

# Planning a Geophysical Program

## Introduction

In an average year, Quantec completes approximately 75 geophysical surveys and in addition, reviews in a consulting capacity, another 25-50 data sets. This work constitutes hundreds of kilometres of geophysical data. In completing this work, we find the programs that experience most difficulty generally do so because of poor communications. By this I am referring to poor communication of the survey objectives at the conceptual stage to allow for the development of an effective survey design. This is a fundamental process that is often overlooked.

The objective of this talk is to outline the steps involved in planning an effective geophysical survey. In reviewing this process it will become clear that you as managers can increase the effectiveness of your geophysical programs if you are prepared to follow a set planning process. Not only will you ensure that the program is designed to explore for the proposed geologic model, you will at the end of the program, appreciate what potential targets have not been evaluated by the survey. Knowing what a specific survey will not find is as important as knowing what it will find if a property is to be evaluated effectively.

For those of you interested in the short course, the principal points I will be developing are:

- The single most critical step towards the successful completion of a geophysical program is the definition of the survey's objectives.
- The subsequent survey design process, selects the geophysical method and establishes the survey parameters to best achieve the defined survey objectives.
- The survey design process defines boundary conditions that control what a survey will and will not find.
- The economic implications of the boundary conditions are significant. They dictate the cost of the survey and determine the effectiveness of the geophysical property evaluation.

Communications problems in planning a geophysical survey are encountered more frequently today for two reasons. First, there is an ever-increasing geophysical technology base available to the geologist. To plan a survey effectively he must have at least some basic understanding of the capabilities of this new technology. Second, ore bodies are getting more difficult to find. We are starting to explore in much more difficult environments.

Developments in geophysics during the last decade have been significant. The introduction of the microcomputer and the manufacturing of geophysical instrumentation with microprocessor based, central processing units, has revolutionized the science. We are now capable of recording larger volumes of data at a higher level of data significance. Computerization has also brought about the introduction of new geophysical technology. What previously could not be measured by analogue instrumentation can now be measured through digital acquisition technology. These

developments represent a significant diversification in survey methods, instrumentation, interpretation and cost, all of which must be taken into consideration in the implementation of a geophysical program. While this diversification is an enormous asset it can also represent an equally enormous deterrent to the exploration professional that is not fully aware of these technologies.

This problem is compounded by the expansion of exploration efforts into more difficult areas that require geophysics to effectively evaluate the properties potential. In known mining camps and grassroots exploration plays, efforts are being made to explore to greater depths often in areas with extensive overburden cover. There are many examples of these types of programs. In Sudbury, holes are being drilled on a regular basis to depths of more than 2 kilometres, In Nevada exploration has moved from the range areas into the pediment areas. Here, conductive sediments overlay the basement rocks of interest. There is no surface expression of geology. This is not unlike the situation that many of you face in Chile, Bolivia and Peru. The recent interest in porphyry copper exploration in these areas has resulted in exploration programs in overburden areas that previously had been ignored.

Consequently, the exploration geologist finds himself in an increasingly difficult situation. As it gets more and more difficult to track the advances in geophysical technology he is having to rely more heavily on geophysics to assist in the evaluation of a property. As a result, geophysical programs are being designed by geophysicists who understand the technology but have limited geologic information on the specific property being explored. This then is the problem. In order to effectively evaluate the property, both the geologist and the geophysicist must understand clearly the objectives of the program. This is the single most critical step, the written definition of the survey objectives. It is critical because the geophysicist will design all other phases of the survey to fulfil as many of the objectives as is cost effective. In so doing, he defines boundary conditions that dictate what the survey will or will not find. If the objectives are clearly defined the survey will be properly planned and the boundary conditions will be well understood. The geologist can then, on the basis of the results of the survey:

- Drill the geophysical anomalies delineated,
- If none are delineated, re-evaluate the property for different models (adjust survey parameters or change the method) or
- Proceed with the property evaluation on a geological basis only.

