UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

DIGHEM^{IV} Survey for the U.S. Geological Survey along the Getchell Trend, Humboldt County, Nevada

by

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with a preface by

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Table of Contents

PREFACE

The quest for minerals, particularly in the developed nations, is today focusing more and more on exploration in covered terrains as the probability of new discoveries in exposed areas diminishes. For the explorationist, the problems posed by cover require more sophistication in the application of existing technology and development of new techniques. Improvements may involve better ways of looking through cover rocks, or better methods for identifying subtle differences within the cover arising from buried structures or mineralization at depth. Geophysical methods will play an increasingly important role in integrated exploration programs in the future, because of their ability to directly address the problems presented by covered deposits. This applies to surveys at all scales from deposit to regional extent.

The U.S. Geological Survey (USGS) in its minerals assessment programs faces the same problems as industry does in evaluating the potential for mineral commodities in covered areas. The work presented in this paper describes one of several airborne surveys flown by the USGS that is part of an integrated geological, geochemical, and geophysical study addressing the problems of covered areas (Hoover and others, 1989; Hoover and Pierce, 1989). In 1988 funding was made available by Chief Geologist Benjamin A. Morgan III for several airborne geophysical demonstration programs that were intended to show the application of multi-sensor surveys. An integrated airborne program along the Getchell Trend, Humboldt County, Nevada (fig. 1), was proposed as part of our ongoing research on assessment methods that was already underway in the area. Funding became available in April. Flying began in August and was completed in early November 1988.

The Getchell Trend Airborne Geophysics Demonstration Program was designed to illustrate the potential of an integrated and comprehensive airborne program for addressing exploration or assessment in covered terrains. Additionally, the program would provide data on the geophysical signatures, if any, of a variety of different types of known deposits and their variability. Four distinct geophysical methods were employed: remote sensing, gamma-ray spectrometry, magnetics, and electromagnetics.

The area flown for this demonstration program lies principally on the eastern flank of the Osgood Mountains (fig. 1), and covers an area of about 450 km^2. In general, the northern margin is bounded by the Chimney deposit, and the southern lies along Intersate Highway 80. The western boundary is the crest of the Osgood Mountains. From the crest of the range the survey area extends east about 12 km to where the cover rocks are believed too thick for present exploitation.

The Getchell Trend was chosen for this study because of the presence of a variety of known types of mineral deposits: bedded barite, skarn tungsten, tungsten-bearing manganese, silver, and disseminated gold. Active gold mines include the Preble, Pinson, Mag, Getchell, Rabbit Creek, and Chimney deposits (fig. 1). These known deposits provide a means of testing methods and models. The Rabbit Creek deposit was of particular interest. It was a blind deposit with over 100 m of cover, was being drilled at the time of flying, but stripping of the cover had not yet begun. This provided a unique opportunity to test our methods. The cooperation of most of the mining companies in providing access to their properties for ground studies also was an important factor in selecting this study area.

The report that follows was prepared and submitted by DIGHEM Surveys and Processing Inc., Mississauga, Ontario, Canada on January 10, 1989, describing the results of their combined airborne magnetic and electromagnetic survey of the Getchell Trend conducted under contract as part of the U.S. Geological Survey's Getchell Airborne Geophysical Demonstration Program.

Besides the text, the report includes seven sets of maps consisting of four sheets each at a scale of 1:24,000. The map sets are as follows: sheets 1 through 4 total field aeromagnetic data, sheets 5 through 8, resistivity at 56,000 Hz, sheets 9 through 12 resistivity at 7,200 Hz, sheets 13 through 16 resistivity at 900 Hz, sheets 17 through 20 filtered VLF data, sheets 21 through 24 flight line data, and sheets 25 through 28, 60 Hz monitor profiles.

In addition to the 1:24,000-scale contour maps of the data presented in this report, the digital data used to make the maps is also available from the National Geophysical Data Center, U.S. Department of Commerce, 325 Broadway, Boulder, Colorado 80303.

REFERENCES

Hoover, D.B., and Pierce, H.A., 1989, An integrated airborne geophysical study along the Getchell trend of gold deposits, north-central Nevada, U.S.A.: Abstracts 1st Congresso da Sociedade Brasileira de Geofisica, p. 62.

Hoover, D.B., Grauch, V.J.S., Krohn, M.D., Labson, V., and Pitkin, J.A., 1989, The Getchell trend airborne geophysical demonstration project, north-central Nevada, in Schindler, K.S., ed., USGS Research on Mineral Resources - 1989, Abstracts with Programs: U.S. Geological Survey Circular 1035, p. 32.

