1777

ENVIRONMENTAL IMAGING
TO INVESTIGATE SUBSURFACE CONDITIONS
AT THE F29 SUMP LOCATION
NORTHWEST OF INUVIK, NORTHWEST TERRITORIES

prepared for

Devon Canada Corporation
Calgary, Alberta

directed by

Newpark Environmental Services
Calgary, Alberta

produced by

Essis Ltd.
Calgary, Alberta

Respectfully submitted,
ESSIS LTD.

PERMIT TO PRACTICE
ESSIS LTD.
Signature
Date Nov 4 2004
PERMIT NUMBER: P 6825
The Association of Professional Engineers, Geologists and Geophysicists of Alberta

Per:

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Geophysics and Imaging

Approved:

PROFESSIONAL GEOPHYSICIST OF ALBERTA
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Sr. Environmental Geophysicist

November 4th, 2004
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Essis

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1. INTRODUCTION

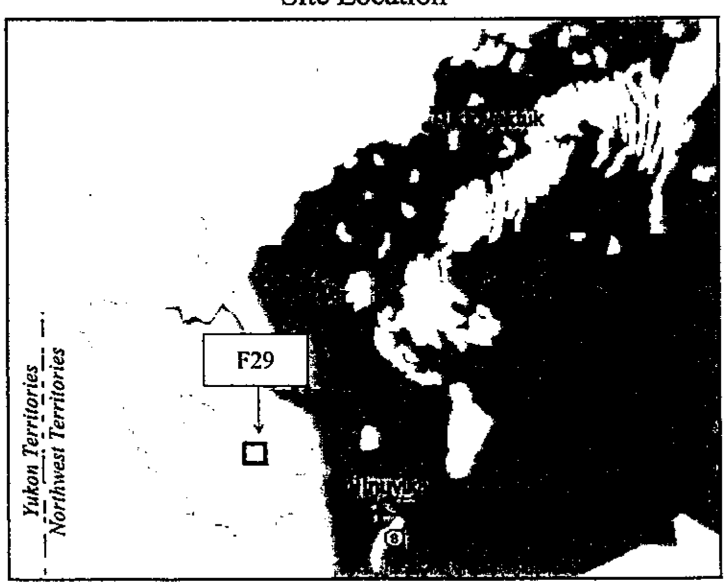
This report describes an environmental imaging (EI) investigation carried out under contract to Newpark Environmental Services of Calgary, Alberta for Devon Canada Corporation of Calgary, Alberta. The survey was carried out on September 9th, 2004 at the F29 sump, located northwest of Inuvik, Northwest Territories.

The survey objectives were to identify and delineate possible subsurface ionic occurrences on site. This investigation was compared to a previously conducted survey (see Essis Project #1346 06, September 2003) to determine possible changes in subsurface ion-distributions.

The Geonics EM38 and EM31 were used to meet these objectives. Two Trimble Pathfinder Power DGPS receivers provided positional control. Data were differentially corrected using Central Alaska, Alaska, USA base station data.

All project work was carried out in accordance to discussions with Mr. Aaron Trites of Newpark Environmental Services of Calgary, Alberta.

FIGURE 1
Site Location



2. ENVIRONMENTAL IMAGING (EI) - DATA ACQUISITION

EI refers to the imaging of the subsurface for anomalous environmental conditions. Various tools are applicable to this process, each of unique capability and purpose. This section describes the tools used to image environmental subsurface conditions on site.

Appendix A contains geophysical (Geonics EM38 and EM31) and DGPS positioning (Trimble Pathfinder Power) specifications. Appendix B contains a technical paper by the instrument manufacturer (Geonics Limited). This paper provides in-depth technical background on the applied geophysical technique (Frequency-Domain EM induction).

2.1 LATERAL CONDUCTIVITY (GEONICS EM38/31)

Appendix A contains Geonics EM38/31 instrument specifications. The Geonics EM38/31 use electromagnetic (EM) inductive forces to delineate subsurface conductivities. These instruments are digitally synchronized to differentially-corrected GPS (DGPS). This arrangement allows positioning and geophysical data to be stored simultaneously on handheld dataloggers. Data are acquired swiftly at high sampling density. EM38 readings were taken in the 'EM38 – Horizontal Coils at Ground Level' mode, approximating measurements of the initial 1.5 m of topsoil (Table 1). EM31 readings were taken in the 'EM31 – Horizontal Coils at Hip Level' mode, approximating measurements of the initial 5 m of topsoil (Table 1).

Please note that an inherent property of EM signals prevents deep penetration into conductive media. Tabulated depths of penetration (Table 1) are skindepths of the penetrating EM signal and are a function, in part, of overall soil conductivity (conductive soil reduces depth-of-penetration). The various coil orientations are not used to delineate the depth-extent of conductive media but rather the depth-onset of conductive media.

TABLE 1

EM38/31 Coil Orientations and Corresponding Effective Depths of Penetration

Coil Orientation	Effective Depth of Penetration
EM38 – Horizontal Coils at Ground Level	**1.5 m**
EM38 – Vertical Coils at Ground Level	1 m
EM31 – Vertical Coils at Ground Level	2 m
EM31 – Horizontal Coils at Hip Level	**5 m**
EM31 – Horizontal Coils at Ground Level	6 m

2.2 DGPS POSITIONING (TRIMBLE PATHFINDER POWER)

Appendix A contains DGPS instrument specifications. Positioning data were differentially corrected using Central Alaska, Alaska, USA base station data. The moving DGPS receiver (Rover) was synchronized to geophysical instruments providing positioning control of geophysical measurements. Although this system can readily apply corrections in real-time, post-processing using specialized software is more accurate and avoids potential interference by real-time correcting radio signals. Positioning accuracies in the several decimeters range are generally possible. Table 2 lists various DGPS survey parameters. Site features have been surveyed on site and serve as reference markings for follow-up work.

TABLE 2

DGPS Survey Parameters

Base Station UTM Coordinates:	
Central Alaska, Alaska, USA	7265957.73N, 607453.44E, 283.51 m
Rover UTM Zone	08
Final UTM Datum:	NAD83

3. ENVIRONMENTAL IMAGING (EI) - DATA PROCESSING AND PRESENTATION

EI data processing was initiated infield and completed at headquarters. Data processing was designed to enhance results by carefully applying specific mathematical algorithms. Such algorithms may filter unwanted data, enhance trend continuity or highlight otherwise unclear or invisible data.

3.1 LATERAL CONDUCTIVITY (GEONICS EM38/31)

EM38/31 data were processed to moderate responses from buried metal and powerline interference. Additional data processing enhanced trend continuity and amplified hidden anomalies. Key data processing parameters are tabulated (Table 3) to enable future data processing repeatability. Two 'Lateral Conductivity Distribution (EM38/31) & Site Features' maps were created (Maps 1/2 and 2/2) and are included in the clear plastic pouch accompanying this report. Reduced versions of both maps are bound into the report. The large-format maps detail site features better and offer finer EM-imaging than their small-format counterparts.

The lateral conductivity image was overlain onto an aerial photograph (taken by Essis crew during the mobilization flight) to improve feature identification during follow-up work. As the aerial photograph exhibits focal distortion, the DGPS surveyed features on the maps should be used for referencing field locations. The aerial photograph is bound in following the report.

TABLE 3
EM38/31 - Key Data Processing Parameters

Data Gridding:	Kriging (1 x 1)
Data Filtering:	Moving Average (5, 5)
Data Imaging:	Non-linear, 10 - 60 mS/m
Image Enhancement:	Resolution enhancement to 150 dpi, Low-Pass (2)

3.2 DGPS POSITIONING (TRIMBLE PATHFINDER POWER)

Positioning data were corrected for ionospheric effects. Specialized processing software by Trimble Navigation incorporated Central Alaska, Alaska, USA base station data to differentially correct all rover positions. PDOP (Positional Dilution of Precision) was generally below 3.5. PDOP is a statistical measure of positional accuracy related to satellite geometry relative to the receiver. In general, PDOP values in excess of five suggest somewhat more inaccurate positioning. Final UTM coordinates were projected in NAD83.

4. MAPS – INTERPRETATION AND SITE ANALYSIS

Maps (1/2) and (2/2) are titled 'Lateral Conductivity Distribution (EM38/31) & Site Features'. The large-format maps are scaled at 1:600. The small-format, bound maps are scaled at 1:950. Data are presented in UTM coordinates and projected in NAD83. The UTM grid coordinate system displays in units of metres (as opposed to degrees) and allows distance measurements to be read directly off the maps. UTM X and Y grid lines (the fine vertical and horizontal lines on the maps) are spaced 10 m apart. Site features have been DGPS surveyed and are included on the maps to provide reference control during follow-up work. Aerial photograph #1 (bound in following the report) represents an overlay of the EM38 image to an aerial photograph of the site (taken by Essis crew on September 8th, 2004 during a mobilization flight).

Lateral conductivity is also referred to as apparent conductivity. Apparent conductivity approximates the bulk conductivity from surface to skindepth of the primary EM field. Conductivity variations are generally caused by a combination of ionic contaminants (nitrates, chlorides), natural soil salinity, buried metal (pipes, scrap, etc.), changes in soil type and saturation.

Metallic and ionic responses can often be distinguished by interpreting their characteristic behaviour. Such behaviour is a function of geometric coupling between the instrument and buried metal. Buried metal is easily identified when geometric coupling is maximized (for example, when surveying perpendicularly across pipelines). Consequently, buried metal is not always identified when coupling is minimized (for example, when surveying parallel to pipelines). Please note that while the EM38/31 respond to buried metal, these tools are not specifically designed to map buried metals.

