

MAPPING SOIL RESISTIVITY

by Richard Jurick and Robert McHattie



INTRODUCTION

Soil borings have traditionally provided the principal source of information used in foundation investigations for new roads, runways and structures. Drilling techniques allow for the visual examination and physical testing of borehole samples. While the quality of this information is high, it is very localized and may not truly represent the general soil conditions of the area or may miss some anomalous feature (such as a mass of ground ice). Drilling is also expensive, and in some locations and situations is an inconvenient means of soil exploration.

Recently, because of improved equipment, electromagnetic geophysical techniques have become a practical aid to foundation investigations. While none of these methods can duplicate the exact nature of borehole sampling, they can provide a more continuous picture of foundation materials. The integration of geophysical mapping and borehole sampling can compensate for the weakness of each technique. Expensive boreholes can be rationally drilled in locations where ground truth is needed to interpret the mappings, and the mappings can be used to extrapolate subsurface soil conditions away from borehole sites. The number of boreholes needed can be minimized in areas where geophysical data indicates uniform soil conditions.

One of the more practical geophysical techniques involves measuring the ground's ability to conduct electrical current. Evidence concerning a subsurface soil type, its moisture content, or whether it is frozen or unfrozen can, in certain situations, be revealed from surface resistivity measurements. Techniques based

on measuring resistivity have been understood and used for years by scientists, but remain unknown to the general public. Little work has been done on using such methods for permafrost detection, because until recently, ground resistivity measurement devices have been either too temperamental, too sophisticated or too labor-intensive to allow their widespread use. Many devices require a great deal of data analysis before practical use can be made of the results. For these reasons, most geophysical techniques have been relegated to the domain of the research scientist and mineral and petroleum companies.

Now there are several commercially available instruments which can perform these functions without many of the earlier restrictive features. These instruments can provide a relatively inexpensive and highly informative supplement to modest drilling programs. In foundation surveys, instrument readings along with a small amount of drilling information can be used to correlate soil types and delineate soil boundaries. In this paper we are reporting on the use of one particularly attractive instrument, a Model EM-31 Non-Contacting Terrain Conductivity Meter, made by Geonics, Ltd. of Mississauga, Ontario. This lightweight portable device is capable of obtaining even and rapid continuous subsurface data to depths of 20 to 25 feet without physical ground contact.

Early in 1981, we received a small grant from the Alaska Council on Science and Technology to test and demonstrate this instrument and to develop a survey technique for small-scale soil exploration. Response from a TV interview aired in

Fairbanks led to six home and three mining site surveys during the summer of 1981. This report presents field data obtained from some of these sites in the form of soil resistivity plots. These plots (maps) are discussed in terms of their relationship to available ground truth as supplied through boreholes and other techniques.

This approach is not limited to building and mining applications, although those are the only ones investigated as part of this study. Other practical uses have included:

- Mapping gravel and sand deposits for construction material sources.
- Locating hot and/or mineralized water sources associated with geothermally active areas.
- Mapping shallow bedrock or mineralized zones.
- Mapping archaeological sites.
- Locating pipes and other buried metallic conductors.

ELECTRICAL PROPERTIES OF SOILS

The electrical resistivity of a substance, such as soil, is the measure of its ability to resist the flow of electrical current through it. The EM-31 measures this ability in units of conductivity, simply the reciprocal of resistivity. Most soils and rocks are highly resistive (i.e., have low conductivities) and are classified as electrical insulators.

The conductivity of a soil is primarily determined by: the number, shape and size of the soil particles; moisture content; concentration of dissolved electrolytes; temperature and phase state of the moisture; and amount and composition of colloids present. Figures 1 and 2 list resis-

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tivity values that can be expected from some soils and rocks.

Minerals such as magnetite, graphite and various sulfides may occur naturally in sufficient quantities to increase the ground's overall conductivity. This characteristic can sometimes be used to locate mineralized zones, as in our Survey No. 9, included in this article. However, most current flow in "standard" soils is electrolytic in nature and takes place through and around the moisture-filled pores and minute cracks within the soil matrix.

