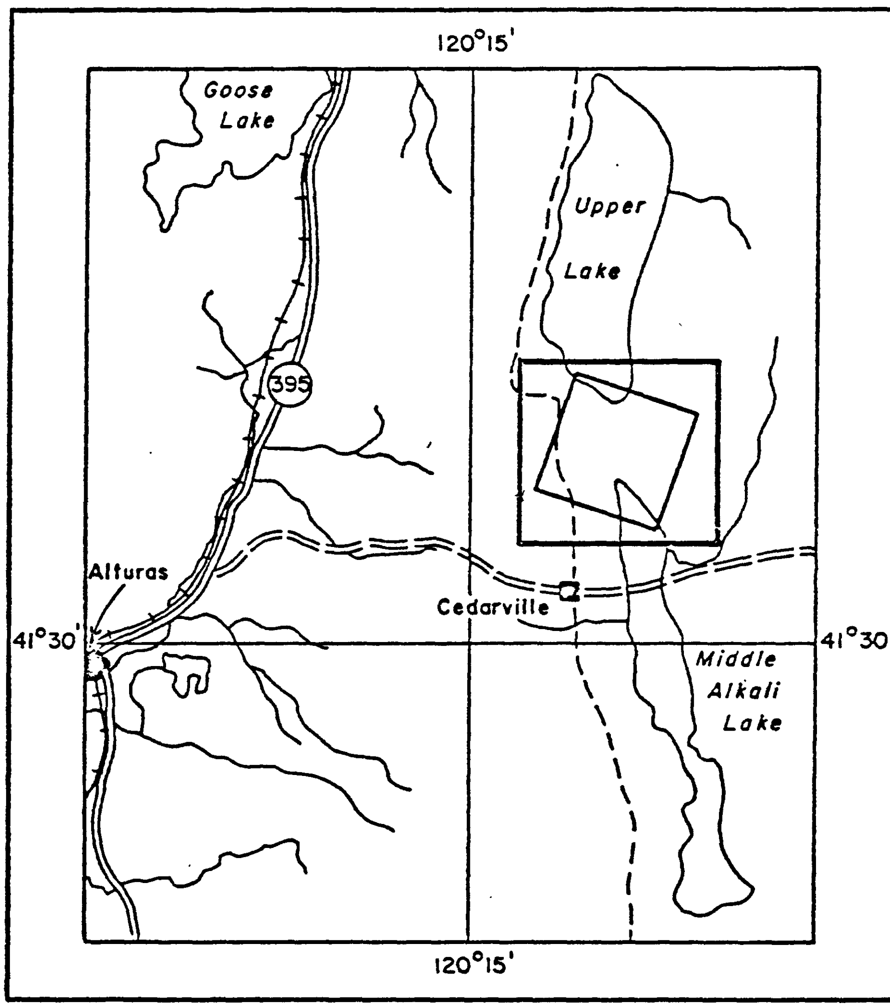

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FIGURE 1e THE SURVEY AREA
AREA 5
SURPRISE VALLEY

LOCATION MAP

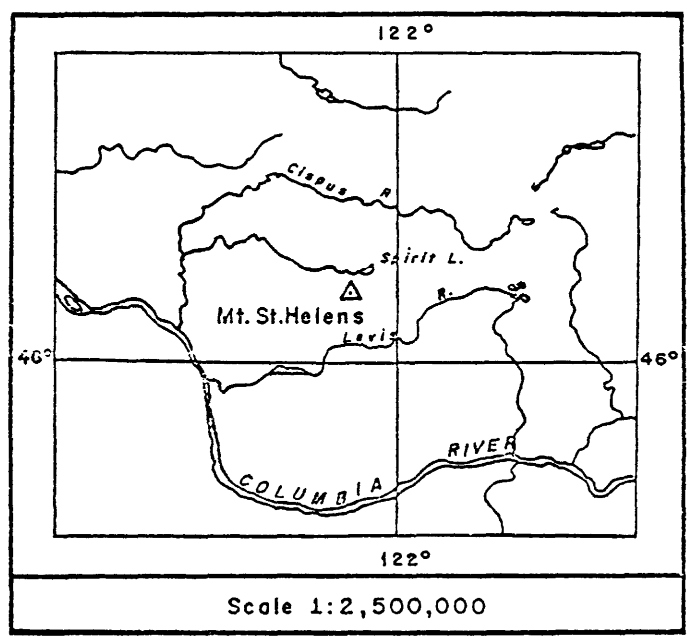

FIGURE 1g THE SURVEY AREA
AREA 7
MOUNT ST. HELENS

CONTENTS

INTRODUCTION

DIGHEM[II] surveys of 2,125 line-km was flown with 1/8, 1/4, and 1/2 mile line-spacing for the United States Geological Survey, from January 25 to March 22, 1981 over seven areas in Oregon, Washington and California (Figures 1a to 1g).

The Lama C-GDEM turbine helicopter flew with an average airspeed of 113 km/h and EM bird height of 35 m. Ancillary equipment consisted of a Sonotek PMH-5010 magnetometer with its bird at an average height of 50 m, a Sperry radio altimeter, Geocam sequence camera, Barringer 8-channel hot pen analog recorder, and a Sonotek SDS 1200 digital data acquisition system with a DigiData D 1130 9-track 800-bpi magnetic tape recorder. The analog equipment recorded four channels of EM data at approximately 900 and 3,600 Hz, two ambient EM noise channels (for the coaxial and coplanar receivers), and one channel each of magnetics and radio altitude. The digital equipment recorded the EM data with a sensitivity of 0.20 ppm/bit and the magnetic field to one gamma/bit.

The Appendix provides details on the data channels, their respective noise levels, and the data reduction procedure. The quoted noise levels are generally valid for wind speeds up to 35 km/h. Higher winds may cause the system to be grounded because excessive bird swinging produces difficulties in flying the helicopter. The swinging results from the 5 m^2 of area which is presented by the bird to broadside gusts. The DIGHEM system nevertheless can be flown under wind conditions that seriously degrade other AEM systems.

ELECTROMAGNETICS

DIGHEM electromagnetic responses fall into two general classes, discrete and broad. The discrete class consists of sharp, well defined anomalies from discrete conductors such as sulfide lenses and steeply dipping sheets of graphite and sulfides. The broad class consists of wide anomalies from conductors having a large horizontal surface such as flatly dipping graphite or sulfide sheets, saline water-saturated sedimentary formations, conductive overburden and rock, and geothermal zones. A vertical conductive slab with a width of 100 m would straddle these two classes.

The vertical sheet (half plane) is the most common model used for the analysis of discrete conductors. All anomalies plotted on the electromagnetic map are interpreted according to this model. The following section entitled Discrete conductor analysis describes this model in detail, including the effect of using it on anomalies caused by broad conductors such as conductive overburden.

The conductive earth (half space) model is suitable for broad conductors. Resistivity contour maps result from the use of this model. A later section entitled Resistivity mapping describes the method further, including the effect of using it on anomalies caused by discrete conductors such as sulfide bodies.

Discrete conductor analysis

The EM anomalies appearing on the electromagnetic map are interpreted by computer to give the conductance (i.e., conductivity-thickness product) in mhos of a vertical sheet model. DIGHEM anomalies are divided into six grades of conductance, as shown in Table I. The conductance in mhos is the reciprocal of resistance in ohms.

Table I. EM Anomaly Grades

Anomaly Grade	Mho Range
6	greater than 99
5	50 - 99
4	20 - 49
3	10 - 19
2	5 - 9
1	less than 5

The mho value is a geological parameter because it is a characteristic of the conductor alone; it generally is independent of frequency, and of flying height or depth of burial apart from the averaging over a greater portion of the conductor as height increases.[1] Small anomalies from deeply buried strong conductors are not confused with small anomalies from shallow weak conductors because the former will have larger mho values.