The colour images on the maps represent the lateral conductivity distribution on site. The possibility of conductive media increases from dark blue (cold colours) to dark red (hot colours). Regions that have been surveyed (as noted by the presence of geophysical measurement stations, fine crosses) and are not coloured (appearing white) are presumed background. Background readings can vary between sites in response to varying soil types. Dry accumulations of sand or gravel typically yield low backgrounds. Naturally occurring ions, fertilized, fine-grained and/or saturated soils yield elevated backgrounds. Elevated backgrounds can sometimes match magnitudes typical of contaminated regions. Lab results from soil core gathered within anomalous regions (hot colours) should reveal the cause of anomalous responses. Similarly, lab results from soil core gathered outside anomalous regions (cold colours) should reveal the nature of background responses.

In general, Maps (1/2) and (2/2) reveal shallower and deeper conductivity data on site, respectively. Comparison of this current 2004-fall survey to the previous 2003-fall survey (Essis Project #1346 06, September 2003) reveals generally similar conductivity trends and magnitudes within the sump area. Potential contaminant migration paths not suggested by last year's survey may have been revealed. Background responses are typical of dry sands, commonly found in this region.

The investigated sump is identified in the southwest corner of the clearing on the east side of the maps. Both maps reveal anomalous responses within and immediately surrounding the sump. Elevated responses are likely caused by ionic contamination. Potential contamination appears to have dispersed towards the east from the southeast side of the sump. Aerial photograph #1 reveals a corresponding body of pooled water matching well with the extents of suspected contamination.

5. CONCLUSIONS AND RECOMMENDATIONS

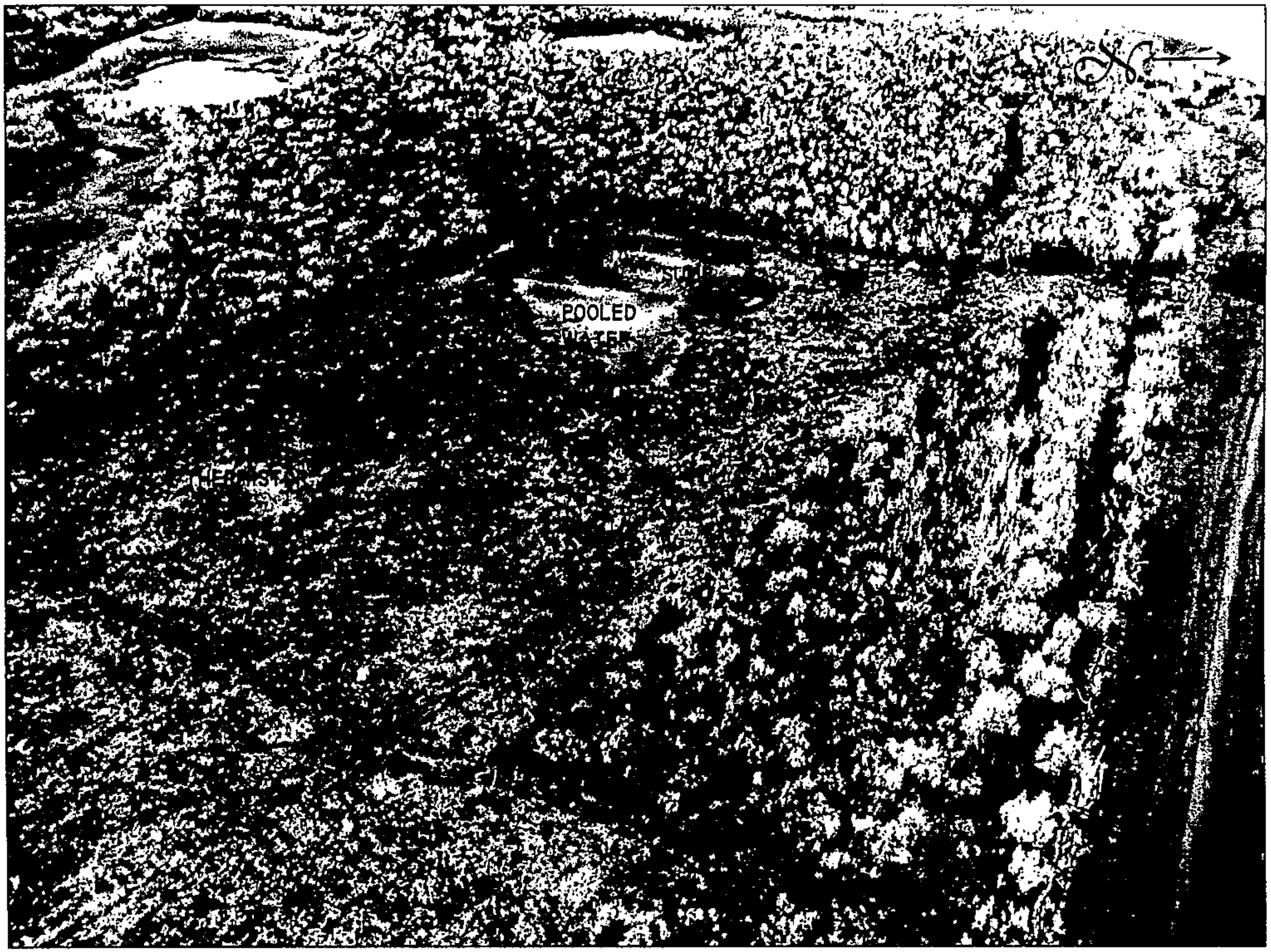
The survey objectives were to identify and delineate possible subsurface ionic occurrences at the F29 sump location. This investigation was compared to a previously conducted survey (see Essis Project #1346 06, September 2003) to determine possible changes in subsurface ion-distributions.

The Geonics EM38 and EM31 were used to meet these objectives. Two Trimble Pathfinder Power DGPS receivers provided positional control. Data were differentially corrected using Central Alaska, Alaska, USA base station data.

Lateral conductivity mapping revealed anomalous responses suggesting ionic contamination within the sump. Suspected contaminants may have migrated east and southwest from the sump. The extents of easterly contaminant movement corresponded with an area of pooled water. Southwestern migration occurred along a narrow belt of dead trees, extending towards a lake. Buried metal may have been identified immediately southwest of the sump.

Geophysical data should be correlated to future lab results of strategically gathered soil and ground water samples on site. The combined interpretation of all data ensures a comprehensive understanding of site conditions.

Site features have been DGPS surveyed to assist follow-up work. As well, aerial photographs taken of the site should support in-field feature identification. Caution is advised during subsequent sampling to avoid unidentified buried objects.



COMMENTS:

THE OVERLAY ILLUSTRATES THE CORRELATION OF EM RESPONSES TO REGIONAL FEATURES. THE PROCESS OF MERGING EM DATA WITH THE AERIAL PHOTOGRAPH GENERATES FOCAL AND PERSPECTIVE DISTORTION.

TECHNICAL SUMMARY:

GEOPHYSICAL INSTRUMENT:	GEONICS EM38
MEASURED QU[illegible]ITIES:	QUADRATURE IN MS/M

AERIAL PHOTOGRAPH & EM38 OVERLAY

F29

10 15 20 25 30 35 40 45 50 55 60

APPARENT CONDUCTIVITY

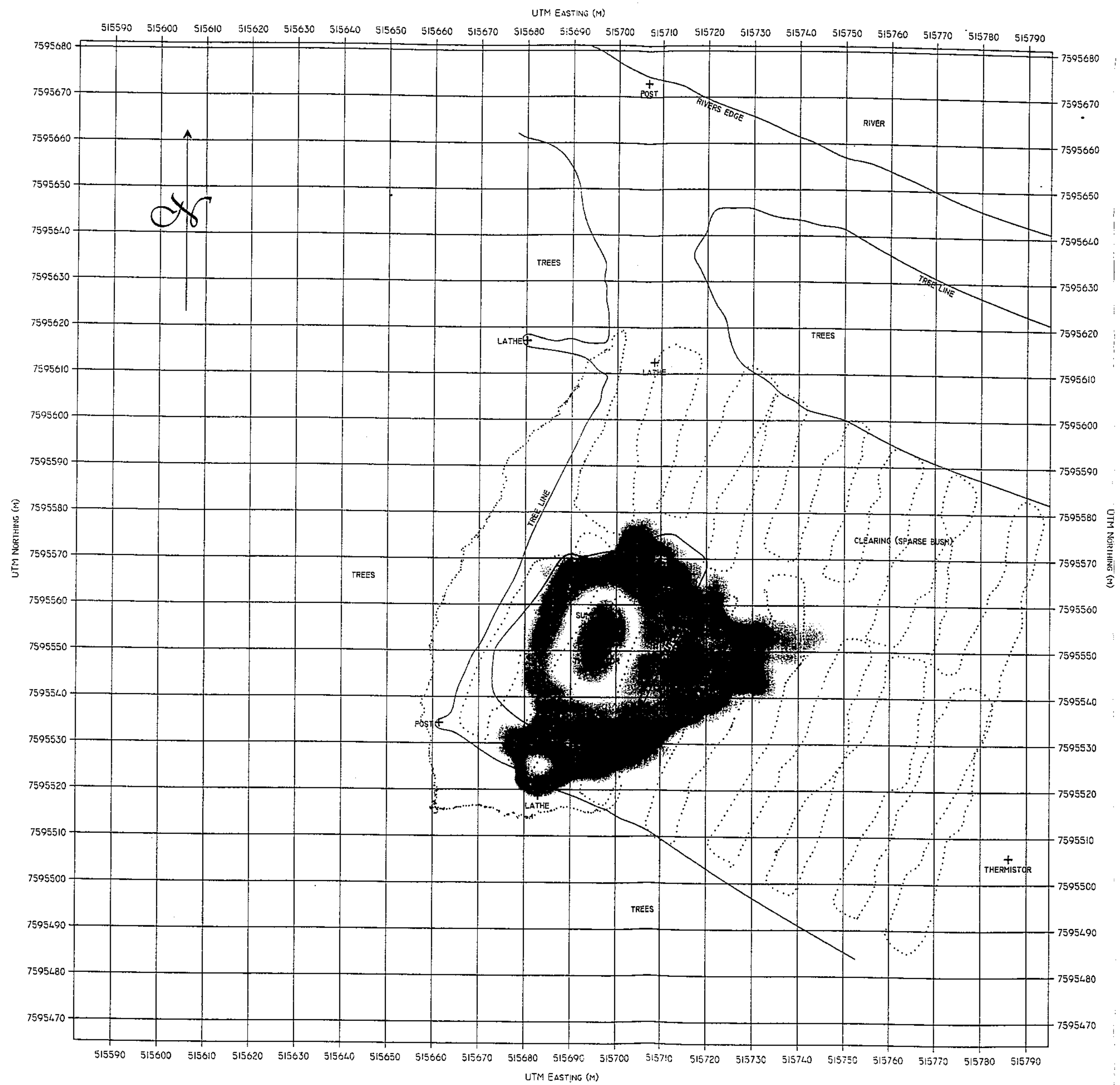
(M[illegible])