The general classification of soils is by grain size; sand is coarser than silts which are coarser than clays. Sands and silts are generally excellent insulators, as is completely dry clay. However, the introduction of moisture to clay changes its electrical characteristics substantially. The fine-grained nature of clay results in an immense surface area per unit volume of material which, with the addition of water, permits considerable ion mobility. As a general rule, resistivity increases with increasing soil particle size, decreasing colloidal fraction, and decreasing moisture content.

The resistivity of an electrolyte is inversely proportional to the number of ions available in solution and the mobility of these ions within the solution. In distilled water, there are few ions so its resistivity is correspondingly high. The concentration of dissolved salts in ground

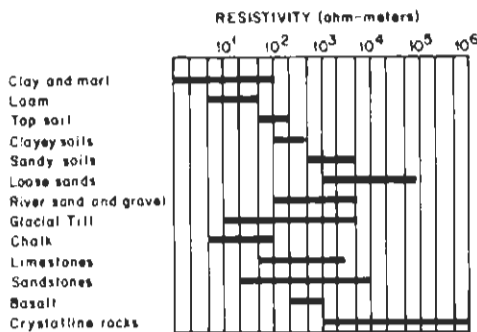


Figure 1. Resistivity ranges for various terrain materials.¹



Figure 3. Author Robert McHattie measuring terrain conductivity with the EM-31. Although the 12-foot boom somewhat limits maneuverability in heavy brush, the instrument is lightweight and well balanced.

moisture can strongly influence the bulk resistivity of a soil. For example, the contamination of an area by sea water can easily mask variations in geological subsurface features; this possibility should be considered in making resistivity surveys near coastal areas.

The resistivity of an electrolyte varies almost inversely with temperature over

normally encountered ranges. Temperature variations with season and depth must be considered because of this effect. As pore water freezes, its resistivity abruptly increases. The use of resistivity measurements for detecting ice masses or ice-rich soils relies upon this contrast.

Difficulties in establishing good electrical contact with highly resistive soils prevented the use of older techniques in some soil types. The expense involved in acquiring data often led to an insufficient number of measured values to establish a reasonable background against which anomalous readings could be delineated. The Model EM-31 utilizes a magnetic induction method of measuring the terrain conductivity which solves many of the earlier difficulties. This instrument, which weighs about 20 lbs and can be carried by one man, consists of a balanced boom 12 feet long (Fig. 3). The unit is powered by eight standard "C" cell alkaline batteries which demonstrated a useful life of 10 to 15 hours. The measured quantity is the apparent conductivity of the ground beneath the instrument, within an area about 20 ft in diameter and 20-25 ft deep. The apparent conductivity is a "weighed" average measurement of the ground volume within this area, with nearer materials contributing more to the overall measurement. Figure 4

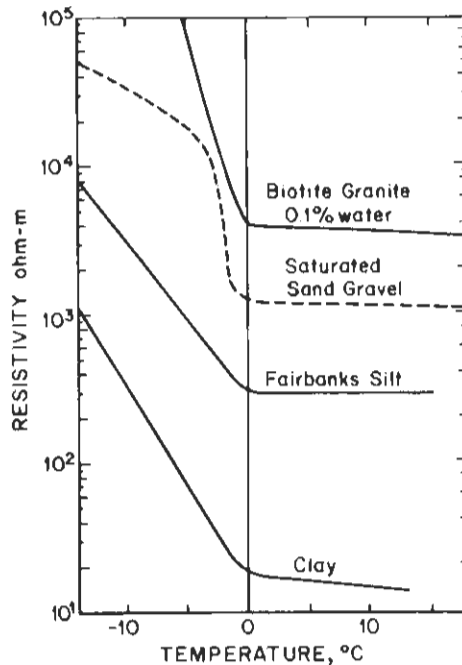


Figure 2. Resistivities of general soil and rock as a function of temperature.²

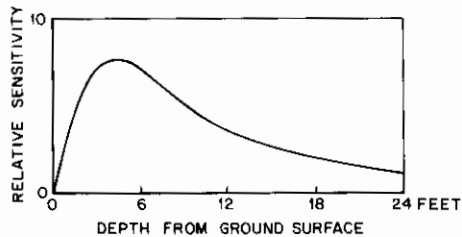


Figure 4. Relative response of EM-31 to material located at a given depth.³

represents the "strength of influence" exerted from specific soil depths on the net (apparent) conductivity measurement. The integral of Figure 4 between selected depths and infinity produces Figure 5, which indicates the percent of total instrument response attributable to all materials *below* a specific depth.