Conductive overburden generally produces broad EM responses which are not plotted on the EM maps. However, patchy conductive overburden in otherwise resistive areas can yield discrete-like anomalies with a conductance grade (cf. Table I) of 1, or even of 2 for conducting clays which have resistivities as low as 50 ohm-m. In areas where ground resistivities can be as low as 1 ohm-m, anomalies caused by weathering variations and similar causes can have conductance grades as high as 4. The anomaly shapes from the multiple coils often allow such surface conductors to be recognized, and these are indicated by the letter S on the map. The remaining anomalies in such areas could be

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[1]This statement is an approximation. DIGHEM, with its short coil separation, tends to yield larger and more accurate mho values than airborne systems having a larger coil separation.

bedrock conductors. The higher grades indicate increasingly higher conductances. Examples: DIGHEM's New Insco copper discovery (Noranda, Quebec, Canada) yielded a grade 4 anomaly, as did the neighbouring copper-zinc Magusi River ore body; Mattabi (copper-zinc, Sturgeon Lake, Ontario, Canada) and Whistle (nickel, Sudbury, Ontario, Canada) gave grade 5; and DIGHEM's Montcalm nickel-copper discovery (Timmins, Ontario, Canada) yielded a grade 6 anomaly. Graphite and sulfides can span all grades but, in any particular survey area, field work may show that the different grades indicate different types of conductors.

Strong conductors (i.e., grades 5 and 6) are characteristic of massive sulfides or graphite. Moderate conductors (grades 3 and 4) typically reflect sulfides of a less massive character or graphite, while weak bedrock conductors (grades 1 and 2) can signify poorly connected graphite or heavily disseminated sulfides. Grade 1 conductors may not respond to ground EM equipment using frequencies less than 2000 Hz.

The presence of sphalerite or gangue can result in ore deposits having weak to moderate conductances. As an example, the three million ton lead-zinc deposit of Restigouche Mining Corporation near Bathurst, New Brunswick, Canada, yielded a well defined grade 1 conductor. The 10 percent by volume of sphalerite occurs as a coating around the fine grained massive pyrite, thereby inhibiting electrical conduction.

Faults, fractures and shear zones may produce anomalies which typically have low conductances (e.g., grade 1 and 2). Conductive rock formations can yield anomalies of any conductance grade. The conductive materials in such rock formations can be salt water, weathered products such as clays, original depositional clays, and carbonaceous material.

On the electromagnetic map, the actual mho value and a letter are plotted beside the EM grade symbol. The letter is the anomaly identifier. The horizontal rows of dots, beside each anomaly symbol, indicate the anomaly amplitude on the flight record. The vertical column of dots gives the estimated depth. In areas where anomalies are crowded, the identifiers, dots and mho values may be obliterated. The EM grade symbols, however, will always be discernible, and the obliterated information can be obtained from the anomaly listing appended to this report.

The purpose of indicating the anomaly amplitude by dots is to provide an estimate of the reliability of the conductance calculation. Thus, a conductance value obtained from a large ppm anomaly (3 or 4 dots) will be accurate whereas one obtained from a small ppm anomaly (no dots) could be inaccurate. The absence of amplitude dots indicates that the anomaly from the coaxial coil-pair is 5 ppm or less on both the inphase and quadrature channels. Such small anomalies could reflect a weak conductor at the surface or a stronger conductor at depth. The mho value and depth estimate will illustrate which of these possibilities fits the recorded data best.

Flight line deviations occasionally yield cases where two anomalies, having similar mho values but dramatically different depth estimates, occur close together on the same conductor. Such examples illustrate the reliability of the conductance measurement while showing that the depth estimate can be unreliable. There are a number of factors which can produce an error in the depth estimate, including the averaging of topographic variations by the altimeter, overlying conductive overburden, and the location and attitude of the conductor relative to the flight line. Conductor location and attitude can provide an erroneous depth estimate because the stronger part of the conductor may be deeper or to one side of the flight line, or because it has a shallow dip. A heavy tree cover can also produce errors in depth estimates. This is because the depth estimate is computed as the distance of bird from conductor, minus the altimeter reading. The altimeter can lock on the top of a dense forest canopy. This situation yields an erroneously large depth estimate but does not affect the conductance estimate.

Dip symbols are used to indicate the direction of dip of conductors. These symbols are used only when the anomaly shapes are unambiguous, which usually requires a fairly resistive environment.

A further interpretation is presented on the EM map by means of the line-to-line correlation of anomalies, which is based on a comparison of anomaly shapes on adjacent lines. This provides conductor axes which may define the geological structure over portions of the survey area. The absence of conductor axes in an area implies that anomalies could not be correlated from line to line with reasonable confidence.

DIGHEM electromagnetic maps are designed to provide a correct impression of conductor quality by means of the conductance grade symbols. The symbols can stand alone with geology when planning a follow-up program. The actual mho values are plotted for those who wish quantitative data. The anomaly ppm and depth are indicated by inconspicuous dots which should not distract from the conductor patterns, while being helpful to those who wish this information. The map provides an interpretation of conductors in terms of length, strike direction, conductance, depth, thickness (see below), and dip. The accuracy is comparable to an interpretation from a ground EM survey having the same line spacing.

An EM anomaly list attached to each survey report provides a tabulation of anomalies in ppm, and in mhos and estimated depth for the vertical sheet model. The EM anomaly list also shows the conductance in mhos and the depth for a thin horizontal sheet (whole plane) model, but only the vertical sheet parameters appear on the EM map. The horizontal sheet model is suitable for a flatly dipping thin bedrock conductor such as a sulfide sheet having a thickness less than 15 m. The list also shows the resistivity and depth for a conductive earth (half space) model, which is suitable for thicker slabs such as thick conductive overburden. In the EM anomaly list, a depth value of zero for the conductive earth model, in an area of thick cover, warns that the anomaly may be caused by conductive overburden.

Since discrete bodies normally are the targets of EM surveys, local base (or zero) levels are used to compute local anomaly amplitudes. This contrasts with the use of true zero levels which are used to compute true EM amplitudes. Local anomaly amplitudes are shown in the EM anomaly list and these are used to compute the vertical sheet parameters of conductance and depth. Not shown in the EM anomaly list are the true amplitudes which are used to compute the horizontal sheet and conductive earth parameters.

X-type electromagnetic responses

DIGHEM^{II} maps contain x-type EM responses in addition to EM anomalies. An x-type response is below the noise threshold of 2 ppm, and reflects one of the following: a weak conductor near the surface, a strong conductor at depth (e.g., 100 to 120 m below surface) or to one side of a flight line, or aerodynamic noise. Those responses that have the appearance of valid bedrock anomalies on the flight profiles are mentioned in the report. The others should not be followed up unless their locations are of considerable geological interest.

The thickness parameter

DIGHEM[II] can provide an indication of the thickness of a steeply dipping conductor. The ratio of the anomaly amplitude of channel 24/channel 22 generally increases as the apparent thickness increases, i.e., the thickness in the horizontal plane. This thickness is equal to the conductor width if the conductor dips at 90 degrees and strikes at right angles to the flight line. This report refers to a conductor as thin when the thickness is likely to be less than 3m, and thick when in excess of 10 m. In base metal exploration applications, thick conductors can be high priority targets because most massive sulfide ore bodies are thick, whereas non-economic bedrock conductors are usually thin. An estimate of thickness cannot be obtained when the strike of the conductor is subparallel to the flight line,when the conductor has a shallow dip, when the anomaly amplitudes are small, or when the resistivity of the environment is below 100 ohm-m.

Resistivity mapping

Areas of widespread conductivity are commonly encountered during surveys. In such areas, anomalies can be generated by decreases of only 5 m in survey altitude as well as by increases in conductivity. The typical flight record in conductive areas is characterized by inphase and quadrature channels which are continuously active; local peaks reflect either increases in conductivity of the earth or decreases in survey altitude. For such conductive areas, apparent resistivity profiles and contour maps are necessary for the interpretation of the airborne data. The advantage of the resistivity parameter is that anomalies caused by altitude changes are virtually eliminated, so the resistivity data reflect only those anomalies caused by conductivity changes. This helps the interpreter to differentiate between conductive trends in the bedrock and those patterns typical of conductive overburden. Discrete conductors will generally appear as narrow lows on the contour map and broad conductors will appear as wide lows.