DATE: SEPTEMBER 9, 2004	AERIAL PHOTOGRAPH #1
JOB NUMBER: 1453 06	SCALE: VARIABLE, NON-LINEAR

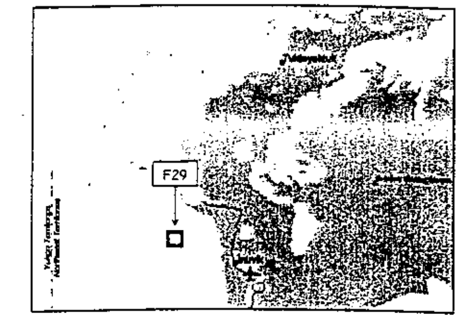
PRODUCED BY: Essis

DIRECTED BY: NEWPARK

CLIENT: devon



Site Location Map



Comments

The colour image reveals the 'Apparent Conductivity Distribution' on site. The term 'Apparent Conductivity' implies that conductivity measurements do not linearly relate to actual soil conductivities.

The presented EM data should be used qualitatively to select targets for vertical (depth) geophysical profiling or soil sampling. Geophysical results are only conclusive after correlation to soil sample data (ground-truthing). The depth response of the electromagnetic (EM) field varies from surface to a unique depth, the 'skindepth' of that particular EM signal. The skindepth of any EM signal is strongly influenced by overall soil conductivity. Since soil conductivity varies randomly, the apparent conductivity distribution does not represent data from any particular depth.

Posted features are surveyed using DGPS. A positional accuracy of several decimeters is generally possible. Positional accuracy diminishes near larger buildings and other satellite-obstructing features.

Technical Summary

Geophysical Specifications

Instrument:	Geonics EM31
Measured Quantities:	Quadrature in mS/m Inphase in ppt, Hs/Hp
Primary Field Source (Tx):	Self-Contained Dipole Tx
Receiver (Rx):	Self-Contained Dipole Rx
Intercoil Spacing:	3.66 m
Operating Frequency:	9.8 kHz
Conductivity Ranges:	10 - 1000 mS/m

Positioning (DGPS) Specifications

GPS Rover:	Trimble Pathfinder Power
GPS Base:	Trimble 4000SSi Dual
Data S/A Corrections:	Post-Processed Differential
Coordinate Projection:	Universal Transverse Mercator (UTM)
UTM Rover Zone:	8
Datum:	North American Datum 1983 (NAD83)
Base Coordinate:	CORS, Central Alaska, Alaska, USA X: 607453.44E Y: 7265957.73N Elev.: 283.51 m (Orthometric)

Legend

Sump

+ Line Feature (Post, Lathe, etc.)

Line Feature (Tree Line, Rivers Edge)

Geophysical Measurement Stations

10 15 20 25 30 35 40 45 50 55 60

Apparent Conductivity (mS/m)

Map 2/2	Scale = 1:950	September 2004	Job No.: 1453 06

Lateral Conductivity Distribution (EM31) & Site Features

F29

Client: devon

Directed by: Newpark

Produced by: Essis

Approved: ____

Created: ____

REDUCED VERSION

Permit to Practice
Essis Ltd.
Signature ____
Date ____
PERMIT NUMBER: P 6825
The Association of Professional Engineers, Geologists and Geophysicists of Alberta

APPENDIX A

EM38

GROUND CONDUCTIVITY METER with INPHASE CHANNEL

The EM38 measures the conductivity of the ground directly in mS/m. The EM38 also measures the inphase component of response, which enables it to be used as a metal detector or, for poorly to moderately conductive material, a magnetic-susceptibility meter.

The depth to which the EM38 measures conductivity depends solely on the orientation of the instrument. When the instrument is upright in vertical-dipole mode (as shown), depth of measurement is 1.5 m. With the instrument on its side, in horizontal-dipole mode, depth of measurement is 0.75 m. Readings are shown on digital meters which are mounted on the top and side of the EM38, for convenient reading regardless of the orientation of the instrument.

Using EM induction, the EM38 requires no contact with the ground. As a result, surveys can cover large areas rapidly. Readings can be recorded manually, or digitized and stored by the DL720 datalogger.

To survey at walking speed, a special handle allows the operator to carry the EM38 at ground level. The handle is equipped with at switch, which controls continuous recording of data by the DL720. In continuous mode, over 3000 measurements can be recorded per hour.

The EM38 is most commonly used in agricultural soil-salinity surveys, in both dry-land and irrigated areas. Compared to resistivity, EM38 surveys offer better lateral-resolution, and much faster coverage. The EM38 is often mounted on a trailer, and towed behind a tractor or other vehicle.

Other applications include the mapping of archaeological and waste-disposal sites. These applications make good use of the excellent spatial resolution of the EM38, and its ability to map magnetic susceptibility and to detect all types of metal.

Specifications

Measured Quantities	1: Apparent conductivity of the ground in millisiemens per metre (mS/m) 2: Inphase ratio of the secondary to primary magnetic field in parts per thousand (ppt)
EM Source	Dipolar transmitter coil, operating at 14.6 kHz
EM Sensor	Dipolar receiver coil, coplanar with EM source, positioned 1 m from source
Measuring Ranges	Conductivity: 100, 1000 mS/m Inphase: 2.9, 29 ppt
Noise Levels	Conductivity: 0.1 mS/m Inphase: 0.3 ppt
Power Supply	1 alkaline 9V battery, for up to 30 h of operation
Operating Weight & Dimensions	2.5 kg 103 x 12 x 2.5 cm
Shipping Weight & Dimensions	10kg 117 x 19 x 13 cm

GEONICS LIMITED

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EM31

GROUND CONDUCTIVITY METER with INPHASE CHANNEL

The EM31 measures the conductivity of the ground directly in mS/m. The EM31 also measures the inphase component of response, which is useful for detecting ferrous and non-ferrous buried material.

Two meters on the front panel of the EM31 simultaneously display conductivity and inphase response. Readings can be taken at successive survey stations, or continuously along the survey line.

Using the inductive method, the EM31 operates without the ground contact required by conventional resistivity. As a result, surveys can be done over highly resistive material, such as gravel or asphalt, at the pace of a walk.

Compared to resistivity surveys, EM31 surveys yield detailed, continuous data, with better resolution of small changes in conductivity. This enables the EM31 to identify subtle changes in conductivity that can be caused by contamination, and to delimit affected areas with precision. Depth of exploration is about 6 m, which makes the EM31 suitable for many geotechnical and environmental applications.

The EM31 is synchronized with DGPS instrumentation to simultaneously record positioning and geophysical measurements. The EM31 can be towed behind a skidoo or other vehicle to efficiently cover large terrain.

The EM31 can be applied to mapping ionic-contamination at a variety of site types including oil and gas, salt storage and waste-disposal. The EM31 can map conductive contamination of soil and groundwater, and simultaneously detect buried metal, which makes this instrument the ideal tool for site assessment. It is most commonly used during soil-salinity surveys.

**Technical information provided by Geonics Ltd., Mississauga, Canada. Phone (905) 670-9580*

EM31 SPECIFICATIONS

Measured Quantities:	Quadrature in mS/m Inphase in ppt, Hs/Hp	**Intercoil Spacing:**	3.66 m
Primary Field Source (Tx):	Self-Contained Dipole Tx	**Operating Frequency:**	9.8 kHz
Receiver (Rx):	Self-Contained Dipole Rx	**Conductivity Ranges:**	10-1000 mS/m

GPS Pathfinder Systems

Versatile GIS data collection and maintenance

Key Features and Benefits

- **Total system solution**
- **Easy-to-use software**
- **High accuracy**
- **Real-time GIS data collection and maintenance**
- **Beacon and satellite differential capabilities**
- **Supports leading GIS database formats**
- **WAAS - capable**

Trimble's GPS Pathfinder® systems are a family of high-performance GIS data collection and maintenance products. These versatile systems offer a variety of software, data collector and GPS receiver options so you'll find one that is ideal for your needs. Powerful and easy-to-use, you can quickly collect quality data for utility, urban and natural resource databases. And as the demand for high-quality position and attribute information increases, these systems allow you to update existing GIS data—ensuring that your decisions are made with the most accurate, current and reliable data available.

Powerful, rapid, accurate data collection and maintenance

Easy-to-use Software

Time–saving field software is essential for productive GIS data collection and maintenance.

With Trimble's field software options, you can quickly and easily collect point, line and area features, along with their customized attribute information. Field software makes it easy to take existing data from your GIS into the field for verification and update of position and attribute information. With powerful navigation tools, the field software guides you to an existing feature or landmark using graphical display and textual messages.

Three options are available for collecting and maintaining quality data while out in the field.

Asset Surveyor® software runs on the revolutionary TSC1™ —a rugged, weatherproof, handheld data collector developed and built by Trimble.

TerraSync™ software operates on standard Pocket PC and Windows CE devices, providing the flexibility to choose from a wide range of devices depending on your requirments.