Although the unit is ideally suited for exploring highly resistive material such as gravels, permafrost and bedrock, unfortunately it is very expensive, costing approximately \$7500.

FIELD METHODS AND DATA ANALYSIS

Field Survey Grid

First, a rectangular sampling grid should be established and marked with surveying lath and flagging. The grid divides the ground area into a series of more or less uniformly spaced sampling points and is ideally left in place for future reference. Grid dimensions are determined by the purpose of the survey. The location of small features, such as individual ice masses, requires close grid spacing, whereas a wider spacing is most efficient for determining general soil characteristics on larger parcels of land. A practical grid for one- to five-acre parcels would range between 15 and 50 feet as measured orthogonally from point to point. The grid should be rectangular, with a base line referenced to a permanent landmark such as a property survey marker, utility pole, or existing road. The flagging and lath used to mark each grid point should be individually marked as x-y coordinates. These markings are used as location points during field work and serve as handy markers for referencing specific locations of interest which may be indicated by the resistivity mapping. The main grid lines should be north-south and east-west parallel whenever possible.

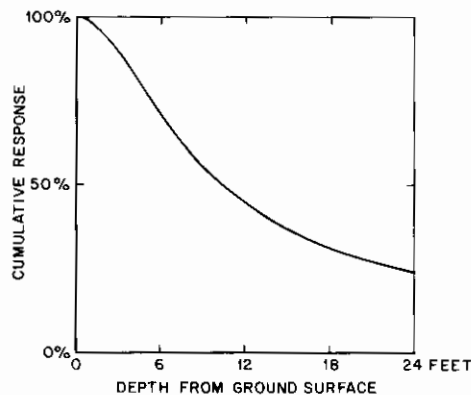


Figure 5. Cumulative response of EM-31 to material located below a given depth.³

This is common survey practice and provides a good directional reference.

Lines can be established on one- to five-acre lots by means of a good hand compass, such as the "Brunton" type. The base line is first put into place from a selected starting point and then succeeding grid lines are run perpendicular from the base line to at least one or two grid spacings beyond the survey's principal area of interest. A common error is to survey too small an area. Each main grid line must extend far enough past the principal area of interest to establish background values of terrain conductivity. In other words, the grid is extended to give the final data interpretation the broadest possible context, e.g., moderate to large size features are easier to identify if they are well defined within a comparatively larger area. Although guidelines in the EM-31 operator's manual indicate that measurement stations with 35-foot spacing can provide maximum resolution of subsurface features, the authors suggest readings on the order of 15–20 feet in areas where, for instance, relatively small masses of ice are suspected. Closer grid spacings are useful if for no other reason than to force the operator to monitor the instrument's readings almost continuously.

Obtaining Data

Before beginning data acquisition or even instrument calibration, the operator should turn on the unit and allow it to come to thermal equilibrium at the work location. This 15- to 45-minute period is followed by a preoperational check procedure outlined in the manufacturer's manual. In addition to the suggested

calibration steps, we recommend the stability of the device be monitored by obtaining readings before, during and after the survey at one or two selected locations. If any instrument drift has taken place, the operator can make appropriate data adjustments.

Gathering data with the EM-31 is a straightforward process. The operator simply walks from grid point to grid point noting the variation in meter readings. This operation is made easier if another person can take notes. Our experience suggests that the instrument should be kept operating between grid point readings. The operator can then monitor the conductivity meter for signs of abrupt terrain change or small features which may otherwise be missed.

Lastly, it should be remembered that the EM-31 is an electromagnetic tool. Although it is relatively unaffected by metallic objects of limited mass such as overhead powerlines, the operator should be suspicious of anomalous readings which appear near obvious conductors. The best advice is to avoid conductors whenever possible. A standoff distance of at least 30 feet should be observed for large metallic objects such as vehicles, structures and large pipes.