Channel 40 (see Appendix) and the resistivity contour map present the apparent resistivity using the so-called pseudo-layer (or buried) half space model defined in Fraser (1978)[2]. This model consists of a resistive layer overlying a conductive half space. Channel 41 gives the apparent depth below surface of the conductive material.

[2]Resistivity mapping with an airborne multicoil electromagnetic system: Geophysics, v 43, p. 144-172.

The apparent depth therefore is simply the apparent thickness of the overlying resistive layer. The apparent depth (or thickness) parameter will be positive when the upper layer is more resistive than the underlying material, in which case the apparent depth may be quite close to the true depth.

The apparent depth will be negative when the upper layer is more conductive than the underlying material, and will be zero when a homogeneous half space exists. The apparent depth parameter must be interpreted cautiously because it will contain any errors which may exist in the measured altitude of the EM bird (e.g., as caused by a dense tree cover). The inputs to the resistivity algorithm are the inphase and quadrature components of the coplanar coil-pair. The outputs are the apparent resistivity of the conductive half space (the source) and the sensor-source distance. The flying height is not an input variable, and the output resistivity and sensor-source distance are independent of the flying height. The apparent depth, discussed above, is simply the sensor-source distance minus the measured altitude or flying height. Consequently, errors in the measured altitude will affect the apparent depth parameter but not the apparent resistivity parameter.

The apparent depth parameter is a useful indicator of simple layering in areas lacking a heavy tree cover. The DIGHEM^{II} system has been flown for the purpose of permafrost mapping, where positive apparent depths were used as a measure of permafrost thickness. However, little quantitative use has been made of negative apparent depths because the absolute value of the negative depth is not a measure of the thickness of the conductive upper layer and, therefore, is not meaningful physically. Qualitatively, a negative apparent depth estimate usually shows that the EM anomaly is caused by conductive overburden. Consequently, the apparent depth channel 41 can be of significant help in distinguishing between overburden and bedrock conductors.

Interpretation in conductive environments

Environments having background resistivities below 30 ohm-m cause all airborne EM systems to yield very large responses from the conductive ground. This usually prohibits the recognition of bedrock conductors. The processing of DIGHEM^{II} data, however, produces four channels which contribute significantly to the recognition of bedrock conductors. These are the inphase and quadrature difference channels (number 33 and 34), and the resistivity and depth channels (40 and 41). The EM difference channels eliminate up to 99% of the response of conductive ground, leaving responses from bedrock conductors, cultural features (e.g., telephone lines, fences, etc.) and edge effects. An edge effect arises when the conductivity of the ground suddenly changes, and this is a source of geologic noise. While edge effects yield anomalies on the EM difference channels, they do not produce resistivity anomalies. Consequently, the resistivity channel aids in eliminating anomalies due to edge effects. On the other hand, resistivity anomalies will coincide with the most highly conductive sections of conductive ground, and this is another source of geologic noise. The recognition of a bedrock conductor in a highly conductive environment therefore is based on the anomalous responses of the two difference channels (33 and 34) and the resistivity channel (40). The most favourable situation is where anomalies coincide on all three channels.

Channel 41, which is the apparent depth to the conductive material, also helps determine whether a conductive response arises from surficial material or from a conductive zone in the bedrock. When this channel rides above the zero level on the grey profile paper (i.e., it is negative), it implies that the EM and resistivity profiles are responding primarily to a conductive upper layer, i.e., conductive overburden. If channel 41 is below the zero level, it indicates that a resistive upper layer exists, and this usually implies the existence of a bedrock conductor.

Channels 35 and 36 are the anomaly recognition functions. They are used to trigger the conductance channel 37 which identifies discrete conductors. In highly conducting environments, channel 36 may not be generated because it is subject to some corruption by highly conductive earth signals. Some of the automatically selected anomalies (channel 37) are discarded by the human interpreter. The automatic selection algorithm is intentionally oversensitive to assure that no meaningful responses are missed. The interpreter then classifies the anomalies according to their source and eliminates those that are not substantiated by the data, such as those rising from geologic or aerodynamic noise.

The resistivity map often yields more useful information on conductivity distributions than the EM map. In comparing the EM and resistivity maps, keep in mind the following:

(a) The resistivity map portrays the absolute value of the earth's resistivity.

(b) The EM map portrays anomalies in the earth's resistivity. An anomaly by definition is a change from the norm and so the EM map displays anomalies, (i) over narrow, conductive bodies and (ii) over the boundary zone between two wide formations of differing conductivity.

The resistivity map might be likened to a total field map and the EM map to a horizontal gradient in the direction of flight[3]. Because gradient maps are usually more sensitive than total field maps, the EM map therefore is to be preferred in resistive areas. However, in conductive areas, the absolute character of the resistivity map usually causes it to be more useful than the EM map.

Reduction of geologic noise

Geologic noise refers to unwanted geophysical responses. For purposes of airborne EM surveying, geologic noise refers to EM responses caused by conductive overburden

[3]The gradient analogy is only valid with regard to the identification of anomalous locations. The calculation of conductance is based on EM amplitudes relative to a local base level, rather than to an absolute zero level as for the resistivity calculation.

and magnetic polarization. It was mentioned above that the EM difference channels (i.e., channel 33 for inphase and 34 for quadrature) tend to eliminate the response of conductive overburden. This marked a unique development in airborne EM technology, as DIGHEM^{II} is the only EM system which yields channels having an exceptionally high degree of immunity to conductive overburden.

Magnetite produces a form of geological noise on the inphase channels of all EM systems. Rocks containing less than 1% magnetite can yield negative inphase anomalies caused by magnetic polarization. When magnetite is widely distributed throughout a survey area, the inphase EM channels may continuously rise and fall reflecting variations in the magnetite percentage, flying height, and overburden thickness. This can lead to difficulties in recognizing deeply buried bedrock conductors, particularly if conductive overburden also exists. However, the response of broadly distributed magnetite generally vanishes on the inphase difference channel 33. This feature can be a significant aid in the recognition of conductors which occur in rocks containing accessory magnetite.

MAGNETICS

The existence of a magnetic correlation with an EM anomaly is indicated directly on the EM map. An EM anomaly with magnetic correlation has a greater likelihood of being produced by sulfides than one that is non-magnetic. However, sulfide ore bodies may be non-magnetic (e.g., the Kidd Creek deposit near Timmins, Ontario, Canada) as well as magnetic (e.g., the Mattabi deposit near Sturgeon Lake, Ontario).

The magnetometer data are digitally recorded in the aircraft to an accuracy of one gamma. The digital tape is processed by computer to yield a standard total field magnetic map which is usually contoured at 25 gamma intervals. The magnetic data also are treated mathematically to enhance the magnetic response of the near-surface geology, and an enhanced magnetic map is produced with a 100 gamma contour interval. The response of the enhancement operator in the frequency domain is shown in Figure 2. The 100 gamma contour interval is equivalent to a 5 gamma interval for the passband components of the airborne data. This is because these components are amplified 20 times by the operator of Figure 2.