In the event that the property is later sold or optioned to a second company, the explorationist who has followed this procedure will appreciate what potential targets could remain on the property. That is, those geologic models that fail outside the boundary conditions dictated by the survey. Similarly, if a property is to be optioned, a reevaluation of previously recorded data sets will provide insight into what mineral potential may still remain.

In order to appreciate the nature of the boundary conditions dictated by a survey, it is necessary to review what is required in a statement of the project objectives and how this information is used to develop a survey design. A statement of program objectives is designed to provide the geophysicist with a geological model and insight into the goals of the program. It should answer simple questions such as:

- **What are we trying to achieve?**

Is it lithologic mapping or direct detection of the targets of interest?

- **Are we evaluating a large area or a small area?**

Large areas may be more suitable for airborne surveys versus ground surveys in small areas.

- **What is the proposed geologic model?**

This should include a description of the:

- Target - the composition and nature of the mineralization dimensions strike and dip,
- Host Environment - overlying, underlying and adjacent rock units, and, indicate the significance of structure.

It is worthwhile to note that it is as important to the geophysicist to understand the host environment as it is the expected target. Direct detection is a function of the physical property contrast between the target and the host.

Other questions that should be addressed in the objectives include:

- At what depth is the proposed geologic model no longer economically feasible?
- Is overburden a factor?  
If so what is the nature of the overburden?
- What are the budgetary constraints?

With this information the geophysicist is in a position to proceed with the survey design process. This is the process of selecting the geophysical method and establishing the survey parameters to best achieve the defined objectives. It is in this procedure that boundary conditions are set that dictate what the survey will or will not find

The key steps in the survey design process include:

- The definition of a physical property model,
- The selection of the method and instrumentation,
- The setting of survey parameters,
- Sensitivity studies through computer assisted surveys modeling and orientation

## The Physical Property Model

In the survey objectives the project geologist describes a geological model based on the general exploration model being applied to the area. The task of the geophysicist is to translate the conceptual geological model into a physical property model. This follows a similar procedure to the definition of the survey objectives. The geophysicist will adopt the physical dimensions of the target as stated in the objectives, assign physical properties to the various components of the model and then define the physical property contrasts. Again this is achieved by answering a few simple questions.

- What are the physical property contrasts between the proposed geologic target and the environment?
- What is the extent of the contrast?
- Are there physical property contrasts within the host environment?
- What is the physical nature of any faulting or shearing that may exist on the property?
- What are the physical properties of the overburden if it is a factor?

At this point a description of the **geologic** model and the corresponding physical property model should be complete. Here is an example of what they might look like.

## The Geologic Model

**Target Description:** Vertical shear zones; narrow, 10-20 meters in width. From previous drill results along strike the zone is both heavily gouged and mineralized with disseminated pyrite, chalcopyrite and sphalerite. The zones strike north-south and are known to strike for distances in excess of 1000 meters.

**Host Description:** The shear zones are hosted principally in greenschist facies metavolcanics and meta sediments. Minor sulphides are present in the host (1-2%). The area is cut by north-south striking diabase dykes that are not mineralized. The area is glaciated but there is little to no alluvial cover.

## The Physical Property Model

**Host Model:** Approximate the host as a half space. The resistivity should be moderate (500 Ohm-m) but should be varied in a sensitivity study. The polarization will be low. Note the presence of the diking which suggests that magnetic interpretation would be useful in a structural interpretation.

**Target Model:** The target is anticipated to display anomalously high chargeability and low apparent resistivity. Strike length is anticipated in the hundreds of meters.

**Response:** The shear zones are anticipated to produce strong anomalies due to the high physical property contrast between the host and the target. Metal Factor based products may be significant. The symmetry of the anomaly should be vertical.

### Selecting the Method and Instrumentation

The selection of the survey method and the instrumentation can only be completed once the objectives and the physical properties are defined. At this point the method selection is fairly obvious because the physical contrast between the host and the target has been determined. Likewise, once the method has been selected the choice of instrumentation is clear.