PROCESSING FIELD DATA

After data has been acquired, the job then becomes one of transforming raw numbers into a form which can be interpreted. Resistivity values collected at a field site usually result in a rather large set of (x, y, z) data values, where x and y refer to sampling grid coordinate locations and z is the measured ground resistivity. The authors heartily suggest the use of computer graphics, such as one presently available on the University of Alaska Computer System, for converting point-by-point grid measurements into a format visually similar to a topographic contour map.

This graphics system package, known as SURFACE II, is an easily used assemblage of subprograms which can produce contour maps from three-dimensional (x, y, z) data. Although we used and suggest a regular grid pattern, SURFACE II is capable of producing plots from points which are randomly located. In addition to typical topographic plots, the program can produce perspective illustrations and

even stereo pairs. The latter two presentation modes can greatly aid the interpretation process. Further information is available from the text "Surface II Graphics System."⁴

Data Interpretation

Ground resistivity values can and have been used directly to identify subsurface materials. However, this method of interpretation is often complicated by a number of factors that can affect resistivity. The net effect is that absolute values of resistivity are not necessarily diagnostic. It is rather the manner in which resistivity varies from point to point that provides the real key to interpretation. With a general knowledge of possible material types and subsurface structural variations, a resistivity "map" allows the engineer/geologist to see features as a result of their shape rather than by direct identification through specific resistivity values. Interpretation of data gathered for the case studies included in this paper was based principally on the *patterns* formed by relative resistivity values and was heavily flavored by the authors' knowledge of local geology and expected resistivity variations.

Alaska's interior is characterized by ground temperatures close to the freezing

point of water. Depending on time of year and frozen or unfrozen condition of the ground, resistivity values can vary greatly at a given location. In residential foundation surveys where boundaries between frozen and non-frozen materials are expected, their presence can be tentatively interpreted from large step changes in resistivity. For example, in one of the case studies a general increase from 100 ohm-meters to almost 1000 ohm-meters characterized a traverse from unfrozen silt (to a depth of at least 15 feet) to a high ice content silt which was completely frozen from the surface downward. Recent investigations by Tom Osterkamp of the University of Alaska's Geophysical Institute have indicated that apparent resistivity changes can extend several meters beyond an actual ice mass. A reasonable interpretation of a suspicious anomaly plotted from resistivity data would be that it is a target indication centered on the ice structure. In other words, a relatively large portion of the anomalous pattern may not necessarily be underlain by ice. Building foundations or other structures which could be adversely affected by melting ground ice should not be constructed within such resistivity anomalies without specific drill hole information.

The following case studies illustrate the utility of resistivity surveys for soil investigation purposes.