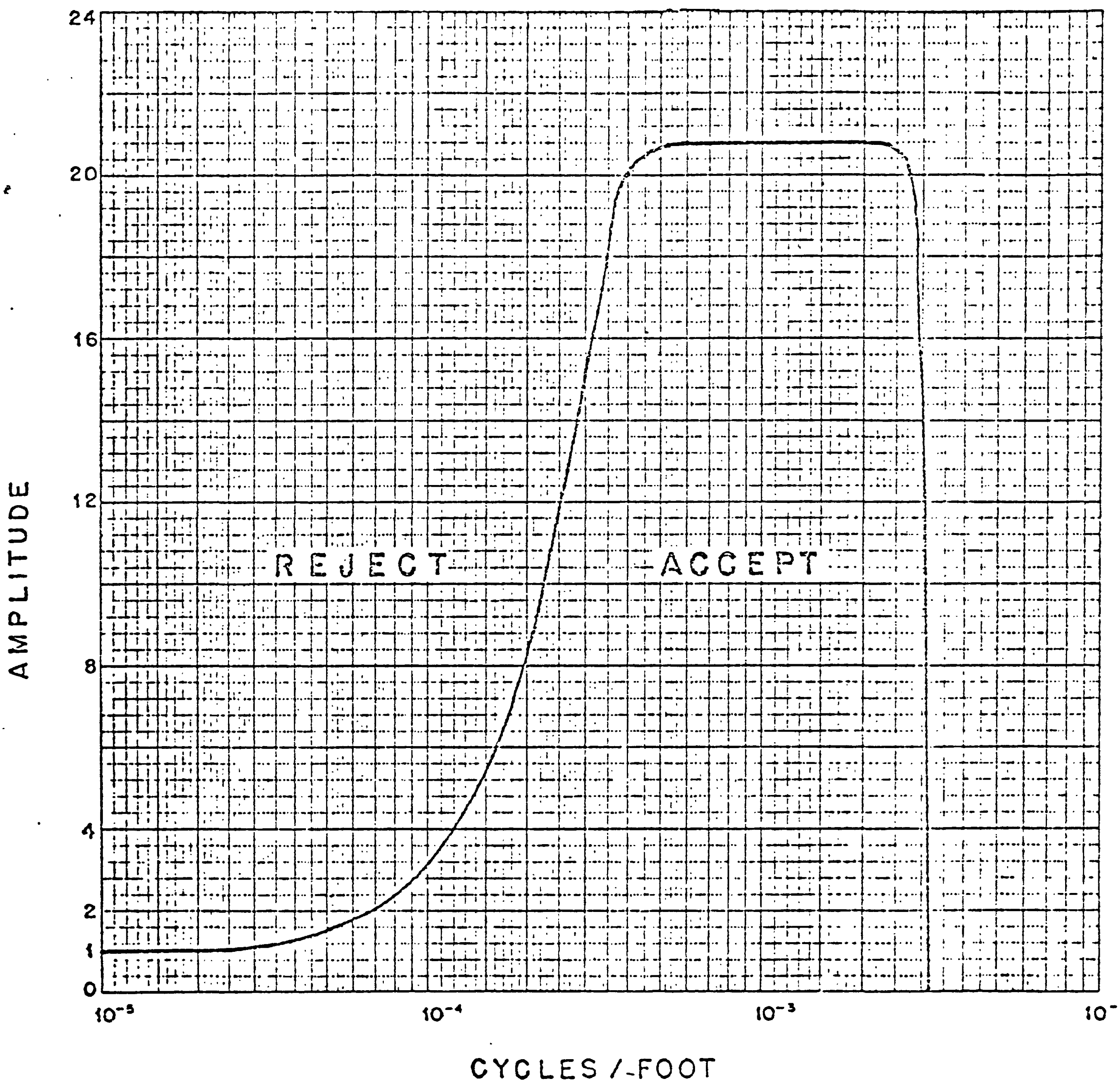

Figure 2 Frequency response of magnetic operator

The enhanced map, which bears a resemblance to a downward continuation map, is produced by digital bandpass filtering the total field data. The enhancement is equivalent to continuing the field downward to a level (above the source) which is 1/20th of the actual sensor-source distance.

Because the enhanced magnetic map bears a resemblance to a ground magnetic map, it simplifies the recognition of trends in the rock strata and the interpretation of geological structure. The contour interval of 100 gammas is suitable for defining the near-surface local geology while de-emphasizing deep-seated regional features.

CONDUCTORS IN THE SURVEY AREA

The electromagnetic maps show the location of conductors and their interpreted conductance (i.e., conductivity-thickness product) and depth. Their strike direction and length are also shown when anomalies can be correlated from line-to-line. When studying the maps for follow-up planning, consult the anomaly listings appended to this report to ensure that none of the conductors are overlooked.

The EM map indicates which anomalies are believed to be caused by culture or surficial sources. Generally, such anomalies are not commented on below as the discussions are directed to identifying bedrock features.

Area 2 Mount Hood, Oregon

Area 2 was flown with the coaxial coil-pair operating at 3600 Hz and the coplanar pair at 900 Hz. Consequently, EM difference channels are not available. Also, geometric information cannot be obtained from a comparison of anomaly shapes on the two coil-pairs.

The electromagnetic anomaly map shows a number of anomalies, almost all of which are caused by culture. The only two exceptions are 220xA and 252E. Considering the proximity of 252E to a power line (cf. channels 29 and 37), concern must be given to the possibility that it also could reflect culture.

Resistivity contour maps were prepared for the two frequencies. Both contain the effect of culture, but a few non-cultural responses also exist. The strongest conductive zone occurs on lines 258 to 260 on the east side of the map area (e.g., on line 258 at fiducial 793.2). It appears that the conductive material occurs beneath the daylight surface.

The total field magnetic map shows that trends exist parallel to the lava flows. The enhanced magnetic map is not useful in such terrains, as it favors steeply dipping strata.

Area 3 Lassen, California

Two resistivity maps were produced, one from the 900 Hz coplanar coil-pair and the other from the 3600 Hz coaxial pair. The upper detection limits are 1000 and 4000 ohm-m, respectively, for the 900 and 3600 Hz frequencies. For both frequencies, the lower limit is set arbitrarily at 1 ohm-m. The greater dynamic range of the high frequency is particularly evident on sheet 1 of this Area 3, at the west end of lines 3180 to 326, where a linear resistivity anomaly is resolved on the 3600 Hz resistivity map but is not apparent on the 900 Hz map.

Care should be exercised in interpreting the resistivity data, particularly with regard to comparing high and low frequency behavior, when EM signal levels are less than 5 ppm. This is because the coaxial coil-pair is subject to non-linear drift. This can cause errors in the zero level by several ppm, thereby distorting the resistivity values.

The resistivities in the area range from in excess of 4,000 ohm-m to less than 10 ohm-m. Broad zones of low resistivity exist in a highly resistive environment. These zones are more clearly resolved at the low frequency.

The magnetics in the area are particularly active and will require detailed study to determine their structural significance. Magnetic features cross-cut each other and strike at a variety of angles to the flight lines.

The two electromagnetic map sheets contain relatively few EM anomalies for an area comprising such large quantities of low resistivity material. This is because the low resistivity zones themselves are often very broad and lack the locally conductive inhomogeneities which, by definition, are the "anomalies" sought by the EM exploration technique. The following describes EM anomalies of possible interest on the two map sheets of this Area 3.

Sheet 1

Group 1

Group 1 consists of several linear and isolated conductors ranging from x-type to grade 5. In general, the conductors appear to be at or near the surface and represent either bedrock or thick conductive overburden. Two of the anomalies in this group 1 (i.e., 304B and 312B) have magnetic correlation but this is likely to be accidental inasmuch as the group generally corresponds to a narrow zone of low magnetic activity. Conductor 311A-316A is particularly anomalous inasmuch as its central portion (i.e., 313B-315A) appears to be at depth (150 to 200 ft) and two of its anomalies indicate a thick source.

Group 2

This group contains many isolated and short linear conductors. The conductors range from x-type to grade 6 and generally appear to be of bedrock origin.

Sheet 2

Anomalies 305A, 305B, 306B	The conductances of these three anomalies range from 1 to 6. They comprise locally anomalous parts of a large, low resistivity zone.
Anomaly 305xA-306A	This anomaly is part of a large zone of low resistivity.
Anomalies 325A, 326B, 327A, 327C	These four anomalies occur within a large zone of low resistivity which strikes parallel to the flight line. This zone also encompasses the anomalies of group 3.
Group 3	This group includes isolated and linear conductors of x-type to grade 6. It corresponds with an area of rather uniformly low resistivity. It is likely that the conductors of this group represent a thick bedrock unit. The unit appears to be at or near the surface over most of the

group. However, there are some indications of depth of burial on lines 318 to 322, although high tree cover could cause an over-estimation of the depth.

Area 4 Medicine Lake, California

As in areas 2 and 3, two resistivity maps were computed, one for the coaxial coil-pair at 3600 Hz and the other for the coplanar coil-pair at 900 Hz. In general, the two resistivity maps give similar results, with the major part of the survey area being in excess of 4,000 ohm-m. Both maps contain four relatively localized resistivity lows as follows:

(1) The most northerly feature appears to be caused by a conductive zone at a depth of about 100 m. It corresponds to conductor axis 405xA-406xA.