In the method selection process the geophysicist will determine what geophysical method would be most sensitive to the defined physical property contrast. In the example given the shear zone and the disseminated sulfides within the shear zone would be easily delineated through an IP/Resistivity survey. The response from the sulfides would be enhanced by the gouge material in the shear. The resistivity contrast between the shear zone and the host environment would be significant enough to expect a definite response in the resistivity data. By the same token the IP/Resistivity survey would be insensitive to diabase dykes therefore conducting the Mag survey to delineate the dykes would be required if they were deemed significant.

Likewise with the survey instrumentation. The method dictates the nature of the instrumentation. The power requirements, if a transmitter is involved, are a function of the conductivity of the host environment; the required depth of exploration; and the logistical access to the property. In the case of an IP survey, the higher the conductivity of the host environment including alluvial and bedrock materials, the greater the ability of the environment to absorb electrical signals. Therefore, to maintain minimum signals, the power must be increased as the conductivity of the host increases. Similarly large depths of exploration dictate with most methods the use of higher-powered transmitters because of the lower return signal levels. This in turn brings into consideration the logistical access to the property. Generally any transmitter over 10 kW will require road or helicopter support.

The specification of the method and the instrumentation also dictates the cost of the proposed survey. Geophysical equipment is relatively expensive. For example, IP systems can vary in cost from \$50,000.00 to in excess of \$150,000.00 depending on the power number of simultaneous channels, the speed of the analogue to digital converter, signal recognition, etc. If the cost exceeds the budgetary constraints then the objectives should be re-evaluated and the method

reviewed. It is generally relatively easy to arrive at a happy medium without compromising the quality of the data.

## Setting the Survey Parameters

Having selected the method, the next step is to optimize the survey parameters to obtain the best resolution of anomalies possible. This is the second most frequently abused process in the survey design next to the definition of objectives. All too often survey parameters are compromised for the sake of covering a property for a reduced cost. It doesn't work. Inevitably the money saved is lost through repeat surveys, additional drilling, or worse, a missed opportunity.

Of all the steps in the survey design process the setting of survey parameters has the most direct influence on the boundary conditions that is, determining what the survey will or will not find. Mistakes at this point will increase the difficulty of interpreting the data. Single point anomalies, poorly resolved multiple sources and generally complex geometrical responses are all examples of surveys that have been run with poor survey parameters.

This is best illustrated by returning to the model we defined earlier. If we elect to use an IP survey with an electrode spacing of 100 meters to prospect for a 10 meter wide shear zone, problems will occur:

- Because of the averaging nature of the IP measurement and the large volume of ground being sampled the zone may not even be detected. If it is, it will probably appear as a single point anomaly that might be mistaken as noise.
- If by chance it is detected, the exact location of the source cannot be determined. If the source width is 10m and electrode spacing is 100m, the minimum uncertainty in locating the source is 100m; the maximum uncertainty may be as much as 200m.
- There is difficulty in determining the nature of the source. The response from a 10-meter wide zone containing 5 to 6 percent sulfides will look similar to a 60m wide rock unit containing 1 to 2 % sulphides.

The sensitivity of an IP survey to electrode spacing is also demonstrated in the following case history from the Hemlo area. This data was made available courtesy of Dr. Phil Hallof.

The Hemlo area is famous for the gold mineralization that has been discovered there over the past few years. It is located on the north shore of Lake Superior (see Figure 1).

The results I am presenting are from a Dipole-Dipole IP survey as illustrated in Figure 2, which was conducted over a multiple source anomaly at three different electrode spacings. They illustrate the value of detailing with smaller electrode spacings if the target sought is narrow. Ideally in an IP survey the electrode spacing should equal the width of the source of interest. This isn't always practical.

The definite IP anomaly shown in Figure 3 was located during a reconnaissance survey using an electrode spacing of 50 meters. In preparation for spotting a drill hole, the source centred at 2+50N to 3+00N was detailed with an electrode spacing of 25 meters (see Figure 4). In this pseudosection there is a suggestion of multiple bodies at 2+50N to 2+75N and 3+00N to 3+25N.