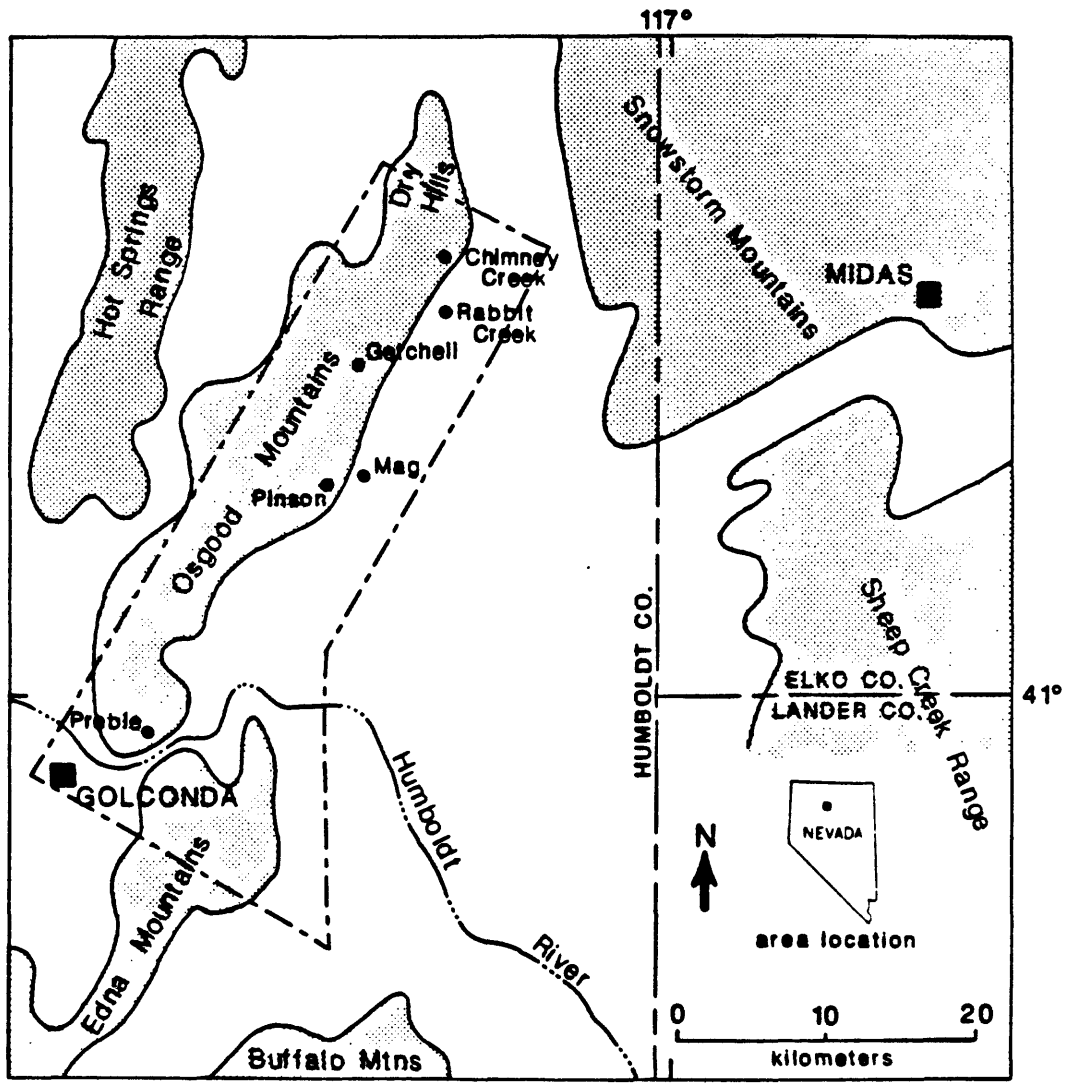

Figure 1. Map showing the location of the DIGHEM^{IV} electromagnetic survey, Humboldt County, Nevada.

Report #543

DIGHEM IV SURVEY
FOR
U.S. GEOLOGICAL SURVEY
GETCHELL TREND
NEVADA

DIGHEM SURVEYS & PROCESSING INC.
MISSISSAUGA, ONTARIO
January 10, 1989

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A0543JAN.90R

SUMMARY

A DIGHEM^{IV} survey was flown for the United States Geological Survey, over the Getchell Trend in Nevada.

The purpose of the survey was to map bedrock structure and lithology using apparent resistivity and the magnetic properties of the bedrock units.

The 900 Hz, 7200 Hz and 56,000 Hz coplanar EM data were used to produce resistivity maps. A comparison of the three resistivity parameters, and additionally the calculated depth channels, should be useful in determining the depths and extent of conductive sources below surface. The total field magnetic maps yield valuable information about bedrock geology. Both the resistivity and the magnetics show numerous linear features which may reflect structural breaks. The VLF maps may be useful in the more resistive areas of the survey.

Care must be taken in evaluating features on the resistivity and magnetics as there are numerous cultural sources in the area. On-site checks may be necessary to verify some anomalies.