(2) The one other resistivity low that appears to occur at some depth (i.e., 30 to 90 m) is on line 410. It corresponds to the x-type response 410xA.

(3) The resistivity low corresponding to 407A-408xA appears to originate at or near the surface and does not appear to be associated with the zone of surface conductivity just to the east.

(4) The fourth conductive zone is located just to the east of zone (3). It appears to be caused by conductive overburden because the depth channel is negative (see channel 41, line 408).

A fifth low resistivity zone occurs only on the high frequency map, because the low is in excess of 1000 ohm-m. This low occurs between the above zones (1) and (4).

The magnetic map of the area is considerably active but reveals no obvious structural order. However, the above conductive zones (1) and (3) have an apparent correlation with magnetic lows.

Area 5 Surprise Valley, California

The survey area of Surprise Valley is underlain by material of quite high conductivity. The EM anomaly-picking algorithm is untrustworthy in conductive areas when difference channels are not available, as in this two-frequency survey. In fact, it is difficult to recognize anomalies manually, as EM peaks are generated by local decreases in flying height. The anomalies on the EM map may have little physical significance. On the other hand, the resistivity maps are ideal for mapping the conductivity distribution in areas such as Surprise Valley.

Two resistivity maps were computed, one for each of the coil-pairs (coaxial 3600 Hz, coplanar 900 Hz) and both reveal the same overall conductivity pattern. The general background resistivity ranges from 10 to 30 ohm-m. There are two zones with resistivities less than 1 ohm-m. These low resistivities are likely caused by a build up of salts in the intermittent lakes that are outlined by the resistivity contours.

The high resistivity in the southwest corner of the area is probably an indication of the true resistivity of the bedrock, assuming an absence of conductive cover at this location.

The magnetics in the area reveal several regional features. The enhanced magnetic map suggests that an east-west trend may exist for the near-surface magnetization.

Area 7 Mount St. Helens, Washington

A small area on the north side of Mount St. Helens was surveyed using the two-frequency mode.

A single strong EM anomaly (708A) occurred, yielding a prominent resistivity low at both frequencies. The anomaly is best defined by the resistivity parameters. It is too broad to fit a vertical half plane model and, therefore, the conductance value of 2 mhos is not meaningful. The resistivity of this feature is of the order of 100 ohm-m, and it occurs in a background of 4,000+ ohm-m.

A few other resistivity lows exist, but all are weak, appearing mainly on only the high frequency resistivity map.

The magnetic maps are quite active, reflecting magnetite in the flows.

Respectfully submitted,
DIGHEM LIMITED

D.C. Fraser
President

Thirty-eight map sheets accompany this report:

Electromagnetics	8 map sheets
Resistivity	14 map sheets
Magnetics	8 map sheets
Enhanced magnetics	8 map sheets

APPENDIX A

THE FLIGHT RECORD AND PATH RECOVERY

Both analog and digital flight records are produced. The analog profiles are recorded on green chart paper in the aircraft during the survey. The digital profiles are generated later by computer and plotted on grey chart paper at a scale usually identical to the geophysical maps. The digital profiles, which may be displayed, are as follows:

Channel Number	Label	Parameter	Scale units/mm	Noise
20	MAG	magnetometer	10 gamma	2 gamma
21	ALT	bird height	10 feet	5 feet
22	CXI	coaxial coil-pair inphase	1 ppm	1-2 ppm
23	CXQ	coaxial coil-pair quadrature	1 ppm	1-2 ppm
24	CPI	coplanar coil-pair inphase	1 ppm	1-2 ppm
25	CPQ	coplanar coil-pair quadrature	1 ppm	1-2 ppm
26	VLFT	VLF-EM total field	1 %	1-2 %
27	VLFQ	VLF-EM vertical quadrature	1 %	1-2 %
28	CXS	ambient noise monitor (coaxial coil)	1 ppm	1 ppm
29	CPS	ambient noise monitor (coplanar coil)	1 ppm	1 ppm
33	DIFI	difference function inphase	1 ppm	1-2 ppm
34	DIFQ	difference function quadrature	1 ppm	1-2 ppm
35	REC1	first anomaly recognition function	1 ppm	1-2 ppm
36	REC2	second anomaly recognition function	1 ppm	1-2 ppm
37	SIGT	conductance	1 mho	
40	RES	log resistivity at main frequency	.03 decade	
41	DP	apparent depth at main frequency	3 m	
45	RES2	log resistivity at secondary frequency	.03 decade	
46	DP2	apparent depth at secondary frequency	3 m	

Note: Channels 42 to 44 are experimental.

The log resistivity scale of 0.03 decade/mm means that the resistivity changes by an order of magnitude in 33 mm. The resistivities at 0, 33, 67 and 100 mm up from the bottom of the chart are respectively 1, 10, 100 and 1000 ohm-m.

The fiducial marks on the flight records represent points on the ground which were recognized by the aircraft navigator. Continuous photographic coverage allowed accurate photo-path recovery locations for the fiducials, which were then plotted on the geophysical maps to provide the track of the aircraft.

The fiducial locations on both the flight records and flight path maps were examined by a computer for unusual helicopter speed changes. Such changes may denote an error in flight path recovery. The resulting flight path locations therefore reflect a more stringent checking than is provided by standard flight path recovery techniques.

The following brief description of DIGHEM^{II} illustrates the information content of the various profiles*.

*For a detailed description, see D.C. Fraser, Geophysics, v.44, p.1367-1394.

Single-frequency surveying

The DIGHEM^{II} system has two transmitter coils which are mounted at right angles to each other. Both coils transmit at approximately the same frequency. (This frequency is given in the Introduction.) Thus, the system provides two completely independent surveys at one pass. In addition, the digital flight chart profiles (generated by computer) include an inphase channel and a quadrature channel which essentially are free of the response of conductive overburden. Also, the EM channels may indicate whether the conductor is thin (e.g., less than 3 m), or has a substantial width (e.g., greater than 10 m). Further, the EM channels include channels of resistivity, apparent depth and conductance. A minimum of 11 EM channels are provided. The DIGHEM^{II} system therefore gives information in one pass which cannot be obtained by any other airborne or ground EM technique.

Figure A1 shows a DIGHEM^{II} flight profile over the massive pyrrhotite ore body in Montcalm Township, Ontario. It will serve to identify the majority of the available channels.