ASPEN® software runs on your pen or notebook computers, when extra processing power or storage is important for your field operations.

Real-time Receivers

Because you need immediate results, the GPS Pathfinder systems family includes Trimble's real-time differential GPS (DGPS) receivers. Real-time DGPS is key for relocating existing assets and for verifying that the correct feature is being updated.

The **GPS Pathfinder Pro XRS** system integrates GPS, real-time beacon, satellite differential and Wide Area Augmentation System (WAAS) capabilities.

The **GPS Pathfinder Pro XR** system integrates GPS, real-time beacon and WAAS capabilities.

The **GPS Pathfinder Power** receiver integrates GPS, real-time satellite differential, and WAAS capabilities into a single, lightweight unit.

Efficient Planning and Processing

The powerful GPS Pathfinder Office software allows you to quickly plan your data collection and maintenance work and process your field data for use in your GIS. Important functions such as data dictionary creation, data viewing and editing, and differential correction can all be completed with ease. GPS Pathfinder Office software can process real-time DGPS data, ensuring your data is of the highest quality before exporting it to many leading GIS packages.

With powerful field and office software and integrated real-time DGPS, the GPS Pathfinder systems family meets your GIS data collection and maintenance needs today and into the future.

Trimble

GPS Pathfinder Pro XR antenna

General	Right-hand, circular polarized; omnidirectional; hemispherical coverage
Size	15.5 cm diameter x 10.8 cm high (6.1" x 4.2")
Weight	0.49 kg (1.08 lbs)
Operating temp	–30° C to +65° C (–22° F to +149° F)
Storage temp	–40° C to +85° C (–40° F to +185° F)
Humidity	100% fully sealed
Casing	Dustproof, waterproof, shock resistant

GPS Pathfinder Pro XRS antenna

Specifications for the Pro XRS antenna are the same as for the Pro XR antenna with the following exceptions:

Size	15.5 cm diameter x 14 cm high (6.1" x 5.5")
Weight	0.55 kg (1.2 lbs)

GPS PATHFINDER POWER RECEIVER/ANTENNA SPECIFICATIONS

- Integrated GPS/Satellite Differential receiver and antenna
- RTCM input

General	12 channel, L1/CA code tracking with carrier phase filtered measurements.
Update rate	1 Hz
Power	3.1 Watts, 9 to 32 V
Accuracy (RMS) (Note A)	
MCORR400 differential correction	Submeter + 1 ppm on a second-by-second basis (horizontal)
	Submeter + 2 ppm on a second-by-second basis (vertical)
Carrier phase processing	30 cm + 5 ppm with 5 minutes tracking satellites
	20 cm + 5 ppm with 10 minutes tracking satellites
	10 cm + 5 ppm with 20 minutes tracking satellites
	1 cm + 5 ppm with 45 minutes tracking satellites (with Centimeter Processing option)
RTCM satellite differential correction	Better than 1 meter (Note B)
Time to first fix	30 seconds (typical)
Size	15.2 cm diameter x 12.7 cm high (6" x 5")
Weight	0.625 kg (1.38 lbs)
Temperature	–30° C to +60° C (–22° F to +140° F) (operating)
	–40° C to +80° C (–40° F to +176° F) (storage)
Humidity	100% fully sealed
Casing	Fully sealed, dustproof, waterproof, shock resistant

TRIMBLE TSC1 DATA COLLECTOR SPECIFICATIONS

Logging memory	2 MB, memory extension through user accessible Type II ATA PC card slot (Note C)
Size	26.7 cm x 11.7 cm x 4.2 cm (10.5" x 4.6" x 1.65")
Weight	0.85 kg (1.875 lbs), including rechargeable Lithium Ion battery
Operating temp	–30° C to +65° C (–22° F to +149° F)
Storage temp	–30° C to +80° C (–22° F to +176° F)
Humidity	100% fully sealed against sand, dust and moisture, buoyant, waterproof against accidental immersion
Display	240 x 200 extended temperature graphics STN LCD display
Power	<1 Watt

(footnotes)

Note A: At least 5 satellites, PDOP ≤6, signal to noise ratio ≥6, satellite elevation mask at 15 degrees.

Note B: RTCM SC-104 standard format broadcast from a Trimble reference station.

Note C: Memory extension through user-accessible Type II PC card slot. 16 MB PCMCIA Data Cards are available (33050-16)

Trimble follows a policy of continuous product improvement. Specifications are therefore subject to change without prior notice.

ORDERING INFORMATION

For further information, contact your nearest Trimble Authorized Distributor or Trimble Office. Please visit our web site at www.trimble.com

Pathfinder Office Software

GPS Data Processing Software for Microsoft Windows

Powerful software for planning and processing mapping and GIS data capture projects.

Built on the solid foundation established by PFINDER software, Pathfinder Office™ is the next generation of Trimble's GPS planning and data processing software and is an integral part of the GPS Pathfinder™ product line. The software is Microsoft Windows-based and is designed for ease-of-use and high productivity.

The software provides all of the tools to complete your projects quickly. GPS Planning software is fully integrated with Pathfinder Office. Planning your data collection sessions is a simple task that lets you make the most of field data collection time.

The Data Dictionary Editor lets you build custom data collection menus to be uploaded to your data collector. Items can be quickly added, edited, and moved within the data dictionary. A graphic display makes the process far easier by helping you understand the structure of the data dictionary at a glance.

With Pathfinder Office's Batch Processor, you can automate your workflow. Data can be transferred from your data collector, differentially corrected, and exported to your GIS or CAD system as a single automated function. After your data has been processed, you can print it or plot it to scale using a pen plotter.

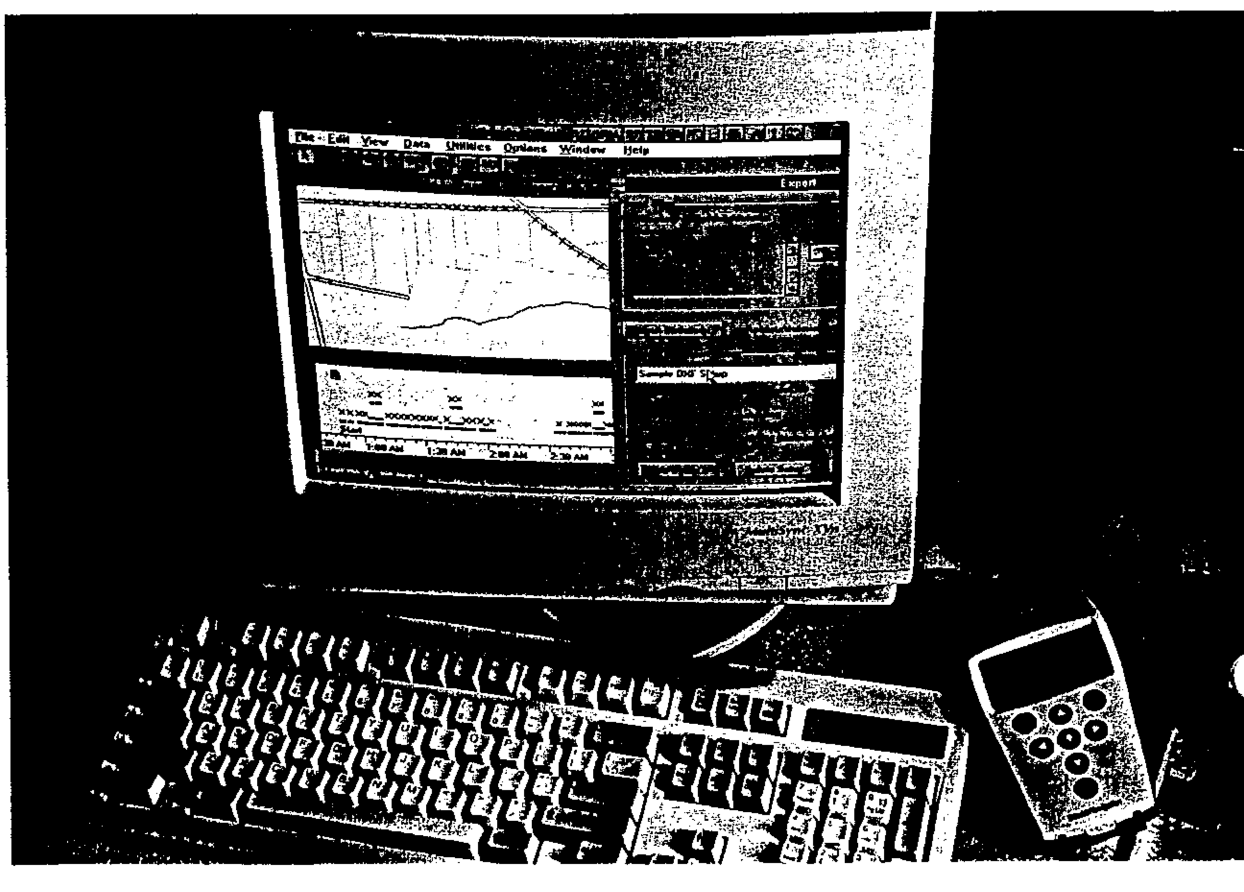
A carrier phase processing module for high accuracy positions is a standard component of the Pathfinder Office system. Using this processing system, you can achieve accuracies in the range of 10 to 75 centimeters, depending on which GPS Pathfinder product you are using.

Pathfinder Office software makes exporting GPS data to your GIS or CAD system a simple process. Parameters for exporting data can be set up in the system once and saved for use on future projects. This allows you to export data without going through setup each time.

With Pathfinder Office software, you can display a background map behind your GPS data. This allows you to see where you have collected data and how it relates to features for which you already have information, such as roads or property boundaries. Data formats for background files include DXF, Shapefile, BMP, and TIFF.

The Time Line window lets you visualize your data from a chronological point of view. For example, if you wanted to review data collected before a lunch break, you could look for that time period on the Time Line. Highlighting the feature on the Time Line also highlights it on the map display.