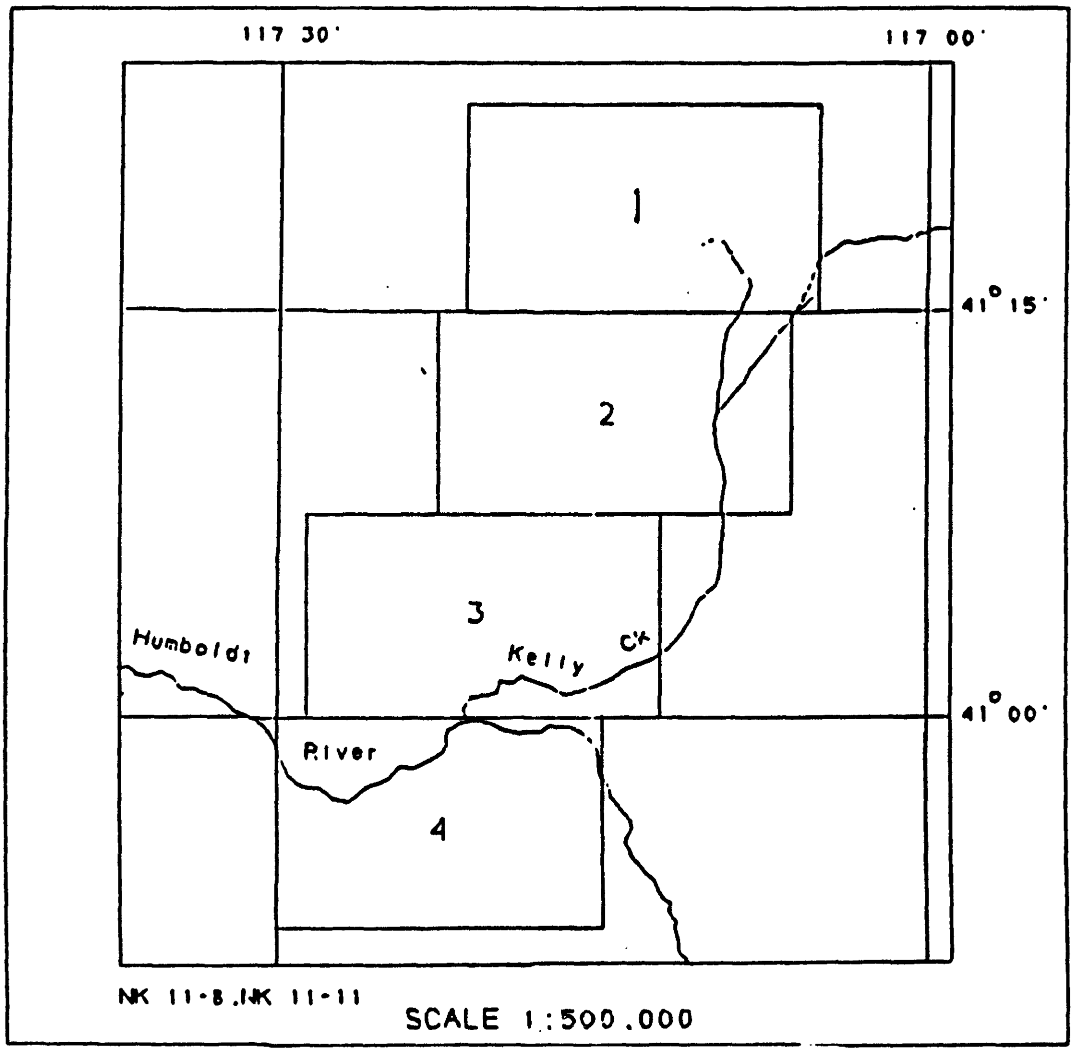

FIGURE 1

THE SURVEY AREA

CONTENTS

INTRODUCTION

A DIGHEM^{IV} electromagnetic/resistivity/magnetic/VLF survey was flown for the U.S. Geological Survey, from November 6 to November 11, 1988, over a survey block near Winnemucca, Nevada. The survey area included several operating gold mines and prospects including, Rabbit Creek, Preble, Pinson, Getchell and Chimney.

Survey coverage consisted of approximately 1150 line-miles. Flight lines were flown with a line separation of approximately 1/4 of a mile in an azimuthal direction of 301°/121°. Fill in lines were flown at 1/8 of a mile spacing in blocks over the aforementioned deposits. Tie lines were flown perpendicular to the flight line direction with a 4 mile line spacing. Several lines were extended outward from the main survey block to cover additional areas of interest.

The survey employed the DIGHEM^{IV} electromagnetic system. Ancillary equipment consisted of a magnetometer, radio altimeter, video camera, analog and digital recorders, a VLF receiver and an electronic navigation system.

This report is divided into six sections. Section 2 provides details on the equipment used in the survey and lists the recorded data and computed parameters. Section 3 reviews the data processing procedures, with further information on the various parameters provided in Section 5. Section 4 describes the geophysical results.

The survey results are shown on 4 separate map sheets for each parameter. Table 1-1 lists the products which can be obtained from the survey. Those which are part of the contract are indicated in this table by showing the presentation scale. These total 28 maps.

Table 1-1 Plots Available from the Survey

MAP [Parameter number]*	NO. OF SHEETS	ANOMALY MAP	PROFILES ON MAP	CONTOURS INK	CONTOURS COLOR	SHADOW MAP
Flight Lines [7]	4	N/A	24,000	N/A	N/A	N/A
Electromagnetic Anomalies	-	-	N/A	N/A	N/A	N/A
Probable Bedrock Conductors	-	-	N/A	N/A	N/A	N/A
Resistivity (900 Hz) [2]	4	N/A	-	24,000	-	-
Resistivity (7,200 Hz) [3]	4	N/A	-	24,000	-	-
Resistivity (56,000 Hz) [4]	4	N/A	-	24,000	-	-
EM Magnetite	-	N/A	-	-	-	-
Total Field Magnetics [1]	4	N/A	-	24,000	-	-
Enhanced Magnetics	-	N/A	-	-	-	-
Vertical Gradient Magnetics	-	N/A	-	-	-	-
2nd Vertical Derivative Magnetics	-	N/A	-	-	-	-
Magnetic Susceptibility	-	N/A	-	-	-	-
VLF [6]	4	N/A	-	24,000	-	-
EM Profiles (60 Hz monitor) [5]	4	N/A	24,000	N/A	N/A	N/A
EM Profiles	-	N/A	-	N/A	N/A	N/A
Overburden Thickness	-	N/A	-	-	-	-
Distance Based Digital Profiles						24,000

- Not required
24,000 Scale of delivered map, i.e, 1:24,000
* The parameter number is identified on each map with the sheet number.

SURVEY EQUIPMENT

This section provides a brief description of the geophysical instruments used to acquire the survey data:

Electromagnetic System

Model:	DIGHEM^{IV}
Type:	Towed bird, symmetric dipole configuration, operated at a nominal survey altitude of 100 feet. Coil separation is 26.2 feet for all coil-pairs except the 56,000 Hz which has a 20.7 foot separation.
Coil orientations/frequencies:	coaxial / 900 Hz coplanar/ 900 Hz coplanar/ 7,200 Hz coplanar/56,000 Hz
Sensitivity:	0.2 ppm at 900 Hz 0.4 ppm at 7,200 Hz 1.0 ppm at 56,000 Hz
Sample rate:	10 per second

The electromagnetic system utilizes a multi-coil coaxial/coplanar technique to energize conductors in different directions. The coaxial transmitter coil is vertical with its axis in the flight direction. The coplanar coils are horizontal. The secondary fields are sensed simultaneously by means of receiver coils which are maximum coupled to their respective transmitter coils. The system yields an inphase and a quadrature channel from each transmitter-receiver coil-pair. The system is also equipped to provide two environment noise monitor channels.

Magnetometer

Model: Picodas Cesium 3000

Sensitivity: 0.01 nT

Sample rate: 10 per second

The magnetometer sensor is towed in a bird 50 ft. below the helicopter.

Magnetic Base Station

Model: Geometrics G-826A

Sensitivity: 0.50 nT

Sample rate: once per 5 seconds

An Epson recorder is operated in conjunction with the base station magnetometer to record the diurnal variations of the earth's magnetic field. The clock of the base station is synchronized with that of the airborne system to permit subsequent removal of diurnal drift.

VLF System

Manufacturer: Herz Industries Ltd.

Type: Totem-2A

Sensitivity: 0.1%

The VLF receiver measures the total field and vertical quadrature components of the secondary VLF field. Signals from two separate transmitters can be measured simultaneously. The VLF sensor is towed in a bird 33 feet below the helicopter.

Radio Altimeter

Manufacturer: Honeywell/Sperry

Type: AA 220

Sensitivity: 1 ft

The radio altimeter measures the vertical distance between the helicopter and the ground. This information is used in the processing algorithm which determines conductor depth.

Analog Recorder

Manufacturer: RMS Instruments

Type: GR33 dot-matrix graphics recorder

Resolution: 4x4 dots/mm

Speed: 1.5 mm/sec

The analog profiles were recorded on chart paper in the aircraft during the survey. Table 2-1 lists the geophysical data channels and the vertical scale of each profile.

Digital Data Acquisition System

Manufacturer: Sonotek

Type: SDS 12000

Tape Deck: RMS TCR-12, 6400 bpi, tape cartridge recorder

The digital data were used to generate several computed parameters.