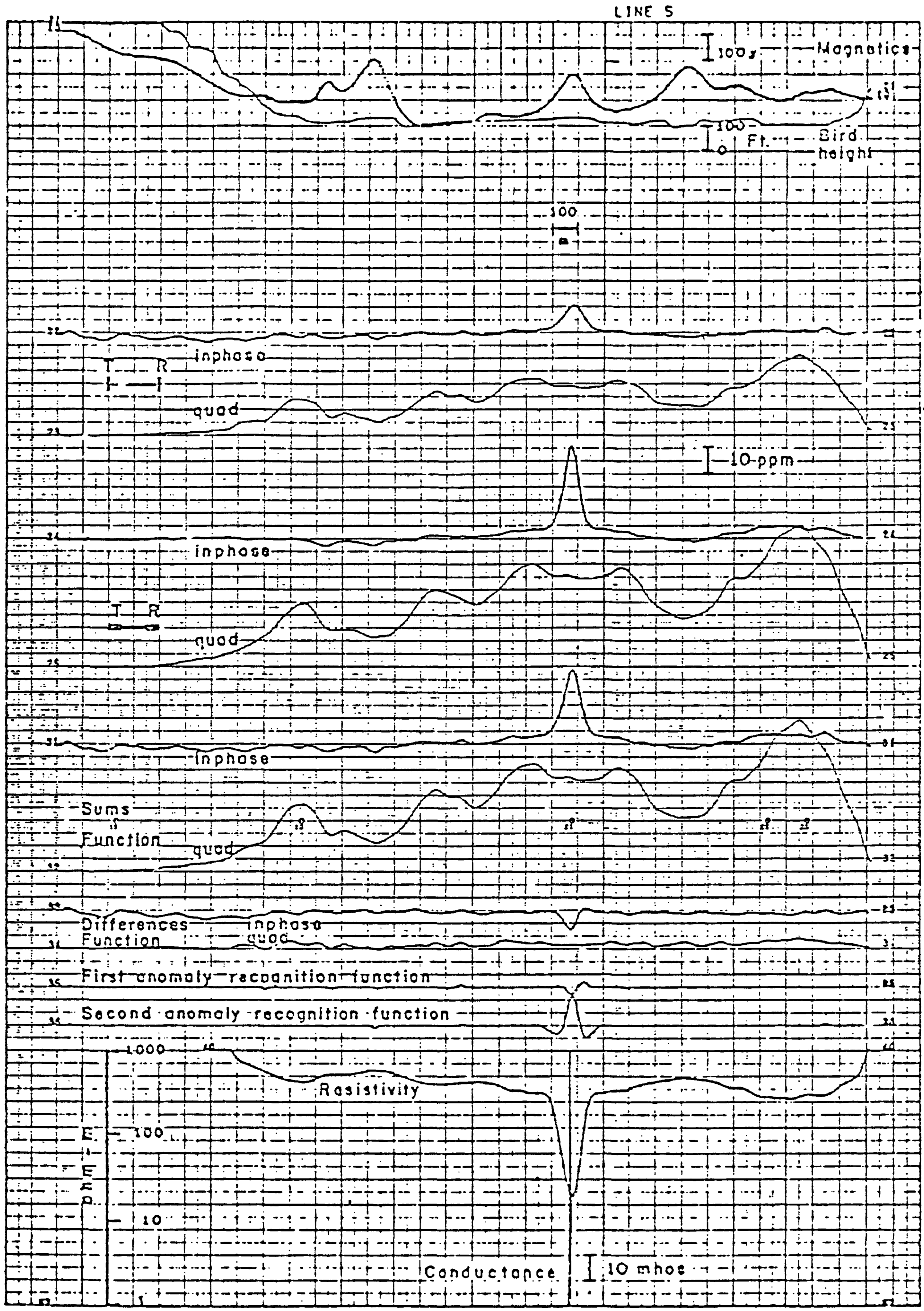

Fig. A1. Flight over Montcalm deposit, with line parallel to strike

The two upper channels (numbered 20 and 21) are respectively the magnetics and the radio altitude. Channels 22 and 23 are respectively the inphase and quadrature of the coaxial coil-pair, which is termed the standard coil-pair. This coil-pair is equivalent to the standard coil-pair of all inphase-quadrature airborne EM systems. Channels 24 and 25 are the inphase and quadrature of the additional coplanar coil-pair which is termed the whaletail coil-pair.

Channels 31 and 32 are inphase and quadrature sum functions of the standard and whaletail channels; they provide a condensed view of the four basic channels 22 to 25. The sum channels normally are not plotted.

Channels 33 and 34 are inphase and quadrature difference functions of the standard and whaletail channels. The difference channels are almost free from the response of conductive overburden. Channel 37 is the conductance. The conductance channel essentially is an automatic anomaly picker calibrated in conductance units of mhos; it is triggered by the anomaly recognition functions shown as channels 35 and 36.

Channel 40 is the resistivity, which is derived from the whaletail channels 24 and 25. The resistivity channel 40 yields data which can be contoured, and so the DIGHEM^{II} system yields a resistivity contour map in addition to an electromagnetic map, a magnetic contour map, and an enhanced magnetic contour map. The enhanced magnetic contour map is similar to the filtered magnetic map discussed by Fraser.*

Figure A2 presents the DIGHEM^{II} results for a line flown perpendicularly to the Montcalm ore body. Channel 20 shows the 175 gamma magnetic anomaly caused by the massive pyrrhotite deposit. For the EM channels, the following points are of interest:

1. On channels 22-25 and 31-34, the ore body essentially yields only an inphase response. The quadrature response is almost completely caused by conductive overburden (which also gives a small inphase response). The hachures show the EM response from the overburden. The overburden response vanishes on the

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*Cdn. Inst. Mng., Bull., April 1974.

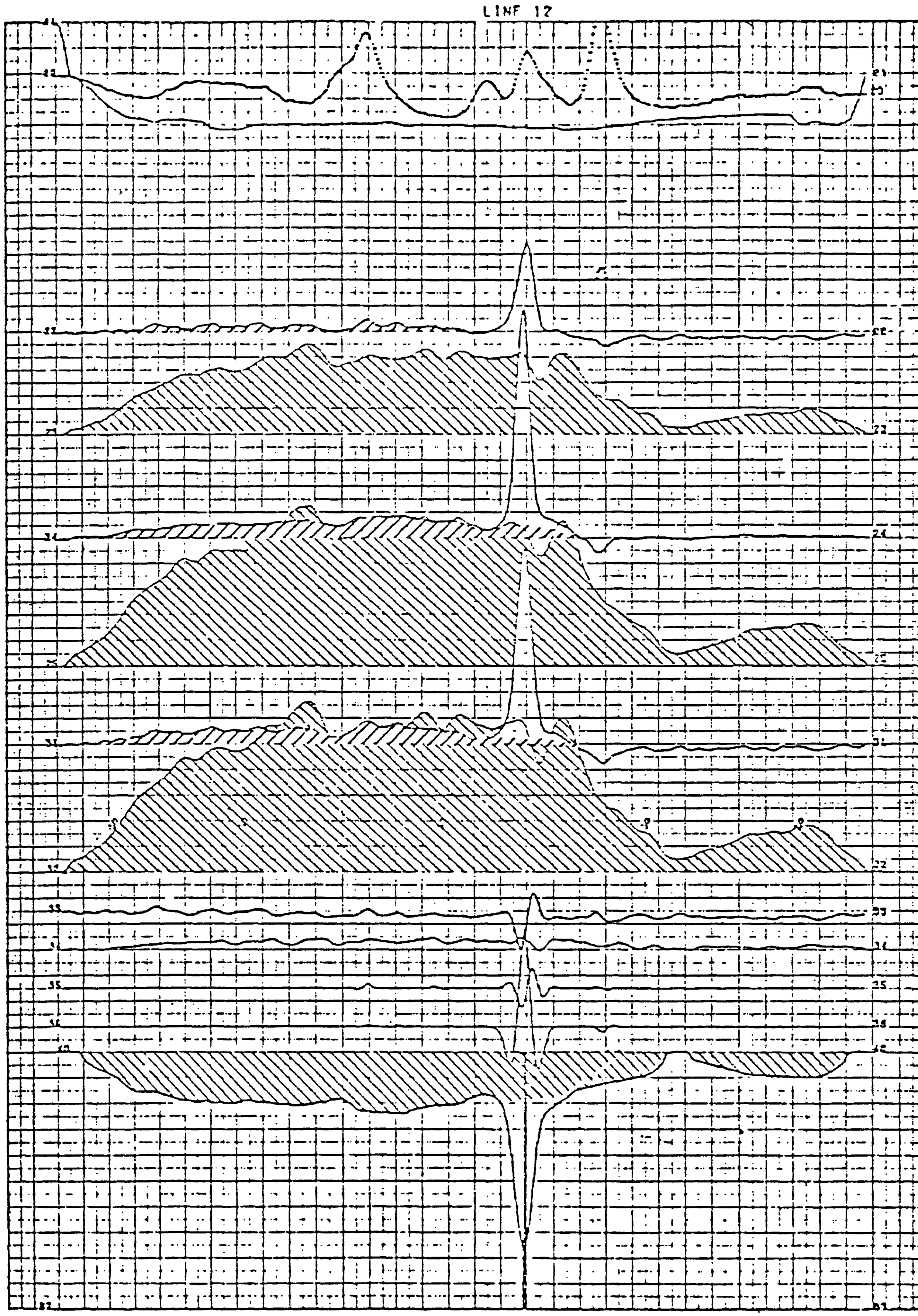

Fig. A2. Flight over Montcalm deposit, with line perpendicular to strike.

difference EM channels, as can be seen by comparing the quadrature channels 25 and 34. This is an important point to note because DIGHEM^{II} is the only EM system which provides an inphase channel and a quadrature channel which are essentially free of conductive overburden response.

2. The whaletail anomaly of channel 24 has a single peak. This shows that the conductor has a substantial width. If the width had been under 3 m, the conductor would have produced a weak m-shaped anomaly on channel 24.