Pathfinder Office software sets a new standard for GPS planning and processing software. It provides all the tools needed to make your GPS data collection easy and successful.



APPENDIX B

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Technical Note TN-6

ELECTROMAGNETIC TERRAIN CONDUCTIVITY MEASUREMENT at LOW INDUCTION NUMBERS

JD McNEILL

October, 1980

Table of Contents

I. INTRODUCTION

The measurement of terrain resistivity to map geology has been utilized for over half a century. Several shortcomings, however, have prevented this technique from being widely accepted for engineering purposes. The first of these is that conventional galvanic resistivity surveys require a relatively large amount of manpower to execute and are thus expensive. Secondly, the actual value of resistivity itself is seldom diagnostic; it is the lateral or vertical variations of resistivity which form the basis of any interpretation. However the high cost of resistivity surveying generally means that fewer measurements are made than would be desirable, with the result that either (i) the survey area is not made large enough to establish a reasonable background against which the anomalous areas are to be delineated or (ii) the anomalous area itself is obscure and lacks definition.

An additional problem inherent to conventional resistivity techniques is that although the effective depth of exploration is determined by the selected inter-electrode spacing, resistive inhomogeneities which are small compared to this depth but which are located near the potential electrodes can cause a significant error in the measurement. Such fluctuations in the measured results are truly geological "noise" because it is not possible to determine the physical size, resistivity contrast, or location of the source. As a result of such inhomogeneities resistivity profiles carried out at constant interelectrode spacing tend to be noisy, limiting the resolution in resistivity that can be achieved, even though the instrumentation itself is capable of producing much higher accuracy.

It was an awareness of both the advantages of resistivity for engineering geophysical surveys and the disadvantages of conventional resistivity techniques that led Geonics Limited to examine the possibility of employing electromagnetic (inductive) techniques as an alternative for resistivity surveys. With the development of the EM31 and the EM34-3 it is now possible to map terrain conductivity virtually as fast as the operator(s) can walk; furthermore the sample volume is averaged in such a manner as to yield unexcelled resolution in conductivity.

These patented instruments have been designed to cover the range of depths generally useful for engineering geophysics; the EM31, one-man portable, has an effective depth of approximately 6 meters and the EM34-3, two-man portable, has stepwise selectable depths from 7.5 meters to a maximum of 60 meters.

Typical applications for the EM31 and EM34-3 instrumentation are:

(i) Delineating regions of permafrost (frozen pore water)
(ii) Locating gravel
(iii) Extending known gravel deposits
(iv) Mapping saline intrusions
(v) Detecting cavities in carbonate rocks
(vi) Mapping pollution plumes in groundwater
(vii) Mapped bedrock topography
(viii) Mapping terrain conductivity for electrical grounding
(ix) General geological mapping (soil types, fault and fracture zones, etc.)
(x) Archaeological exploration
(xi) Locating pipes (EM31) and metallic-type conductors

This technical note describes both the principles and the instrumentation employed to measure terrain conductivity using electromagnetic techniques at low induction numbers. For a detailed discussion of the concept of terrain resistivity/conductivity and of the various factors that control this parameter the reader is referred to Geonics Limited Technical Note "Electrical Conductivity of Soils and Rocks".

II. PRINCIPLE OF OPERATION

The application of electromagnetic techniques to the measurement of terrain resistivity, or more properly, conductivity* is not new and excellent descriptions of this technique are given in the literature [1], [2].

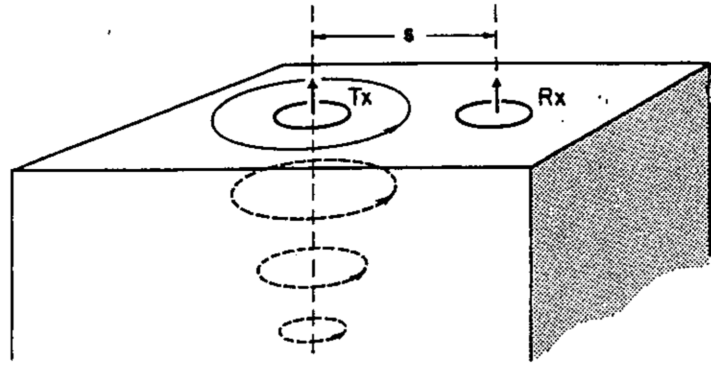


FIGURE 1. Induced current flow (homogeneous halfspace).

Consider Figure 1 in which a transmitter coil Tx energized with an alternating current at an audio frequency, is placed on the earth (assumed uniform) and a receiver coil Rx is located a short distance s away. The time-varying magnetic field arising from the alternating current in the transmitter coil induces very small currents in the earth. These currents generate a secondary magnetic field H_s which is sensed, together with the primary field, H_p, by the receiver coil.

In general this secondary magnetic field is a complicated function of the intercoil spacing s, the operating frequency, f, and the ground conductivity σ. Under certain constraints, technically defined as "operation at low values of induction number" (and discussed in detail in the appendix) the secondary magnetic field is a very simple function of these variables. These constraints are incorporated in the design of the EM31 and EM34-3 whence the secondary magnetic field is shown to be:

$$\frac{H_s}{H_p} \simeq \frac{i\omega\mu_o\sigma s^2}{4} \qquad (1)$$

where H_s = secondary magnetic field at the receiver coil
H_p = primary magnetic field at the receiver coil
$\omega = 2\pi f$
f = frequency (Hz)
μ_o = permeability of free space
σ = ground conductivity (mho/m)
s = intercoil spacing (m)
$i = \sqrt{-1}$

The ratio of the secondary to the primary magnetic field is now linearly proportional to the terrain conductivity, a fact which makes it possible to construct a direct-reading, linear terrain conductivity meter by simply measuring this ratio. Given H_s/H_p the apparent conductivity indicated by the instrument is defined from equation (1) as

$$\sigma_a = \frac{4}{\omega\mu_o s^2}\left(\frac{H_s}{H_p}\right) \qquad (2)$$

The MKS units of conductivity are the mho (Siemen) per meter or, more conveniently, the millimho per meter.

III. INSTRUMENTATION

The EM31 (shown in Figure 2) has an intercoil spacing of 3.7 meters, which yields an effective depth of exploration of about 6 meters. The instrument can also be operated on its side, in which

*Conductivity is preferred with inductive techniques since the response is generally proportional to conductivity and inversely proportional to resistivity.

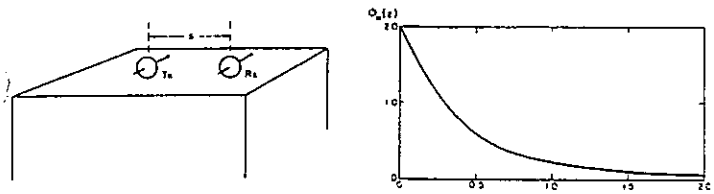


FIGURE 5. Relative response versus depth for horizontal dipoles

makes a very small contribution to the secondary magnetic field and therefore this coil configuration is insensitive to changes in near surface conductivity.

Figure 5 illustrates the function of Figure 4 for the case of both transmitter and receiver dipoles horizontal coplanar rather than vertical coplanar. For the coil configuration of Figure 5 (commonly used for the EM34-3 since it is less critical to intercoil alignment) the relative contribution from material near-surface is large and the response falls off monotonically with depth.

A comparison of the function ϕ for both coil configurations in Figure 6 emphasizes the different manner in which they respond to material at different depths. The difference is important since either instrument can be rolled over so that the vertical dipole transmitter/receiver geometry becomes a horizontal dipole transmitter/receiver geometry and vice versa. As will be seen later, this feature is useful in diagnosing and defining a layered earth. The figure also shows that for regions greater than one intercoil spacing in depth the vertical transmitter/receiver dipole gives approximately twice the relative contribution of the horizontal transmitter/receiver dipole.

To summarize, with either horizontal or vertical transmitter/receiver dipole orientation it is possible to construct a function which gives the relative response to the secondary magnetic field at the receiver from a thin layer of ground at any depth. That this is possible arises from the fact that (i) all current flow is horizontal and (ii) all current loops are independent of all other current loops. It should be noted that it is not possible to construct such functions for conventional resistivity techniques.

Finally, since as shown in Section II the definition of apparent conductivity is given in terms of the secondary magnetic field at the receiver, the functions in Figure 6 also give the relative contribution from material at different depths to the *apparent conductivity* indicated by the instrument meter. The integral of either function from zero to infinity gives the total secondary magnetic field at the receiver coil from a homogeneous halfspace which is directly related to the electrical conductivity of the halfspace by equation (1). It is therefore possible to state with great precision the relative influence of material at different depths to the indicated apparent conductivity.

IV. 2. Multi-Layered Earth Response

The functions shown in Figure 6 are useful for describing the relative sensitivity of either of the two coil configurations to material at various depths. However a function derived from them is more useful for performing calculations. It is defined as the relative contribution to the secondary magnetic field or apparent conductivity from all material below a depth z and is given by

$$R_{\substack{V\\H}}(z) = \int_z^{\infty} \phi_{\substack{V\\H}}(z)dz \qquad (3)$$

Called the cumulative response, this function is illustrated in Figure 7 for vertical coplanar transmitter/receiver dipoles. The figure shows, for example, that for this configuration all material below a depth of two intercoil spacings yields a relative contribution of approximately 0.25 (i.e. 25%) to the secondary magnetic field at the receiver coil.