Tracking Camera

Type: Panasonic Video

Model: AG 2400/WVCD132

Fiducial numbers are recorded continuously and are displayed on the margin of each image. This procedure ensures accurate correlation of analog and digital data with respect to visible features on the ground.

Navigation System

Model:	Del Norte 547
Type:	UHF electronic positioning system
Sensitivity:	3 feet
Sample rate:	0.5 per second

The navigation system uses ground based transponder stations which transmit distance information back to the helicopter. The ground stations are set up well away from the survey area and are positioned such that the signals cross the survey block at an angle between 30° and 150°. After site selection, a baseline is flown at right angles to a line drawn through the transmitter sites to establish an arbitrary coordinate system for the survey area. The onboard Central Processing Unit takes any two transponder distances and determines the helicopter position relative to these two ground stations in cartesian coordinates.

Aircraft

The instrumentation was installed in an Aerospatiale Lama 315B turbine helicopter. The helicopter flew at an average airspeed of 70 mph with an EM bird height of approximately 100 feet.

Table 2-1. The Analog Profiles

Channel Name	Parameter	Sensitivity per mm	Designation on digital profile
CX1I	coaxial inphase (900 Hz)	2.5 ppm	CXI (900 Hz)
CX1Q	coaxial quad (900 Hz)	2.5 ppm	CXQ (900 Hz)
CP2I	coplanar inphase (900 Hz)	2.5 ppm	CPI (900 Hz)
CP2Q	coplanar quad (900 Hz)	2.5 ppm	CPQ (900 Hz)
CP3I	coplanar inphase (7200 Hz)	5.0 ppm	CPI (7200 Hz)
CP3Q	coplanar quad (7200 Hz)	5.0 ppm	CPQ (7200 Hz)
CP4I	coplanar inphase (56 kHz)	10.0 ppm	CPI (56 kHz)
CP4Q	coplanar quad (56 kHz)	10.0 ppm	CPQ (56 kHz)
CSPX	coaxial sferics monitor	2.5 ppm	
CPPL	coplanar powerline monitor	2.5 ppm	
CXPL	coaxial powerline monitor	2.5 ppm	CXPL
ALT	altimeter	3 m	ALT
VF1T	VLF-total: primary station	5%	
VF1Q	VLF-quad: primary station	5%	
VF2T	VLF-total: secondary stn.	5%	
VF2Q	VLF-quad: secondary stn.	5%	
CMGC	magnetics, coarse	50 nT	MAG
CMGF	magnetics, fine	5.0 nT	MAG
4DIF	4th difference magnetics		

Table 2-2. The Digital Profiles

Channel Name (Freq)	Observed parameters	Scale units/mm
MAG	magnetics	20 nT
ALT	bird height	6 m
CXI (900 Hz)	vertical coaxial coil-pair inphase	4 ppm
CXQ (900 Hz)	vertical coaxial coil-pair quadrature	4 ppm
CPI (900 Hz)	horizontal coplanar coil-pair inphase	4 ppm
CPQ (900 Hz)	horizontal coplanar coil-pair quadrature	4 ppm
CPI (7200 Hz)	horizontal coplanar coil-pair inphase	8 ppm
CPQ (7200 Hz)	horizontal coplanar coil-pair quadrature	8 ppm
CPI (56 kHz)	horizontal coplanar coil-pair inphase	20 ppm
CPQ (56 kHz)	horizontal coplanar coil-pair quadrature	20 ppm
CXPL	coaxial powerline monitor	2 ppm
	Computed Parameters	
RES (900 Hz)	log resistivity	.06 decade
RES (7200 Hz)	log resistivity	.06 decade
RES (56 kHz)	log resistivity	.06 decade
DP (900 Hz)	apparent depth	6 m
DP (7200 Hz)	apparent depth	6 m
DP (56 kHz)	apparent depth	6 m

PRODUCTS AND PROCESSING TECHNIQUES

The following products are available from the survey data. Those which are not part of the survey contract may be acquired later. Refer to Table 1-1 for a summary of the maps which accompany this report and those which are recommended as additional products. Most parameters can be displayed as contours, profiles, or in colour.

Base Maps

Base maps of the survey area were prepared from 1:24,000 and 1:62,500 scale topographic maps.

Flight Path

The cartesian coordinates produced by the electronic navigation system were transformed into UTM grid locations during data processing. These were tied to the UTM grid on the base map. In the case of a photomosaic base map, the UTM grid must be transferred from a topographic map to the photomosaic.

Prominent topographical features were correlated with the navigational data points, to ensure that the data is accurately registered on the base map.

Electromagnetic Anomalies

Anomalous electromagnetic responses are selected and analysed by computer to provide a preliminary electromagnetic anomaly map. This preliminary EM map is used, by the geophysicist, in conjunction with the computer generated digital profiles, to produce the final interpreted EM anomaly map. This map includes bedrock, surficial and cultural conductors. A map containing only bedrock conductors can be generated, if desired.

Resistivity

The apparent resistivity in ohm-m may be generated from the inphase and quadrature EM components for any of the frequencies, using a pseudo-layer halfspace model. A resistivity map portrays all the EM information for that frequency over the entire survey area. This contrasts with the electromagnetic anomaly map which provides information only over interpreted conductors. The large dynamic range makes the resistivity parameter an excellent mapping tool.

EM Magnetite

The apparent percent magnetite by weight is computed wherever magnetite produces a negative inphase EM response. The results are usually displayed on a contour map.

Total Field Magnetics

The aeromagnetic data are corrected for diurnal variation using the magnetic base station data. The regional IGRF gradient is removed from the data, if required under the terms of the contract.

Enhanced Magnetics

The total field magnetic data are subjected to a processing algorithm. This algorithm enhances the response of magnetic bodies in the upper 1,500 feet and attenuates the response of deeper bodies. The resulting enhanced magnetic map provides better definition and resolution of near-surface magnetic units. It also identifies weak magnetic features which may not be evident on the total field magnetic map. However, regional magnetic variations, and magnetic lows caused by remanence, are better defined on the total field magnetic map. The technique is described in more detail in Section 5.