3. The ore body yields a resistivity of 5 ohm-m in a background of about 200 ohm-m (cf. channel 40). A dipole-dipole ground resistivity survey with an a-spacing of 50 m showed a similar background, but the ore body gave a low of only 53 ohm-m because of the averaging effect inherent in the ground technique.

4. The ore body has a conductance of 330 mhos according to its EM response on this particular flight line. The conductance channel 37 saturates at 100 mhos, and so the deposit is indicated by a 100-mho spike.

Figure A1 illustrates the DIGHEM^{II} results for a line flown subparallel to the ore body. The ore body anomaly is small on the standard coil-pair (channel 22) but shows up strongly on the whaletail coil-pair (channel 24).

Dual-frequency surveying

For surveys flown primarily for resistivity mapping, as opposed to EM surveying, the two transmitter coils may be energized at two well-separated frequencies (e.g., 900 and 3600 Hz). Apparent resistivity and apparent depth maps can be made independently for each frequency. The interpretation procedure involves comparing the apparent resistivities and apparent depths at the two frequencies.

The use of two different coil-pair orientations (i.e., standard and whaletail) for dual-frequency resistivity mapping is an unorthodox procedure. However, as long as the current flow patterns are primarily horizontal, the different coil orientations do not influence the results, according to superposed dipole theory. Wire fences and other cultural features will produce local deviations, because they usually respond preferentially to one or the other of the coil-pairs.

The difference channels 33 and 34 are not produced because the divergent frequencies of the two coil-pairs renders them meaningless. In addition, channels 35 to 37 also are not produced.

APPENDIX B

EM ANOMALY LIST

	COAXIAL COIL		COPLANAR COIL		VERTICAL DIKE		HORIZONTAL SHEET		CONDUCTIVE EARTH	
LINE & ANOMALY	REAL PPM	QUAD PPM	REAL PPM	QUAD PPM	COND MHOS	DEPTH* FEET	COND MHOS	DEPTH FEET	RESIS OHM-M	DEPTH FEET
252A	10	0	2	1	1420	69	1	338	138	143
252B	11	1	9	0	30	27	1	343	148	147
252C	0	1	19	7	1	0	6	300	6	231
252D	3	2	22	5	3	217	6	319	5	252
252E	2	1	7	2	2	267	1	363	71	217
253A	3	2	6	5	2	212	1	414	70	266
254A	4	0	0	0	108	238	1	684	1035	0
254B	3	1	4	12	3	205	1	564	108	381
256A	2	0	0	2	826	378	1	592	1035	0
256B	2	3	0	0	1	165	1	656	1035	0
256C	8	3	7	7	5	133	1	416	127	232
259A	6	4	0	1	3	74	1	622	1035	0
260A	16	5	20	3	10	109	4	519	14	423
260B	10	0	5	1	1407	83	2	355	39	232
261A	3	0	0	0	965	303	1	684	1035	0
261B	15	8	7	3	5	95	2	541	49	401
263A	5	4	0	0	2	111	1	674	1035	0

* ESTIMATED DEPTH MAY BE UNRELIABLE BECAUSE THE STRONGER PART OF THE CONDUCTOR MAY BE DEEPER OR TO ONE SIDE OF THE FLIGHT LINE, OR BECAUSE OF A SHALLOW DIP OR OVERBURDEN EFFECTS.

140 AREA 3 SHEET 1 LASSEN U.S.G.S. MARCH/81

LINE & ANOMALY	COAXIAL COIL REAL PPM	COAXIAL COIL QUAD PPM	COPLANAR COIL REAL PPM	COPLANAR COIL QUAD PPM	VERTICAL DIKE COND MHOS	VERTICAL DIKE DEPTH* FEET	HORIZONTAL SHEET COND MHOS	HORIZONTAL SHEET DEPTH FEET	CONDUCTIVE EARTH RESIS OHM-M	CONDUCTIVE EARTH DEPTH FEET
302B	1	0	2	1	8	339	3	322	15	228
302C	8	5	8	8	3	42	2	73	48	0
303A	15	11	9	18	3	0	1	98	67	0
304A	4	2	6	5	5	48	3	217	23	113
304B	8	7	5	10	2	11	1	166	68	35
305A	1	2	1	3	1	217	2	317	44	201
305B	5	4	2	6	2	30	2	180	40	68
305C	5	2	0	0	5	209	2	390	41	276
306A	1	1	4	3	2	339	2	258	38	149
306B	9	3	5	10	2	17	2	118	50	7
306C	4	3	1	7	2	81	2	151	47	35
307A	11	13	5	15	1	19	2	114	53	10
309B	4	2	2	1	3	51	3	234	16	140
311A	10	4	12	7	6	0	5	117	7	52
312B	23	9	42	13	12	0	9	88	2	40
313B	8	1	10	3	21	129	7	301	4	236
314A	6	0	8	4	72	96	6	268	5	195
315A	9	1	15	7	33	109	5	219	8	151

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140 AREA 3 SHEET 1 LASSEN U.S.G.S. MARCH/81

LINE & ANOMALY	COAXIAL COIL REAL PPM	COAXIAL COIL QUAD PPM	COPLANAR COIL REAL PPM	COPLANAR COIL QUAD PPM	VERTICAL DIKE COND MHOS	VERTICAL DIKE DEPTH* FEET	HORIZONTAL SHEET COND MHOS	HORIZONTAL SHEET DEPTH FEET	CONDUCTIVE EARTH RESIS OHM-M	CONDUCTIVE EARTH DEPTH FEET
316A	33	15	28	31	8	0	3	84	18	9
326A	2	0	5	3	39	295	3	284	14	194
327A	14	10	10	14	3	0	3	137	21	57
328A	3	1	5	1	12	74	6	170	6	96
329A	14	16	0	7	2	45	1	183	176	44
330A	18	5	22	15	12	14	6	140	5	83
330B	0	3	1	1	1	0	3	247	20	154
330C	30	22	25	32	4	9	3	123	15	54
331A	22	7	23	17	10	27	5	115	6	58
331C	8	3	5	8	6	101	2	186	29	91
331D	7	6	4	2	2	65	2	178	31	80
331E	8	0	32	0	1317	182	11	122	1	83
332A	13	6	7	11	6	0	3	140	18	58

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140 AREA 3 SHEET 2 LASSEN U.S.G.S. MARCH/81

	COAXIAL COIL		COPLANAR COIL		VERTICAL DIKE		HORIZONTAL SHEET		CONDUCTIVE EARTH	
LINE & ANOMALY	REAL PPM	QUAD PPM	REAL PPM	QUAD PPM	COND MHOS	DEPTH* FEET	COND MHOS	DEPTH FEET	RESIS OHM-M	DEPTH FEET
305A	0	1	0	0	1	0	3	434	23	327
305B	3	0	3	1	174	292	4	337	10	259
306A	6	5	4	7	2	87	1	174	82	45
306B	9	3	16	13	9	105	3	200	24	114
316A	2	0	4	1	835	332	3	295	21	193
318A	10	16	0	14	1	0	1	116	74	0
318B	3	0	6	2	18	276	3	251	20	166
319A	3	0	5	2	100	247	4	274	12	190
320A	8	6	8	10	2	55	2	231	38	122
320B	2	0	4	2	7	304	3	282	19	189
321A	10	2	8	3	12	72	3	183	17	101
322A	8	6	2	5	2	113	1	246	85	110
322B	2	3	2	3	1	140	2	257	49	137
325A	20	5	35	14	13	0	4	110	9	42
326B	3	2	3	2	2	251	4	408	13	321
327A	40	15	45	36	11	0	5	49	6	0
327C	2	0	4	4	100	354	2	255	46	138

* ESTIMATED DEPTH MAY BE UNRELIABLE BECAUSE THE STRONGER PART OF THE CONDUCTOR MAY BE DEEPER OR TO ONE SIDE OF THE FLIGHT LINE, OR BECAUSE OF A SHALLOW DIP OR OVERBURDEN EFFECTS.