Suppose now that our homogeneous halfspace has a conductivity of 20 millimhos per meter (50 ohmmeters). The equipment having been calibrated according to equation (2), the output meter indicates 20 millimhos per meter. From Figure 7 we observed that the material below two intercoil spacings contributed 25% to the secondary magnetic field and therefore 25% to the indicated meter reading. Suppose that we replace this deep material with an infinitely resistive (zero conductivity) substance. Since we have reduced to zero the 25% that this material contributed to the meter reading the new reading will be 75% of 20, or 15 millimhos per meter. Conversely, if we leave all of the material below two intercoil spacings at 20

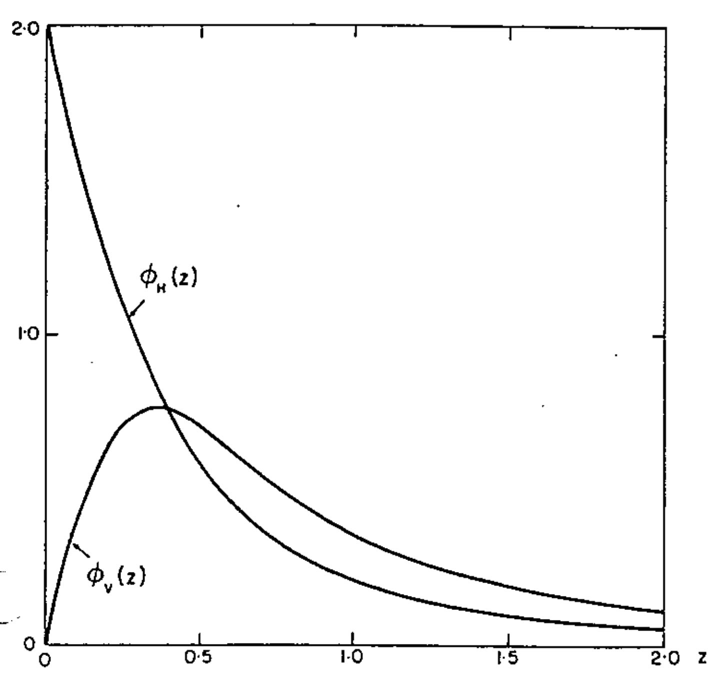


FIGURE 6. Comparison of relative responses for vertical and horizontal dipoles.

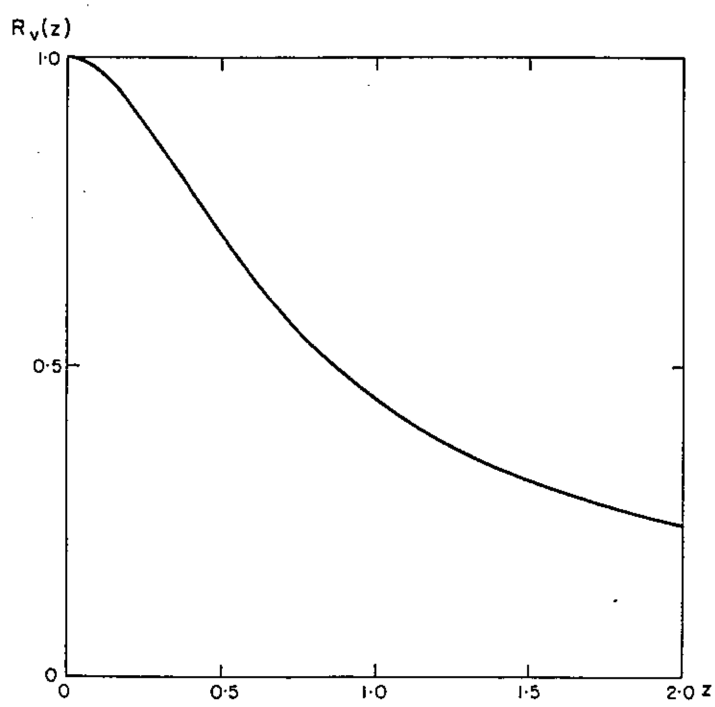
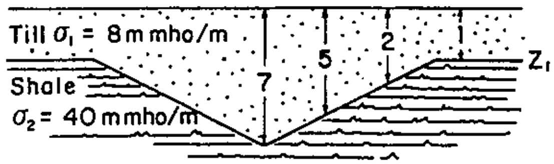


FIGURE 7. Cumulative response versus depth for vertical dipoles. $R_V(z)$ is the relative contribution to H_s from all material below a (normalized) depth z.

CROSS-SECTIONS

BURIED RIVER VALLEY

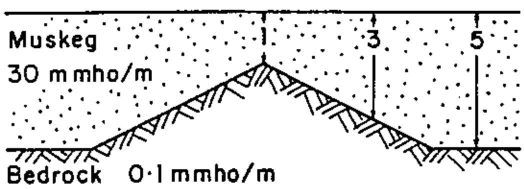


$$\frac{\sigma_a}{\sigma_1} = 1 - R(Z_1) + k_2 R(Z_1)$$

$$k_2 = \frac{\sigma_2}{\sigma_1} = \frac{40}{8} = 5$$

Z_1 (m)	σ_a (mmho/m)
1	32·6
2	26·9
5	18·6
7	16·0

BEDROCK HIGH

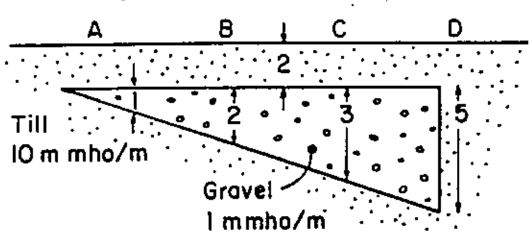


$$\frac{\sigma_a}{\sigma_1} = 1 - R(Z_1) + k_2 R(Z_1)$$

$$k_2 = \frac{\sigma_2}{\sigma_1} = \frac{0{\cdot}1}{30} = 0{\cdot}0033$$

Z_1 (m)	σ_a (mmho/m)
1	6·9
3	15·9
5	20·1

GRAVEL DEPOSIT



$$\frac{\sigma_a}{\sigma_1} = 1 - R(Z_1) + k_2[R(Z_1) - R(Z_2)] + k_3 R(Z_2)$$

$$k_2 = \frac{\sigma_2}{\sigma_1} = \frac{1}{10} = 0{\cdot}10$$

$$k_3 = \frac{\sigma_3}{\sigma_1} = 1{\cdot}00$$

station	σ_a (mmho/m)
A	8·9
B	8·2
C	7·7
D	6·9

FIGURE 10. EM31 calculated response across various geological features, using R (Z) corrected for instrument operation at waist (1 meter) height. Coil separation s = 3.67 meters.

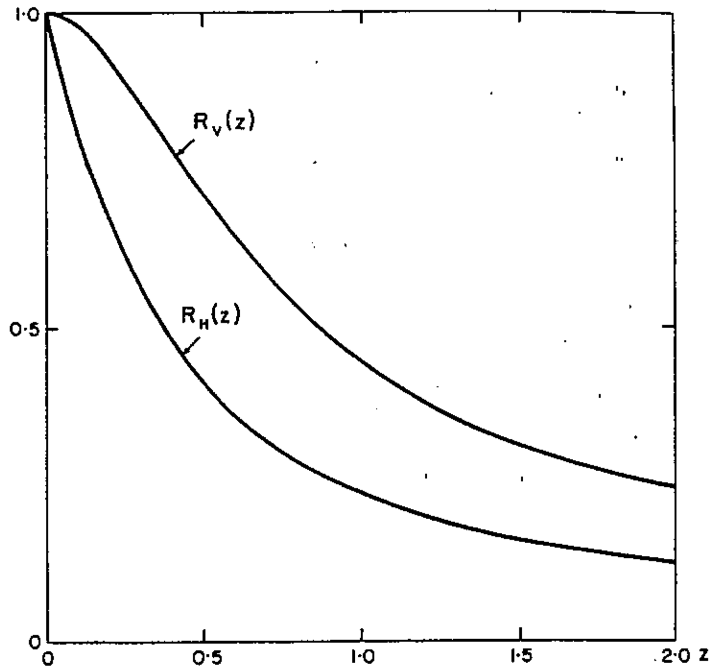


FIGURE 11. Cumulative response versus depth for vertical and horizontal dipoles.

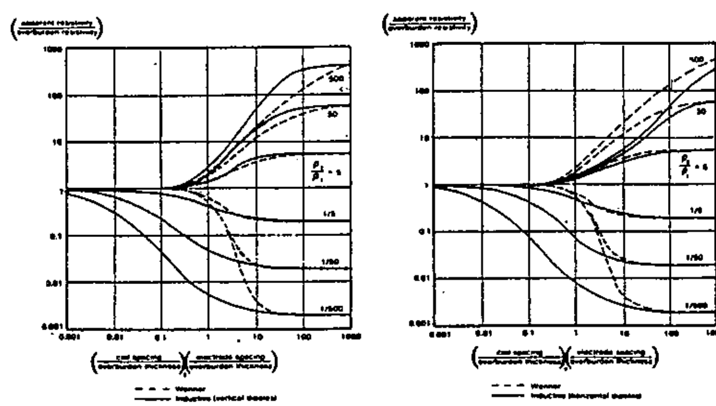


FIGURE 12. Comparison of Wenner array and inductive electromagnetic sounding curves for a two layer earth.

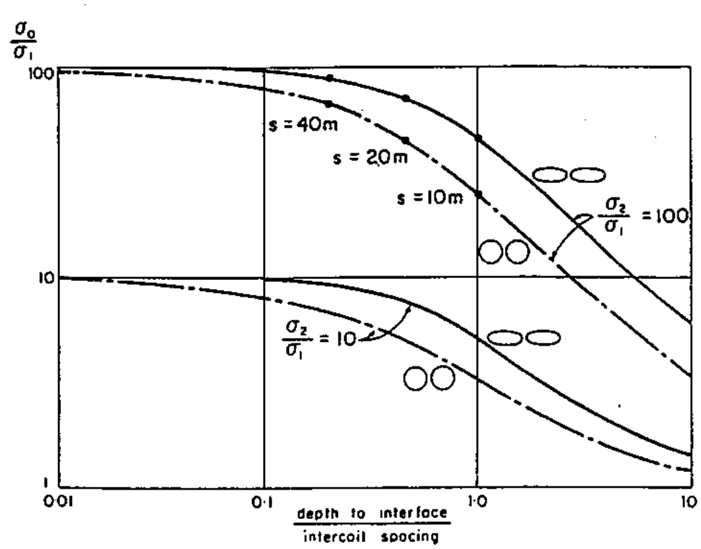


FIGURE 13. Two layer earth response curves (σ_2/σ_1 = 10,100; intercoil spacing varied). Dots indicate typical survey results.

and the zero set there. The more acceptable alternative is to search out a region of very resistive ground, to accurately measure its conductivity using conventional techniques, and to set the instrumental zero at that location. This is the procedure which is actually followed.