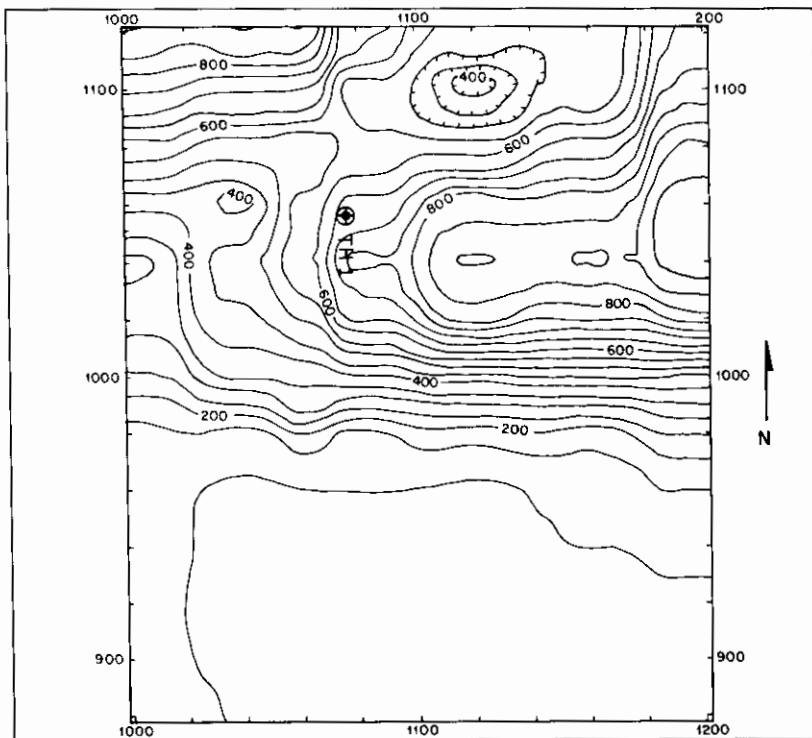
CASE STUDIES

Nine property locations were selected within interior Alaska. Six of the case studies represented foundation investigations for house sites, while the remaining three illustrated an evaluation of placer gold mining properties.*

Resistivity values indicated on the contour maps are in units of ohm-meters. It should be pointed out that the property owners were well aware of the tentative nature of the description of ground conditions as interpreted from resistivity data. As indicated previously, ground truth in the form of borings, trenches, etc. is absolutely necessary to validate the interpretation.

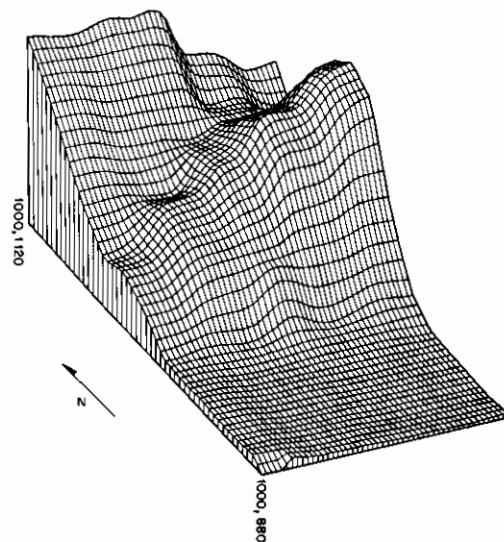
Due to the three-dimensional nature of perspective view plots, a portion of the surface can be hidden from view, depending on the contour of the surface and angle at which the surface is viewed. The plots shown have been oriented to minimize the amount of hidden surface and to present a readily interpretable view. Coordinate identification and directional arrows are provided on both the

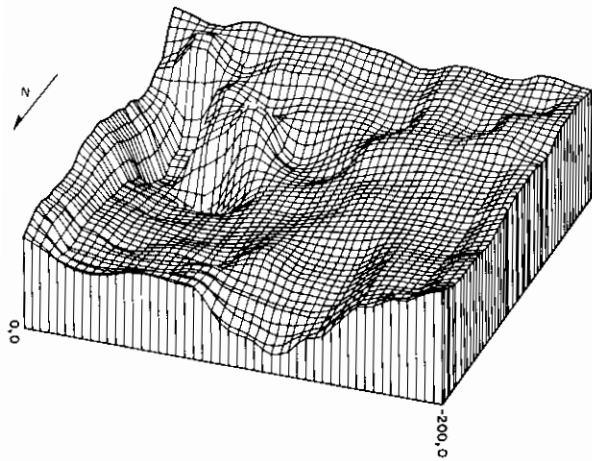
*Because of space considerations, only three of the authors' studies appear here.



Left: Soil resistivity contour map, Case Study # 1.

Below: Perspective view of soil resistivity, Case Study # 1.





Perspective view of soil resistivity, Case Study # 2.

perspective and contour plots so that orientation differences are obvious.

CASE STUDY # 1 was a residential site approximately five miles NE of Fairbanks. Grid spacing was 20 ft x 20 ft. The area was surveyed on March 28, 1981.