	COAXIAL COIL		COPLANAR COIL		VERTICAL DIKE		HORIZONTAL SHEET		CONDUCTIVE EARTH	
LINE & ANOMALY	REAL PPM	QUAD PPM	REAL PPM	QUAD PPM	COND MHOS	DEPTH* FEET	COND MHOS	DEPTH FEET	RESIS OHM-M	DEPTH FEET
407A	12	7	13	10	4	23	3	137	24	49

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	COAXIAL COIL		COPLANAR COIL		VERTICAL DIKE		HORIZONTAL SHEET		CONDUCTIVE EARTH	
LINE & ANOMALY	REAL PPM	QUAD PPM	REAL PPM	QUAD PPM	COND MHOS	DEPTH* FEET	COND MHOS	DEPTH FEET	RESIS OHM-M	DEPTH FEET
501A	172	51	229	132	23	0	12	39	1	12
501B	57	10	76	57	36	0	7	46	4	4
501C	38	24	10	22	5	39	2	56	41	0
501D	24	3	1	0	58	77	1	42	95	0
501E	6	21	16	25	1	0	1	55	61	0
501F	21	46	11	39	1	0	1	37	95	0
501G	37	11	5	5	14	42	1	34	141	0
501H	7	0	2	0	1268	198	1	34	180	0
501I	11	15	2	20	1	61	1	46	93	0
501J	33	17	20	21	8	53	1	61	64	0
501K	14	1	0	0	61	98	1	60	133	0
501M	35	2	2	0	140	80	1	45	110	0
501N	5	17	16	32	1	14	1	52	67	0
501O	37	0	37	8	2202	73	2	83	42	0
501P	15	14	11	22	3	36	1	79	90	0
501Q	9	20	5	17	1	0	1	0	769	0
502A	250	81	195	225	24	0	7	33	3	1
502B	2	4	17	23	1	116	2	83	30	4
502C	7	1	9	4	12	136	2	111	24	26
502D	18	5	7	8	14	95	2	92	35	8
503A	75	18	111	47	25	0	16	42	1	14
503B	30	0	65	20	2068	55	13	45	1	15
503C	8	14	15	27	1	60	2	74	28	2
503D	12	0	8	11	1529	171	2	82	42	2
503E	31	47	26	51	2	0	2	79	23	7
503F	7	10	3	8	1	60	1	109	65	8
503G	7	11	3	8	1	60	1	99	70	3
503H	21	15	3	5	4	41	1	94	76	0
504A	4	0	4	0	1034	296	2	78	34	0
505A	35	0	2	0	2167	78	3	100	17	30
505B	13	0	1	0	1571	113	2	73	29	0

* ESTIMATED DEPTH MAY BE UNRELIABLE BECAUSE THE STRONGER PART OF THE CONDUCTOR MAY BE DEEPER OR TO ONE SIDE OF THE FLIGHT LINE, OR BECAUSE OF A SHALLOW DIP OR OVERBURDEN EFFECTS.

	COAXIAL COIL		COPLANAR COIL		VERTICAL DIKES		HORIZONTAL SHEET		CONDUCTIVE EARTH	
LINE & ANOMALY	REAL PPM	QUAD PPM	REAL PPM	QUAD PPM	COND MHOS	DEPTH* FEET	COND MHOS	DEPTH FEET	RESIS OHM-M	DEPTH FEET
506A	110	25	177	76	31	0	19	35	1	11
506B	17	4	31	6	15	78	6	104	5	54
507A	20	3	42	9	41	73	19	39	1	14
507B	76	15	70	60	33	10	15	44	1	18
507C	170	50	105	131	24	0	12	52	1	24
507D	51	14	50	34	18	22	17	39	1	14
507E	69	0	114	45	2719	3	14	35	1	7
507F	30	0	9	2	2056	108	2	63	22	0
507G	43	29	55	45	5	11	5	38	7	39
508A	1	13	16	12	1	0	3	79	16	15
508B	45	13	23	18	16	51	3	82	20	13
509A	106	21	152	61	36	0	20	35	1	11
509B	148	36	188	93	29	0	17	36	1	11
509C	103	228	62	175	2	0	3	66	14	12
509D	65	57	25	53	4	25	2	69	25	4
509E	92	43	43	59	9	23	2	70	20	3
510A	26	2	26	13	93	86	4	98	11	40
510B	70	21	35	33	17	34	3	84	17	13
510C	1	0	1	2	472	376	2	134	40	25
511B	225	52	158	147	37	0	12	43	1	16
511C	117	19	155	66	50	0	19	34	1	10
511D	60	1	27	18	2299	71	3	68	18	6
512A	42	0	164	13	2300	52	12	33	1	7
512B	33	9	58	29	16	27	7	47	3	6
512C	10	11	4	12	2	66	1	74	80	0
512D	11	0	0	0	1464	154	1	103	106	0
512E	10	17	4	12	1	28	1	98	116	0
512F	8	0	0	0	1313	179	1	116	595	0

* ESTIMATED DEPTH MAY BE UNRELIABLE BECAUSE THE STRONGER PART OF THE CONDUCTOR MAY BE DEEPER OR TO ONE SIDE OF THE FLIGHT LINE, OR BECAUSE OF A SHALLOW DIP OR OVERBURDEN EFFECTS.

	COAXIAL COIL		COPLANAR COIL		VERTICAL DIKE		HORIZONTAL SHEET		CONDUCTIVE EARTH	
LINE & ANOMALY	REAL PPM	QUAD PPM	REAL PPM	QUAD PPM	COND MHOS	DEPTH* FEET	COND MHOS	DEPTH FEET	RESIS OHM-M	DEPTH FEET
513A	18	0	99	11	1746	116	9	51	2	16
513B	6	0	34	3	1139	260	6	110	5	65
513C	16	1	76	14	144	132	7	25	3	0
513D	2	0	0	0	803	260	2	147	44	30
514A	28	0	67	26	2014	73	7	33	3	0
515A	43	5	74	37	55	28	10	31	1	0
516A	22	2	53	3	81	71	22	34	1	11
517A	112	95	94	95	5	4	6	67	4	28
517B	58	16	70	50	18	32	6	55	5	14
517C	12	3	21	13	13	97	16	39	1	10
517D	4	1	6	2	22	133	9	49	2	5
518A	65	49	54	72	5	5	4	67	8	15
518B	39	37	4	29	3	8	1	0	423	0
518C	12	15	0	5	2	55	1	0	500	0
519A	50	1	88	54	812	67	5	66	5	24
519B	0	2	16	14	1	0	4	83	10	28
519C	42	28	19	34	5	16	1	74	65	0
519D	27	28	64	34	3	25	7	66	3	28
520A	59	35	56	65	6	14	3	76	12	16
520B	2	10	7	27	1	10	4	92	8	41
520D	88	55	56	100	7	6	3	65	17	3
520E	35	24	40	24	4	34	5	77	6	31
520F	30	5	7	23	32	63	1	33	54	0
520G	56	34	45	50	6	0	5	55	6	11

* ESTIMATED DEPTH MAY BE UNRELIABLE BECAUSE THE STRONGER PART OF THE CONDUCTOR MAY BE DEEPER OR TO ONE SIDE OF THE FLIGHT LINE, OR BECAUSE OF A SHALLOW DIP OR OVERBURDEN EFFECTS.

	COAXIAL COIL		COPLANAR COIL		VERTICAL DIKE		HORIZONTAL SHEET		CONDUCTIVE EARTH	
LINE & ANOMALY	REAL PPM	QUAD PPM	REAL PPM	QUAD PPM	COND MHOS	DEPTH* FEET	COND MHOS	DEPTH FEET	RESIS OHM-M	DEPTH FEET
701C	0	2	0	0	1	2	1	737	1035	0
701D	7	27	0	17	1	0	1	137	1035	0
701E	8	23	0	16	1	0	1	165	1035	0
708A	13	14	6	18	2	9	1	116	176	0

* ESTIMATED DEPTH MAY BE UNRELIABLE BECAUSE THE STRONGER PART OF THE CONDUCTOR MAY BE DEEPER OR TO ONE SIDE OF THE FLIGHT LINE, OR BECAUSE OF A SHALLOW DIP OR OVERBURDEN EFFECTS.