Additional detailing at an electrode spacing of 10 meters (Figure 5) confirmed the presence of the anomalies. Subsequent investigation of the source of the anomalies through drilling and trenching revealed that the southern source is a narrow concentration of sulfide in a quartz-sericite schist. The zone to the north contained a greater concentration of pyrite. Anomalous gold values were found in the southern zone only. Had the project geologist not recognized the boundary conditions dictated by an IP survey conducted at an electrode spacing of 50 meters, and therefore the value of detailed work, it is unlikely they would have located the southern zone. The distance between the original anomaly, detected with the electrode spacing of 50 meters, and the southern zone is almost 100 meters.

Fortunately, the problem of setting survey parameters can be solved by conducting sensitivity studies through computer modeling. In computer modeling the survey parameters or model characteristics can be easily varied to test the effectiveness of the survey design. The geophysicist in conjunction with the geologist can explore the best and worst case scenarios to determine how sensitive the proposed model is to the method and what is the most effective depth of exploration given the survey parameters.

Finally with respect to survey design, I would like to comment on the value of conducting an orientation survey. There is no substitute for the value of an orientation survey if it is conducted in an area with good geologic control. It gives the geophysicist a chance to increase the effectiveness of the survey through insitu experiments and it gives the geologist a hands-on opportunity to evaluate the product he is buying. Take advantage of orientation surveys if you can.

In the time remaining, I would like to review two additional case histories that illustrate the impact of planning on the outcome of a geological survey. Both case histories are of transient electromagnetic surveys: the first is a surface survey; the second a mine site, underground borehole survey.

The Transient Electromagnetic method is a time domain electromagnetic method that is capable of detecting conductive mineralization such as massive sulphide ore bodies. In the survey, a surface transmitter emits a primary magnetic field that induces eddy currents in any nearby conductors. The eddy currents in turn create a secondary magnetic field, which is detected by a receiver coil. As it is a time domain system, the decaying secondary field is measured during the off time, over a series of contiguous sample gates. The signal received is profiled for interpretation purposes. One profile is plotted for each time gate. Generally two components of the secondary field are monitored, a vertical and a horizontal component.

The first case history is from the Sudbury area (Figure 6) and is an example of a surface Transient Electromagnetic (TEM) survey for conductive massive sulfides.

There are two, fixed loop, surface TEM methods as illustrated in Figure 7. The first and most common method involves reading lines off the long side of a rectangular loop. This method is designed to test for vertical to subvertical conductors. The second method, the "In-Loop" method, consists of reading lines within a fixed loop that surrounds the area of interest. These loops are commonly greater than 1 km square. This method is most effective for testing for flat lying conductors.

The survey parameters that are critical in the use of these methods are the placement of the transmit loop relative to the area of interest and the sample density. Generally if the target has a fairly simple geometry, for example it is plate-like, it is not difficult to select the appropriate method and hence the correct loop placement. However, when the target has a complex shape, (spherical or pipe-like) and therefore a reduced area, greater care must be taken. When this occurs, a decision must be made as to whether to place greater emphasis on the coupling of the primary field with the conductor or on field strength. In this situation it is more advantageous to work in an area of maximum field strength, within the transmit loop (In-Loop Method).

In the following data sets we will see profiles over the same grid line with the two surface TEM methods. The first set of data is the vertical (Figure 8) and horizontal component data (Figure 9) from a survey run with the loop to the side of grid. As you can see, there is no evidence of any conductors. The geologist on receipt of this data assumed that there were no targets of interest but proceeded to drill on the basis of the geology alone. He tested a relatively significant amount of sulfide at approximately 3+35N. At his request, we were asked to review the original data set and make recommendations as to how to proceed with future geophysical programs. The fact that the sulphides had not been detected by the original survey indicated to us that the body must have limited surface area. Our recommendations were to proceed with a second TEM survey but adopt the IN-LOOP method rather than running lines off the side of a loop. The results from the IN-LOOP survey are illustrated in Figures 10 and 11. It is clear the sulphides of interest were detected easily with this method. The drill section from the line surveyed is illustrated in Figure 12.