Magnetic Derivatives

The total field magnetic data may be subjected to a variety of filtering techniques to yield maps of the following:

vertical gradient

second vertical derivative
magnetic susceptibility with reduction to the pole
upward/downward continuations

All of these filtering techniques improve the recognition of near-surface magnetic bodies, with the exception of upward continuation. Any of these parameters can be produced on request. Dighem's proprietary enhanced magnetic technique is designed to provide a general "all-purpose" map, combining the more useful features of the above parameters.

VLF

The VLF data can be digitally filtered to remove long wavelengths such as those caused by variations in the transmitted field strength. The results are usually presented as contours of the filtered total field.

Digital Profiles

Distance-based profiles of the digitally recorded geophysical data are generated and plotted by computer. These profiles also contain the calculated parameters which are used in the interpretation process. These are produced as worksheets prior to interpretation, and can also be presented in the final corrected form after interpretation.

The profiles display electromagnetic anomalies with their respective interpretive symbols. The differences between the worksheets and the final corrected form occur only with respect to the EM anomaly identifier.

Contour, Colour and Shadow Map Displays

The geophysical data are interpolated onto a regular grid using a cubic spline technique. The resulting grid is suitable for generating contour maps of excellent quality.

Colour maps are produced by interpolating the grid down to the pixel size. The distribution of the colour ranges is normalized for the magnetic parameter colour maps, and matched to specific contour intervals for the resistivity and VLF colour maps.

Monochromatic shadow maps are generated by employing an artificial sun to cast shadows on a surface defined by the geophysical grid. There are many variations in the shadowing technique, as shown in Figure 3-1. The various shadow techniques may be applied to total field or enhanced magnetic data, magnetic derivatives, VLF, resistivity, etc. Of the various magnetic products, the shadow of the enhanced magnetic parameter is particularly suited for defining geological structures with crisper images and improved resolution.

Dighem software provides several shadowing techniques. Both monochromatic (commonly green) or polychromatic (full color) maps may be produced. Monochromatic shadow maps are often preferred over polychromatic maps for reasons of clarity.

<u>Spot Sun</u>

The spot sun technique tends to mimic nature. The sun occupies a spot in the sky at a defined azimuth and inclination. The surface of the data grid casts shadows. This is the standard technique used by industry to produce monochromatic shadow maps.

A characteristic of the spot sun technique is that shadows are cast in proportion to how well the sunlight intersects the feature. Features which are almost parallel to the sun's azimuth may cast no shadow at all. To avoid this problem, Dighem's hemispheric sun technique may be employed.

<u>Hemispheric Sun</u>

The hemispheric sun technique was developed by Dighem. The method involves lighting up a hemisphere. If, for example, a north hemispheric sun is selected, features of all strikes will have their north side in sun and their south side in shadow. The hemispheric sun lights up all features, without a bias caused by strike. The method yields sharply defined monochromatic shadows.

The hemispheric sun technique always improves shadow casting, particularly where folding and cross-cutting structures occur. Nevertheless, it is important to center the hemisphere perpendicular to the regional strike. Features which strike parallel to the center of the hemisphere result in ambiguity. This is because the two sides of the feature may yield alternating patterns of sun and shadow. If this proves to be a problem in your survey area, Dighem's omni sun technique may be employed.

<u>Omni Sun</u>

The omni sun technique was also developed by Dighem. The survey area is centered within a ring of sunlight. This lights up all features without any strike bias. The result is brightly defined monochromatic features with diffuse shadows.

<u>Multi Sun</u>

Two or three spot suns, with different azimuths, may be combined in a single presentation. The shadows are displayed on one map by the use of different colors, e.g., by using a green sun and a red sun. Some users find the interplay of colors reduces the clarity of the shadowed product.

<u>Polychromatic Maps</u>

Any of the above monochromatic shadow maps can be combined with the standard contour-type solid color map. The result is a polychromatic shadow map. Such maps are esthetically pleasing, and are preferred by some users. A disadvantage is that ambiguity exists between changes in amplitude and changes in shadow.

Fig. 3-1 Shadow Mapping

SURVEY RESULTS

Resistivity

Apparent resistivity maps were prepared from the 900 Hz, 7200 Hz and 56,000 Hz coplanar EM data. These maps show the conductive properties of the survey area.

The 56,000 Hz data has the greatest dynamic range but is biased towards surficial conductivity. It will primarily provide information about surface detail in the areas with highly conductive near-surface sediments, such as those in the eastern portion of the survey area. The 56,000 Hz resistivity also appears to be more active than the 900 Hz and 7200 Hz resistivities.

All three resistivities define well the boundary between conductive pediment and the more resistive rock units. The resistivity patterns in the area of the sediments may reflect differences in the thickness of the conductive upper layer, or resistivity contrasts due to structure or lithology.

The resistivity contour patterns are similar for the 900 Hz and 7200 Hz, however, the 7200 Hz yields lower resistivities. This is due to greater attenuation of the higher frequency in conductive surficial material.

Power lines and other conductive cultural sources yield lineations and bulls-eye anomalies on all three resistivity maps. Some yield responses on the 60 Hz monitor profile maps, while others do not. Some recent culture may not appear on the base maps. Features of interest on the resistivity maps should be checked on the flight videos, and/or by on-site checks, to verify that they do not correlate with culture. More information on identifying cultural anomalies is presented in the <u>Recognition of culture</u> section, in section 5 of this report.

Magnetics

The total field magnetic data have been presented as contours on the base maps using a contour interval of 5 nT where gradients permit. The IGRF gradient across the survey block has not been removed. The maps show the magnetic properties of the rock units underlying the survey area.

Numerous structural breaks can be inferred from lineaments on the magnetic maps. These structural complexities are evident on the contour maps as variations in magnetic intensity, irregular patterns, and as offsets or

(NLK - 24.8 kHz) and Annapolis, Maryland (NSS - 21.4 kHz). The use of three different stations was necessitated by signal interruptions at the source of transmission. Results from the transmitters at Annapolis and Cutler were presented as contours of the filtered total field.

The contour patterns were influenced somewhat by cultural sources. Very little useful information is apparent on the VLF maps in the more conductive areas of the survey, due to the highly conductive surficial cover.

In the more resistive areas of the survey, structural breaks may be reflected by offsets and discontinuities in the VLF trends.

The VLF method is quite sensitive to the angle of coupling between the conductor and the proposed EM field. Consequently, conductors which strike towards the VLF station will usually yield a stronger response than conductors which are nearly orthogonal to it.