Physical Description of the Property

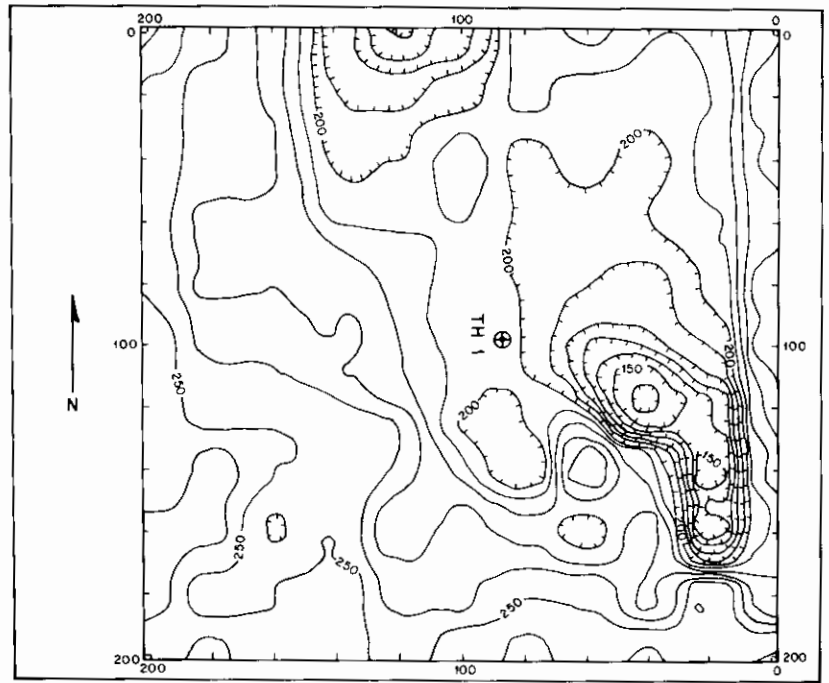
- Relatively flat topography – located in the bottom of a small northeasterly trending valley;
- Northern half of survey area was covered by undisturbed stunted black spruce, small birch and a thick moss layer;
- Southern half of survey area consisted of an old farm field cleared in the late 1940s.

Known Foundation Conditions

Soil types in the area included both frozen and unfrozen silts to depths in excess of 50 feet. Test Hole No. 1 (see contour map) generally revealed frozen silts and organic silts, which contained 5 to 15% visible ice to a depth of 20 feet. In addition a layer of clear ice two feet thick was discovered at 17.5 feet. Silt moisture contents ranged as high as 60–80% in borehole samples.

Interpretation

The cleared area is characterized on the resistivity map by values of less than 200 ohm-meters. An interpretation of this survey would indicate that low resistivity is associated with significant thawing, perhaps in excess of 15 feet.



Soil resistivity contour map, Case Study # 2.

Resistivity values above 300 ohm-meters were associated with areas of the property which had not been previously disturbed. Resistivities above 800 ohm-meters are, in this case, expected to represent soils of high ice content.

The property owner proposed construction of a home near Test Hole No. 1. Both soil boring and resistivity data strongly indicated the use of construction methods which would preserve the foundation site in its frozen condition. Furthermore, it was suggested that the owner's septic flow be routed into the area characterized by resistivity values of less than 150 ohm-meters.

CASE STUDY # 2 was a residential site approximately five miles NW of Fairbanks. The grid spacing was 20 ft x 20 ft. The site was surveyed on January 17, 1981.

Physical Description of the Property

- Located on a gently south-sloping hillside;
- Survey area consisted of an old farm clearing covered with secondary growth of aspen and willow.

Known Foundation Conditions

Test Hole No. 1 indicated slightly organic, unfrozen silts to a depth of at

least 30 feet. Moisture contents of the silts were found to fall within the range of 12 to 17%.