The subsequent survey of the entire grid delineated the zone of interest over a strike length of approximately 250 meters. Drilling indicated that the conductor was a small area elongated lens. Approximately 500,000 tons of mineralization was delineated. Although it wasn't sufficient to justify a mine, it did provide the incentive to attract a second company who optioned the

property and continued with the exploration program.

The data collected in the original survey was not entirely wasted. It indicated clearly to the geologist and us that the plate-like model he had adapted had to be modified.

The second case history is from the South Bay Mine (Uchi Deposit) in Northwestern Ontario (Figure 13).

This is a condensed case history that was originally published by L.E. Reed at the *International Symposium and Workshop on Borehole Geophysics* in 1983. It deals with the mine site evaluation of potential reserves through borehole transient electromagnetics. It is an excellent example of a well-planned survey.

The borehole survey uses the identical equipment as the surface survey except the receive antenna is modified to allow it to be lowered down a drill hole. The transmit loop encircles the mine area. Holes can be logged from surface or underground. The position of the conductor is determined by comparing responses from adjacent holes (Figure 14).

In the late seventies the South Bay Mine was nearing the end of its mineral reserve. In an effort to explore for additional reserves a borehole transient electromagnetic survey was conducted in drill holes collared underground (Figure 15).

A transmit loop was laid out on surface over the hanging wall of the orebody (Figure 16) and 85 holes were surveyed. I will be discussing the results from three of these holes.