Closely-spaced conductors, conductors of short strike length or conductors which are poorly coupled to the VLF field, may escape detection with this method. Erratic signals from the VLF transmitters can also give rise to strong, isolated anomalies which should be viewed with caution.

changes in strike direction. Some of these correlate with features on the resistivity maps.

If a specific magnetic intensity can be assigned to the rock type which is believed to host the target mineralization, it may be possible to select areas of higher priority on the basis of the total field magnetic maps. This is based on the assumption that the magnetite content of the host rocks will give rise to a limited range of contour values which will permit differentiation of various lithological units.

There are several spikes and lineaments on the magnetics that may result from culture. As a result, checks of the flight videos and/or on-site checks will be required to verify some features.

The magnetic results, in conjunction with the other geophysical parameters, should provide valuable information which can be used to effectively map the geology and structure in the survey areas.

VLF

VLF results were obtained from three transmitting stations, Cutler, Maine (NAA - 24.0 kHz), Seattle, Washington

BACKGROUND INFORMATION

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 EM 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 correct 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. The resistivity analysis also helps the interpreter to differentiate between conductive trends in the bedrock and those patterns typical of conductive overburden. For example, discrete conductors will generally appear as narrow lows on the contour map and broad conductors (e.g., overburden) will appear as wide lows.

The resistivity profiles and the resistivity contour maps present the apparent resistivity using the so-called pseudo-layer (or buried) half space model defined by Fraser (1978)[1]. This model consists of a resistive layer overlying a conductive half space. The depth channels give the apparent depth below surface of the conductive material. The apparent depth 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 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

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

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 system has been flown for purposes 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 can be of significant help in distinguishing between overburden and bedrock conductors.

Recognition of culture

Cultural responses include all EM anomalies caused by man-made metallic objects. Such anomalies may be caused by inductive coupling or current gathering. The concern of the interpreter is to recognize when an EM response is due to culture. Points of consideration used by the interpreter, when coaxial and coplanar coil-pairs are operated at a common frequency, are as follows:

1. Channel CXPL monitors 60 Hz radiation. An anomaly on this channel shows that the conductor is radiating power. Such an indication is normally a guarantee that the conductor is cultural. However, care must be taken to ensure that the conductor is not a geologic body which strikes across a power line, carrying leakage currents.

2. A flight which crosses a "line" (e.g., fence, telephone line, etc.) yields a center-peaked coaxial anomaly and an m-shaped coplanar anomaly. When the flight crosses the cultural line at a high angle of intersection, the amplitude ratio of coaxial/coplanar response is 4. Such an EM anomaly can only be caused by a line. The geologic body which yields anomalies most closely resembling a line is the vertically dipping thin dike. Such a body, however, yields an amplitude ratio of 2 rather than 4. Consequently, an m-shaped coplanar anomaly with a CXI/CPI amplitude ratio of 4 is virtually a guarantee that the source is a cultural line.

3. A flight which crosses a sphere or horizontal disk yields center-peaked coaxial and coplanar anomalies with a CXI/CPI amplitude ratio (i.e., coaxial/coplanar) of 1/4. In the absence of geologic bodies of this geometry, the most likely conductor is a metal roof or

small fenced yard.[2] Anomalies of this type are virtually certain to be cultural if they occur in an area of culture.

4. A flight which crosses a horizontal rectangular body or wide ribbon yields an m-shaped coaxial anomaly and a center-peaked coplanar anomaly. In the absence of geologic bodies of this geometry, the most likely conductor is a large fenced area. Anomalies of this type are virtually certain to be cultural if they occur in an area of culture.

5. EM anomalies which coincide with culture, as seen on the camera film or video display, are usually caused by culture. However, care is taken with such coincidences because a geologic conductor could occur beneath a fence, for example. In this example, the fence would be expected to yield an m-shaped coplanar anomaly as in case #2 above. If, instead, a center-peaked coplanar anomaly occurred, there would be concern that a thick geologic conductor coincided with the cultural line.

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[2] It is a characteristic of EM that geometrically similar anomalies are obtained from: (1) a planar conductor, and (2) a wire which forms a loop having dimensions identical to the perimeter of the equivalent planar conductor.

6. The above description of anomaly shapes is valid when the culture is not conductively coupled to the environment. In this case, the anomalies arise from inductive coupling to the EM transmitter. However, when the environment is quite conductive (e.g., less than 100 ohm-m at 900 Hz), the cultural conductor may be conductively coupled to the environment. In this latter case, the anomaly shapes tend to be governed by current gathering. Current gathering can completely distort the anomaly shapes, thereby complicating the identification of cultural anomalies. In such circumstances, the interpreter can only rely on the radiation channel CPS and on the camera film or video records.

MAGNETICS

In some geological environments, 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, Canada) as well as magnetic (e.g., the Mattabi deposit near Sturgeon Lake, Canada).

The magnetometer data are digitally recorded in the aircraft to an accuracy of one nT (i.e., one gamma) for proton magnetometers, and 0.01 nT for cesium magnetometers.

The digital tape is processed by computer to yield a total field magnetic contour map. When warranted, the magnetic data may also be treated mathematically to enhance the magnetic response of the near-surface geology, and an enhanced magnetic contour map is then produced. The response of the enhancement operator in the frequency domain is illustrated in Figure 5-1. This figure shows that the passband components of the airborne data are amplified 20 times by the enhancement operator. This means, for example, that a 100 nT anomaly on the enhanced map reflects a 5 nT anomaly for the passband components of the airborne data.