It is necessary that this zero be accurately maintained over long periods of time and over the wide variations of temperature encountered during geophysical survey in various parts of the world. This produces tight constraints on the circuitry, with the result that the zero may be in error by up to ±0.2 mmhos per meter. Such an error would be negligible over the usual range of terrain conductivities; however in the event that measurements are being made on highly resistive ground the zero error can become significant.

(iii) *Limited Vertical Sounding Capability*. In theory it is possible to use a system such as the EM34-3 at a continuum of intercoil spacings to yield more information about electrical layering in the ground. To achieve a wide variety of inter-electrode spacings with conventional resistivity equipment is simple; in the case of the inductive electromagnetic technique the rapid fall-off of the magnetic field from the dipole transmitter introduces a serious dynamic range problem. In due course there will undoubtedly be instrumentation with a wider variety of spacings at the expense of additional complexity.

VI. CASE HISTORIES

This section describes several case histories obtained with the EM31 and the EM34. The surveys (i) illustrate the resolution in conductivity that can be achieved, (ii) compare the results obtained with conventional resistivity and (iii) illustrate the use of the latter for locating sand, gravel and conductive minerals, determining bedrock topography (including locating a buried river channel) and mapping the pollution plume from a land-fill site. In some cases the indicated conductivity has been converted to resistivity to facilitate comparison with conventional resistivity survey results.

Case History #1

Location: Mississauga, Ontario
Instrument: EM31
Application: Illustrates resolution and repeatability of EM31

For this case history a Rustrak chart recorder was used to monitor the output of an EM31. A line of length 200 meters was traversed in a field in both easterly and westerly directions. Figure 15 demon-

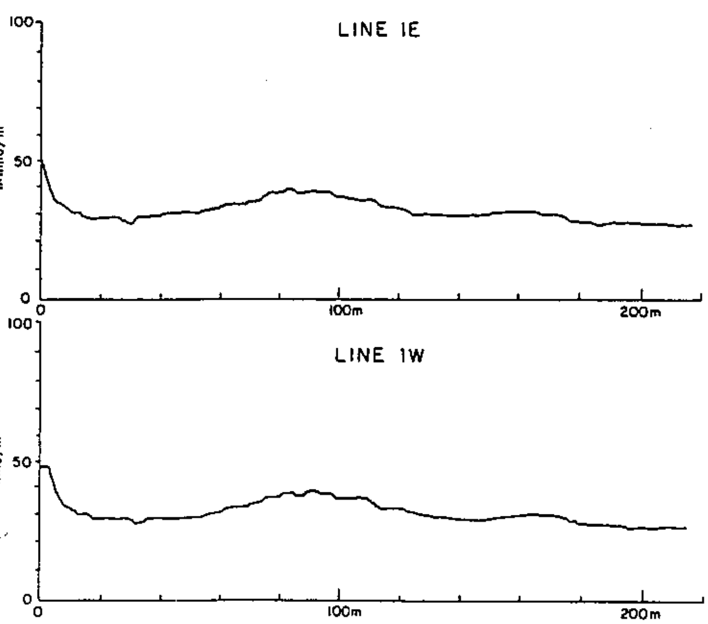


FIGURE 15.

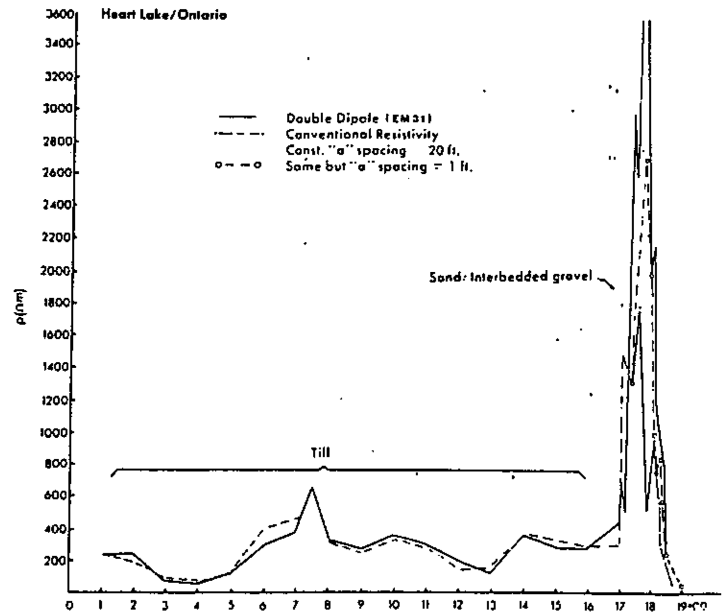


FIGURE 16. Test survey line – Heart Lake, Ont.

strates that the instrument is resolving conductivity changes of less than 1 mmho/m (1% of full scale deflection) and that the repeatability is of the same order. In fact the repeatability is limited in this case by the resolving power of the chart recorder itself. It should furthermore be noted that the instrument is detecting spatial changes in conductivity of a few meters in length – compatible with the intercoil spacing of 3.7 meters.

Case History #2

Location: Hearth Lake, Ontario
Instruments: EM31
Conventional resistivity apparatus
Application: Location of sand/gravel
Comparison of EM31 and conventional resistivity

In this survey a line 1900 ft. (580 meters) in length was surveyed with a measurement interval of 100 ft. (30 meters). The survey area was generally located on a buried esker, however the last few survey stations, 17 + 00 to 19 + 00, traversed a region of exposed sand and gravel (often occurring in the form of concretions) and over this portion of the line measurements were made every 10 ft. (3.0 meters).

The conventional resistivity profile was carried out using a Wenner array with an a spacing of 20 ft. (6.1 meters) except between stations 17 + 00 and 19 + 00 where the a spacing was reduced to 1 ft. (0.30 meters).

In general the correlation between the two sets of data is excellent, and demonstrates the ability of the EM31 to generate good quantitative data even in regions of low conductivity. Over the esker the EM31 was actually read continuously down the line – the data was recorded only at the 100 ft. intervals, with the exception of the reading at station 7 + 50 which was also recorded since it was noted that a conductivity low occurred there. Such an anomaly was, of course, missed by the conventional resistivity where measurements were only made every 100 ft.

Both sets of data become rather erratic between stations 17 + 00 and 19 + 00 as a result of the very rapid lateral changes in resistivity arising from the concreted material referred to above.

Case History #3

Location: Cavendish, Ontario.
Instrument: EM31
Application: Location of metallic type conductors

This survey line, of length 2000 ft. (610 meters), is located at a site

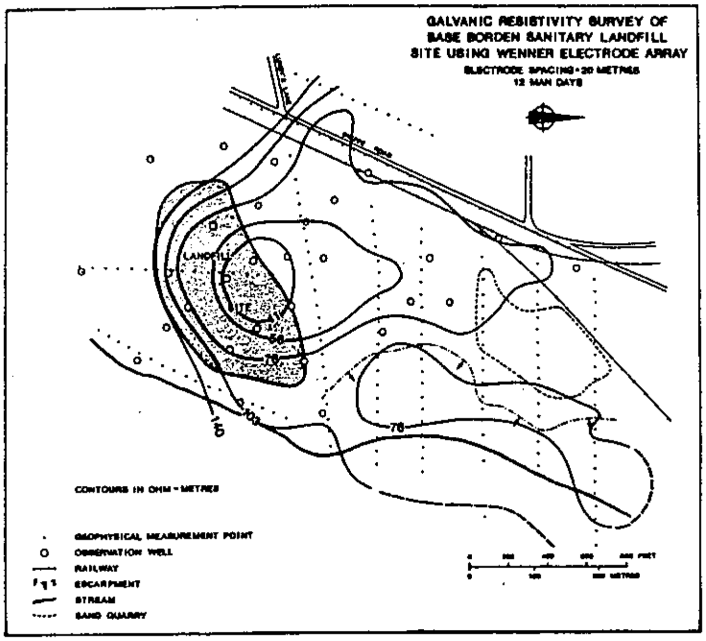


FIGURE 20(a).

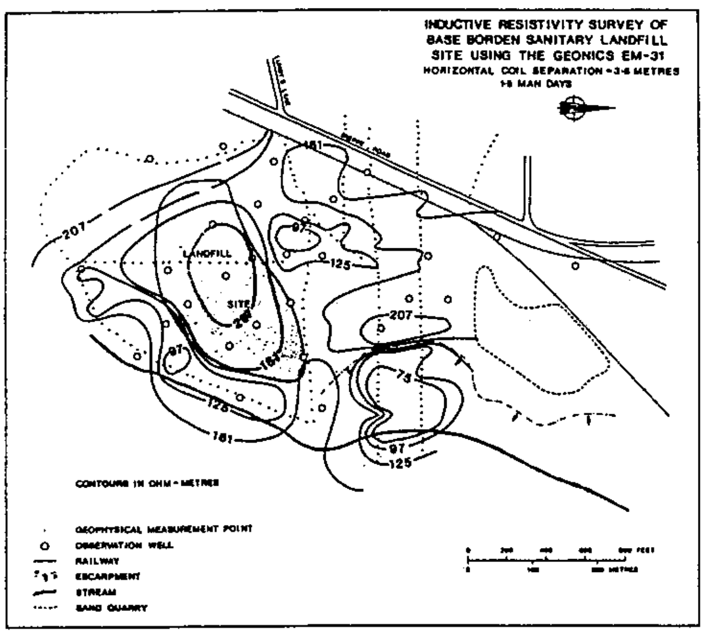


FIGURE 20(b).