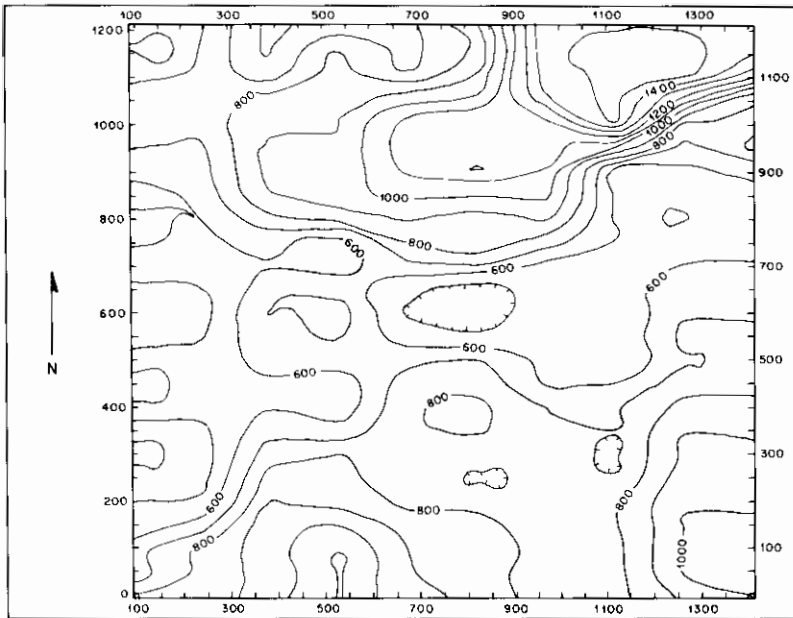
Interpretation

Test hole information combined with relatively low resistivity values of less than 300 ohm-meters tended to indicate the general absence of frozen ground within the survey area. Anomalously low resistivity values near the eastern boundary of the survey indicated soil wetting caused by pump-testing of a nearby water well the previous summer. Interestingly enough, the localized area of low resistivity indicated in the northcentral portion of the map delineated encroachment of a neighbor's septic drainage onto the surveyed property.

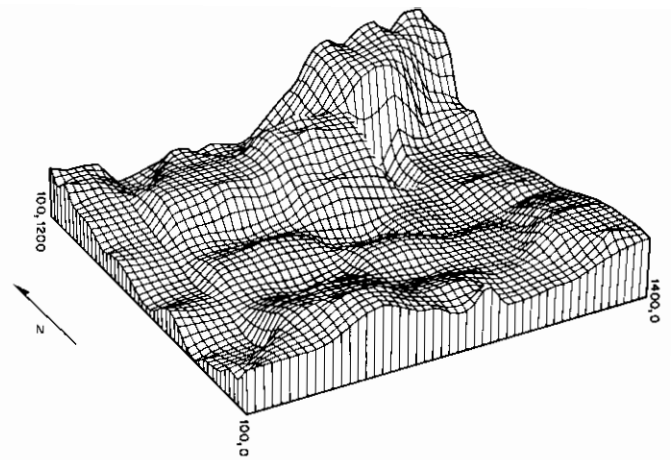
CASE STUDY # 9 was a mining property approximately 80 miles NW of Fairbanks. Grid spacing was approximately 50 ft x 400 ft. The site was surveyed on April 6, 1981.

Physical Description of the Property

- Moderately sloping, south-facing hillside;
- Vegetation consisting of a secondary growth of small to medium size aspen and spruce plus a moderately thick moss layer.



Soil resistivity contour map, Case Study # 9.



Perspective view of soil resistivity, Case Study # 9.

Known Foundation Conditions

Mining activities revealed bedrock consisting of schist and small but numerous quartz-rich granitic intrusions. Bedrock was overlain by two to four feet of weathered schist soils.

Interpretation

This survey revealed resistivity variations associated with different bedrock types. High values noted in the northeastern portion of the survey were found to accompany hard, unweathered schist bedrock covered by a shallow soil layer. An irregular band of resistivity lows transects the central portion of the survey from west to east. Subsequent dozer cuts in this area exposed highly altered schist bedrock. Alteration had produced a dark clay-rich material which became wet, slick and generally untrafficable when thawed.

Although the original intent of the survey was delineation of possible gold-bearing bench gravels, such materials proved to be absent from this location. Instead, a zone of altered schist bedrock was located which may contain areas of intrusive mineralization.

CONCLUSIONS

- Resistivity surveys *can* provide useful information in the exploration of subsurface soils.

- Resistivity surveys prove to be most successful in areas where the number of material types are limited and resistivity differences between material types are significant.

- Correct interpretation of ground resistivity data is critically dependent upon the amount and quality of additional information available.

- Resistivity surveys should be used in conjunction with soil borings, trenching or other methods which can provide positive identification of subsurface soils and conditions.

ACKNOWLEDGMENTS

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