The enhanced map, which bears a resemblance to a downward continuation map, is produced by the digital bandpass filtering of 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. It defines the near-surface local geology while de-emphasizing deep-seated regional features. It primarily has application when the magnetic rock units are

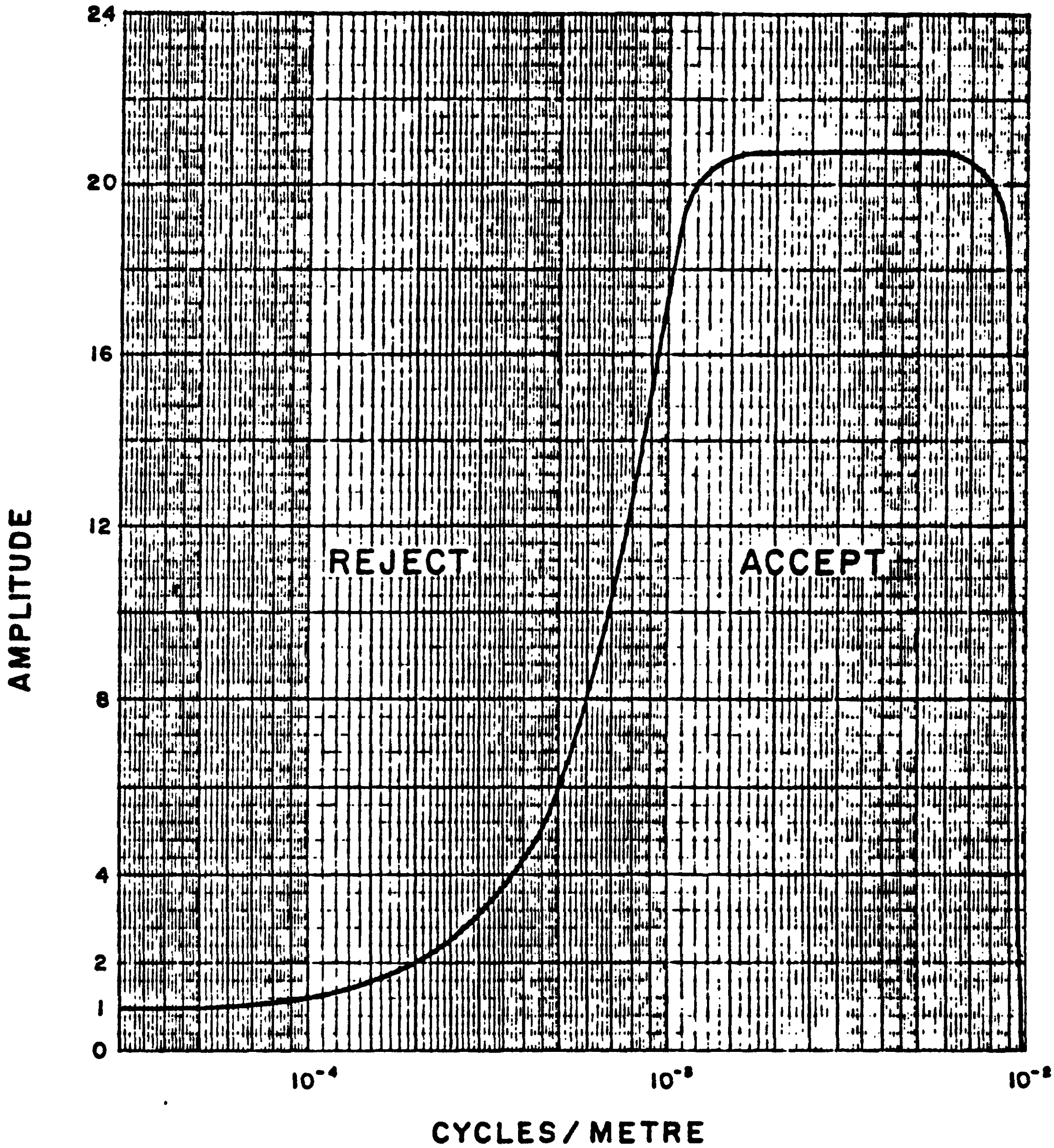

Figure 1 Frequency response of magnetic operator.

steeply dipping and the earth's field dips in excess of 60 degrees.

Any of a number of filter operators may be applied to the magnetic data, to yield vertical derivatives, continuations, magnetic susceptibility, etc. These may be displayed in contour, colour or shadow.

VLF

VLF transmitters produce high frequency uniform electromagnetic fields. However, VLF anomalies are not EM anomalies in the conventional sense. EM anomalies primarily reflect eddy currents flowing in conductors which have been energized inductively by the primary field. In contrast, VLF anomalies primarily reflect current gathering, which is a non-inductive phenomenon. The primary field sets up currents which flow weakly in rock and overburden, and these tend to collect in low resistivity zones. Such zones may be due to massive sulfides, shears, river valleys and even unconformities.

The VLF field is horizontal. Because of this, the method is quite sensitive to the angle of coupling between the conductor and the transmitted VLF field. Conductors which strike towards the VLF station will usually yield a stronger response than conductors which are nearly orthogonal to it.

The Herz Industries Ltd. Totem VLF-electromagnetometer measures the total field and vertical quadrature components. Both of these components are digitally recorded in the aircraft with a sensitivity of 0.1 percent. The total field yields peaks over VLF current concentrations whereas the quadrature component tends to yield crossovers. Both appear as traces on the profile records. The total field data are filtered digitally and displayed as contours to facilitate the recognition of trends in the rock strata and the interpretation of geologic structure.

The response of the VLF total field filter operator in the frequency domain (Figure 5-2) is basically similar to that used to produce the enhanced magnetic map (Figure 5-1). The two filters are identical along the abscissa but different along the ordinant. The VLF filter removes long wavelengths such as those which reflect regional and wave transmission variations. The filter sharpens short wavelength responses such as those which reflect local geological variations.