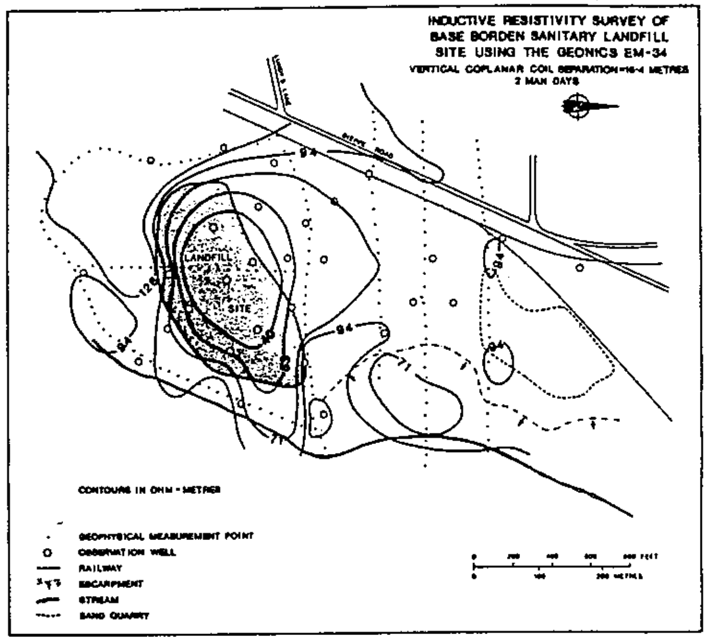


FIGURE 20(c).

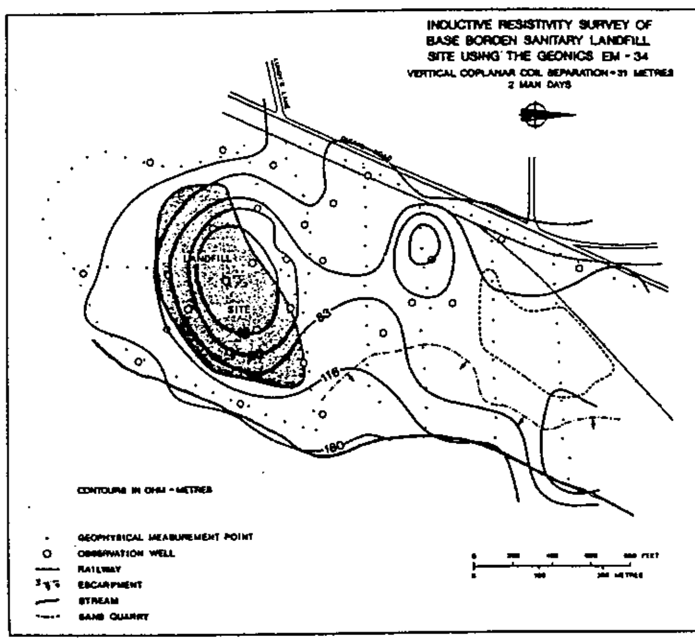


FIGURE 20(d).

currents at low frequencies. It has been shown that certain advantages can be derived from working at low values of induction number. Amongst these are excellent resolution in conductivity, a substantial reduction in man-hours necessary to carry out a conductivity survey and a simplification in the calculation of layered earth response.

Two points should be kept constantly in mind when performing surveys of this type to map geology. The first is that these instruments map only the electrical conductivity. If the conductivity does not vary significantly with the geological environment, or if parameters other than the geology also influence the conductivity, the survey results may be difficult to interpret.

The second point is that measurement of terrain conductivity, like any other geophysical measurement, must begin and end with geology. Such measurements are only an aid to help visualize geological conditions which cannot be seen. It is always necessary to interpret geophysical data against known geology from out-crops, boreholes, or any other such "bench marks". Geophysical measurements can be very effective by allowing interpolation between such sources, or extrapolation away from them. However in every case knowledge derived from geophysical measurements must be eventually reconfirmed against known geological conditions.

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(2) Wait, J.R. 1962. A Note on the Electromagnetic Response of a Stratified Earth. Geophysics V.27, pp 382-85.

(3) Ward, S.H.; Pridmore, D.F.; Rijol, Glenn W.E. Multispectral Electromagnetic Exploration for Sulphides. Geophysics Vol. 39 No. 5 p. 666. 1974.

(4) Survey carried out by Dr. J. Greenhouse, University of Waterloo, Waterloo, Ontario.

made much smaller than R_1 the current flow in loop 1 is simply given by

$$i_1 = \frac{e_p}{R_1} = \frac{i\omega\phi_p}{R_1} = i\omega\phi_p G_1 \quad (9)$$

where ϕ_p = primary flux linking loop 1
G_1 = conductance of loop 1($G_1 = 1/R_1$)
$i = \sqrt{-1}$

We see that the magnitude of the current is linearly proportional to the loop conductance and furthermore that the phase of the current leads the primary flux by 90°. Since the secondary magnetic field at the receiver from current i_1 is in phase with and directly proportional to i_1 it too will be directly proportional to G and will lead the primary flux by 90°. Thus

$$\left(\frac{H_s}{H_p}\right) \propto i\omega G_1 \quad (10)$$

which has the same dependence on frequency and conductance as equation (6). We infer therefore, that the condition $B \ll 1$ is equivalent to stating that for all current loops that affect the receiver output the operating frequency is so low that we can ignore any magnetic coupling between the loops. Thus the current that flows in any loop is (i) completely independent of the current that flows in any other loop since they are not magnetically coupled and (ii) is only a function of the primary magnetic flux linking that loop and of the local ground conductivity.

The lack of interaction between current loops is of great importance in simplifying the data reduction procedures. Of equally great significance is the fact that for any value of B and for any orientation of a magnetic dipole (or indeed of any magnetic source) over either a uniform halfspace or a horizontally stratified earth it can be shown that all current flow is horizontal. That this is the case for a vertical dipole is easy to see from symmetry; for a horizontal dipole it is less evident but equally true. Thus, in a horizontally layered earth no current crosses an interface which is fortunate since, if it did, changing either of the conductivities would, by virtue of refraction of the current, change the direction of the current as it flowed from one medium to the other.

If no current flow crosses an interface and if there is no magnetic coupling between current loops, changing the conductivity of any one of the layers of a horizontally stratified earth will not alter the geometry of the current flow. Varying the conductivity of any layer will proportionately vary only the magnitude of the current in that layer. To calculate the resultant magnetic field at the surface of a horizontally layered earth it is simply necessary to calculate the independent contribution from each layer, which is a function of its depth and conductivity, and to sum all the contributions.

The functions $\phi(z)$ and $R(z)$ discussed in Section II define the relative influence of current flow as a function of depth. Their derivation is involved and will not be given here. The resultant expressions are, however, simple and easily programmed into hand calculators:

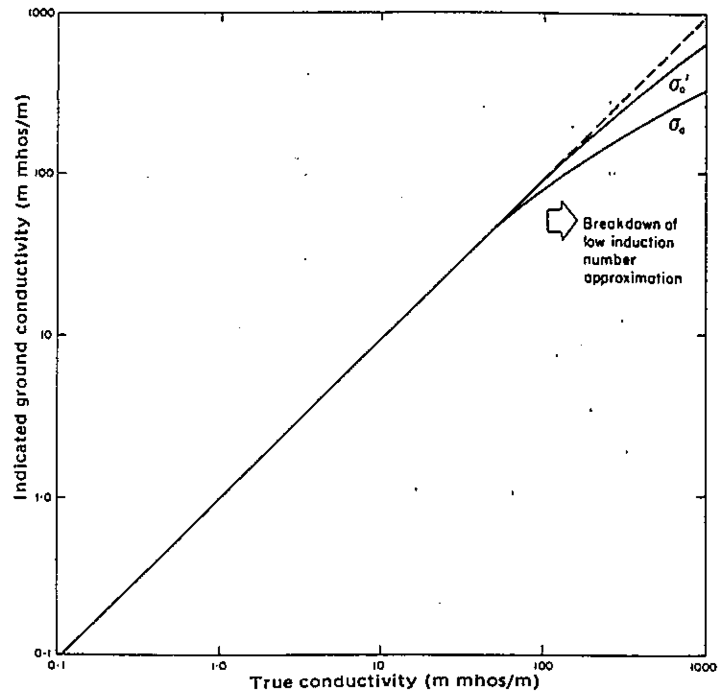

FIGURE AIV. Plot of indicated conductivity for EM31 versus true (homogeneous half-space) conductivity for both vertical (σ_a) and horizontal (σ_a') dipoles.

$$\phi_V(z) = \frac{4z}{(4z^2 + 1)^{3/2}} \quad (11)$$

$$\phi_H(z) = 2 - \frac{4z}{(4z^2 + 1)^{1/2}} \quad (12)$$

$$R_V(z) = \frac{1}{(4z^2 + 1)^{1/2}} \quad (13)$$

$$R_H(z) = (4z^2 + 1)^{1/2} - 2z \quad (14)$$

where z is the depth divided by the intercoil spacing.

Finally it should be noted that for a given frequency and intercoil spacing as the terrain conductivity increases the approximation of equation (6) eventually breaks down and the instrumental output is no longer proportional to terrain conductivity. This effect is illustrated in Figure AIV. which plots apparent (indicated) conductivity against true (homogeneous halfspace) conductivity for both vertical and horizontal transmitter/receiver dipoles for the operating parameters of the EM31. As would be expected the horizontal dipoles exhibit linearity to greater values of conductivity as a result of the reduced depth of penetration in this configuration.