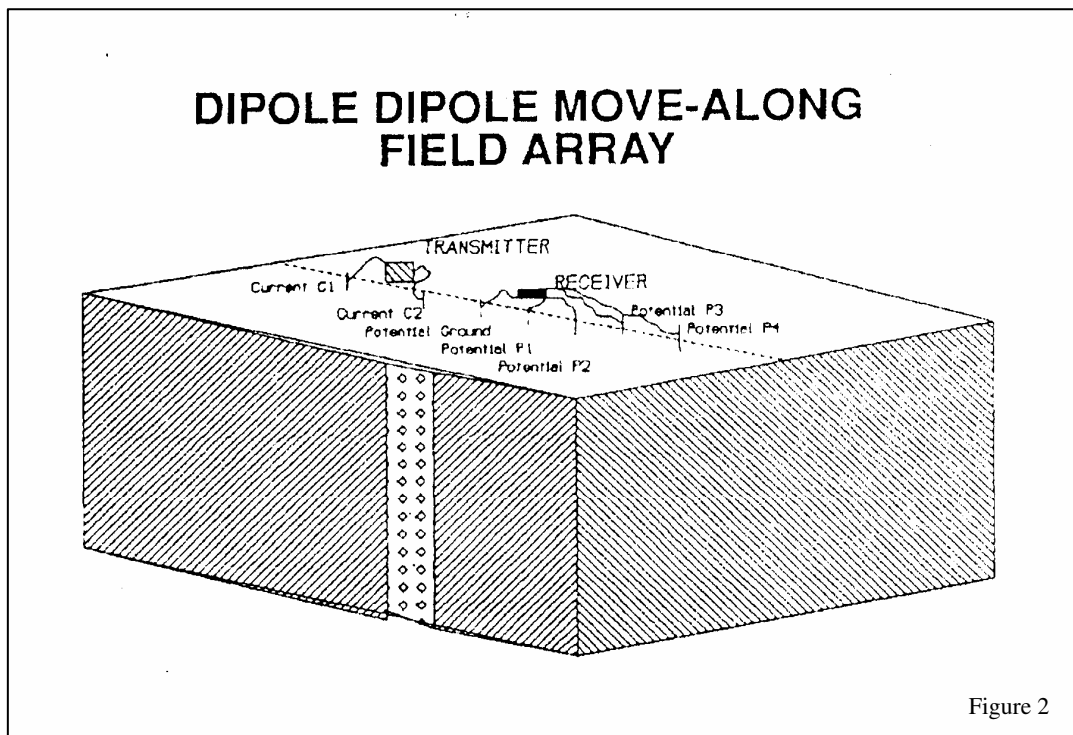
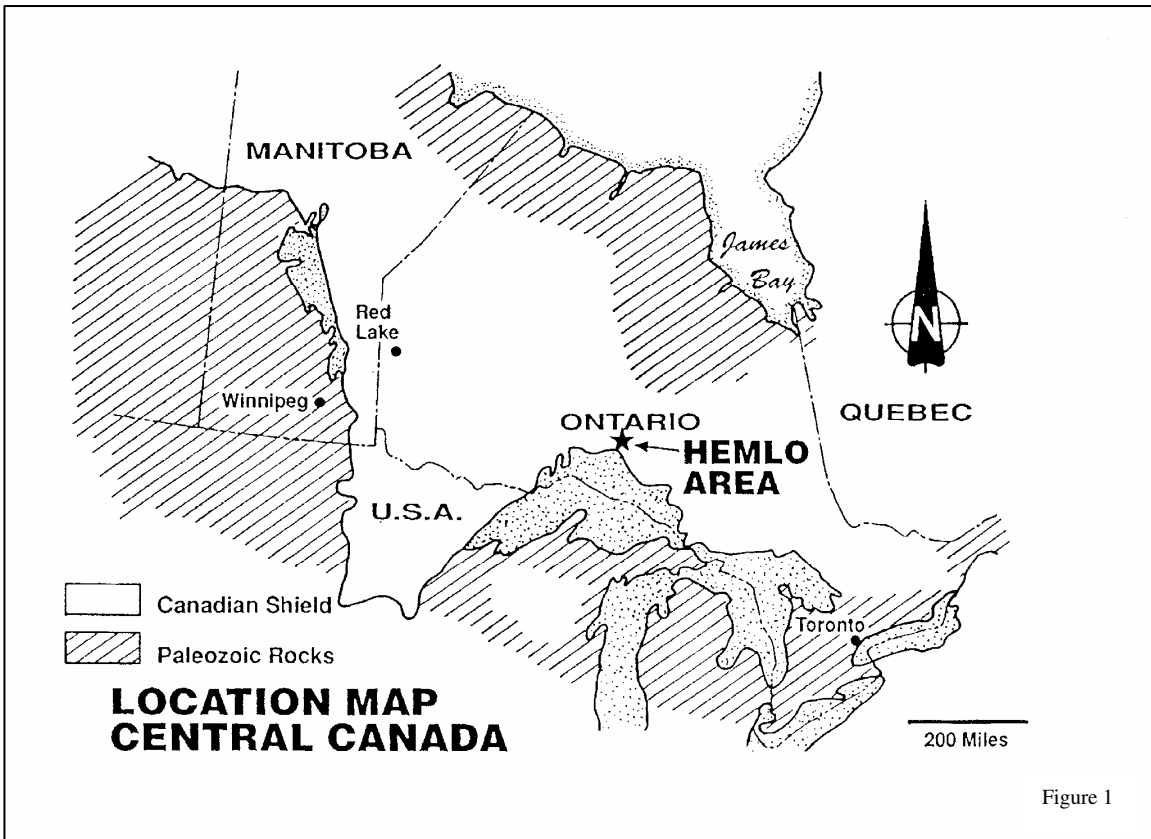
The sulfide lenses of interest consisted of high grade, chalcopyrite, pyrite and sphalerite. The lenses occurred adjacent to a complexly folded rhyolite-quartz porphyry contact. The three holes, of interest in this case history, were drilled parallel to the contact with the intention of subsequently exploring the contact area through borehole geophysics. Because they would also be paralleling the sulfide lenses of interest, the expected response from the conductor would be a crossover pattern. The polarity of the crossover pattern is indicative of where the lens lies with respect to the hole.