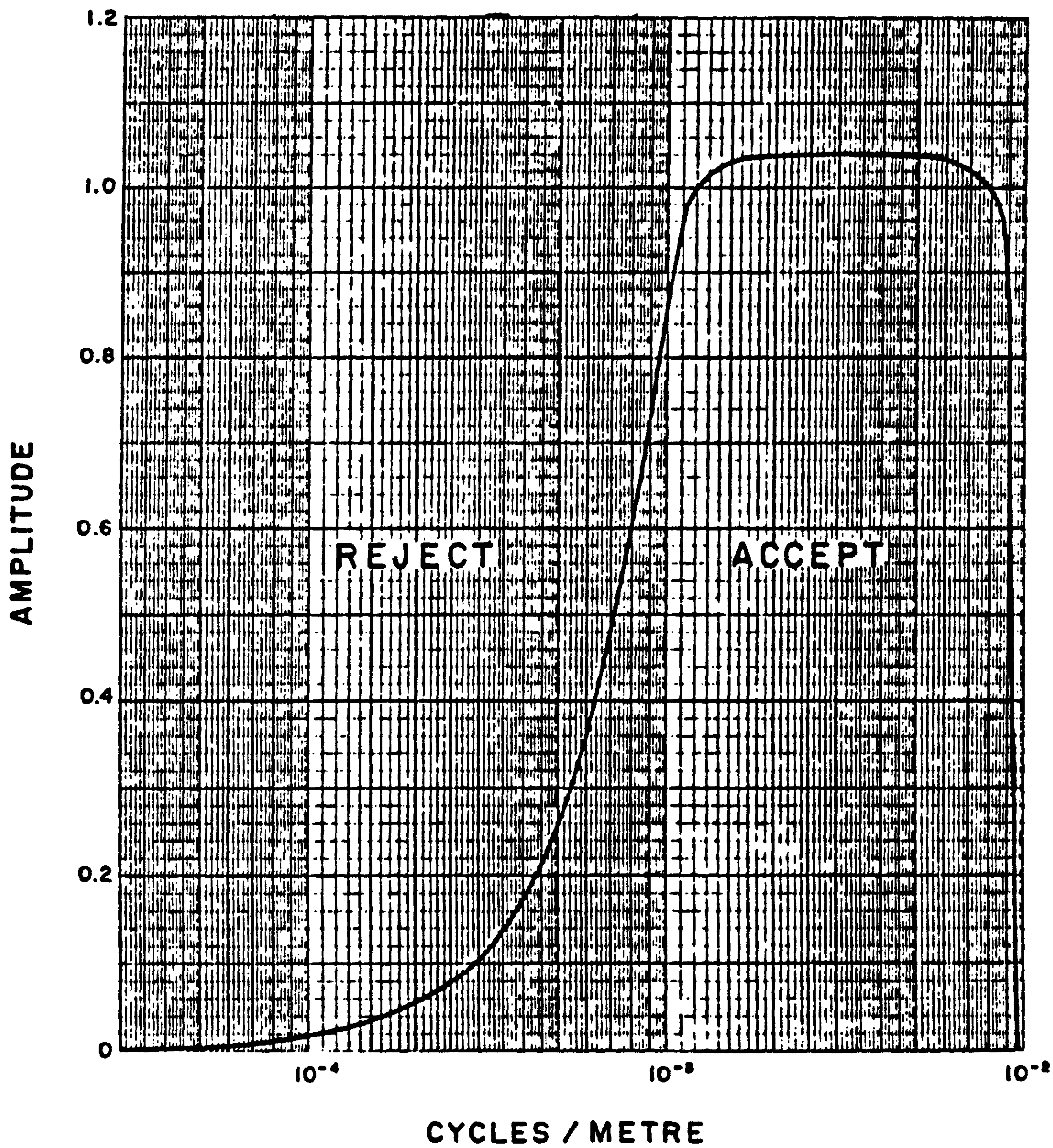

Figure 2 Frequency response of VLF-EM operator.

CONCLUSIONS AND RECOMMENDATIONS

This report provides a brief description of the survey results and describes the equipment, procedures and logistics of the survey.

The various maps included with this report display the magnetic and conductive properties of the survey area. The survey results should be reviewed in detail, in conjunction with all available geological, geophysical and geochemical information. On-site checks are recommended to verify that linear and bulls-eye features on all parameters are not due to culture.

Respectfully submitted,

DIGHEM SURVEYS & PROCESSING INC.

Doug McConnell

Douglas L. McConnell
Geophysicist

DLM/sdp

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APPENDIX A

LIST OF PERSONNEL

The following personnel were involved in the acquisition, processing, interpretation and presentation of data, relating to a DIGHEM^{IV} airborne geophysical survey carried out for U.S.G.S. in the Getchell Trend area, Nevada.

Phillip Miles	Senior Geophysical Operator
Fred Cappo	Pilot (Geoseis Ltd.)
Gordon Smith	Computer Processor
Douglas L. McConnell	Geophysicist
Gary Hohs	Draftsperson
Susan Pothiah	Word Processing Operator

The survey consisted of 1,150 miles of coverage, flown from November 6 to November 11, 1988. Geophysical data were compiled utilizing a VAX 11-780 computer.

All personnel are employees of Dighem Surveys & Processing Inc., except for the pilot who is an employee of Geoseis Ltd.

DIGHEM SURVEYS & PROCESSING INC.

Doug McConnell

Douglas L. McConnell
Geophysicist

DLM/sdp

Ref: Report #543

A0543JAN.90R

APPENDIX B

STATEMENT OF COST

Date: January 18, 1989

IN ACCOUNT WITH
DIGHEM SURVEYS & PROCESSING INC.

To: Dighem flying of Agreement dated September 8, 1988, pertaining to an Airborne Geophysical Survey in the Getchell Trend Area, Nevada

Survey Charges

1070 line-miles of flying US $ 79,715.00

Allocation of Costs

- Data Acquisition (60%)
- Data Processing (20%)
- Interpretation, Report and Maps (20%)

DIGHEM SURVEYS & PROCESSING INC.

Doug McConnell

Douglas L. McConnell
Geophysicist

DLM/sdp

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APPENDIX C

LINE NUMBERS FOR VLF STATION VNAA

11360	10585	10540	10080	10302
11361	10590	10550	10090	10305
11370	10591	10630	10100	10310
11380	10595	10650	10110	10320
11390	10600	10670	10120	10330
11400	10605	10690	10130	10340
11410	10610	10710	10140	10350
11420	10620	10730	10150	10360
11430	10640	10750	10160	10370
11230	10660	10770	10170	10380
11250	10661	11180	10180	10385
11270	10410	11200	10190	19030
11290	10420	11220	10200	19031
11300	10430	11240	10210	10390
11310	10440	11260	10220	10400
11320	10450	11280	10230	19021
11330	10460	11440	10240	19022
11340	10470	10010	10250	19040
11350	10480	10020	10260	19011
11351	10490	10030	10270	19012
10560	10500	10050	10280	19013
10570	10510	10070	10290	
10575	10520	10040	10295	
10580	10530	10060	10301	

LINE NUMBERS FOR VLF STATION VNSS

11210	10910	11000	10790	10900
11090	10915	11010	10800	10905
11100	10920	11020	10810	10911
11110	10925	11030	10820	10921
11120	10930	11040	10830	10935
11130	10940	11050	10840	10680
11140	10950	11060	10850	10700
11150	10960	11070	10860	10720
11160	10970	11080	10870	10740
11170	10980	10760	10880	
11191	10990	10780	10890	

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