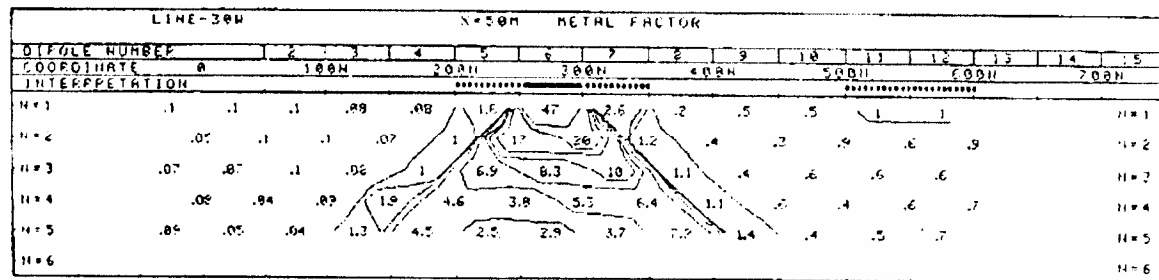
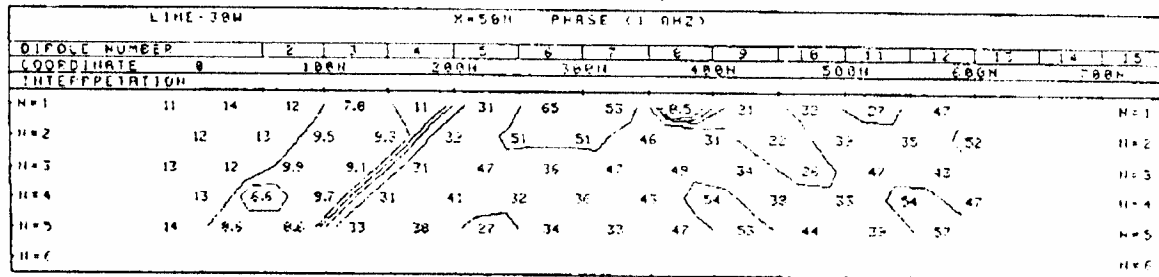
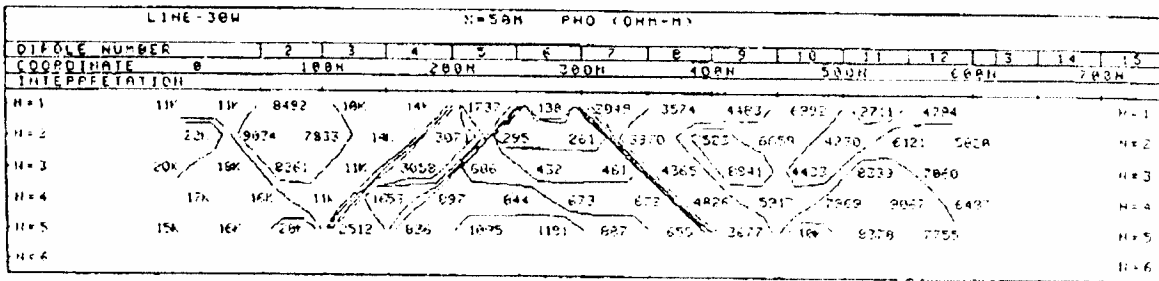
Figure 17 is a plan section of the three holes. You will note that SB528 is drilled in and out of the contact several times. The borehole TEM log of this hole (Figure 18) indicated two conductors paralleling the hole. The first is a weak minus-plus anomaly at 155 feet, the second a stronger plus-minus anomaly at 360 feet. The response at 155 feet was interpreted to be a weak, small conductive lens lying to the south of the hole. The response at 360 feet is a much larger conductor to the north of the hole. SB533 (Figure 19) also detected the larger lens but as a minus-plus response indicating it lies to the south of the hole. The results from SB531 (Figure 20) indicated both conductors were to the north of the hole. The interpreted location of the conductor is shown in Figure 21. A hole was drilled to test the conductor which proved to be stringer sulfides with minor amounts of sphalerite.

In the South Bay Mine borehole survey no additional reserves were discovered to justify keeping the mine open. The borehole survey did satisfy management that no additional sulphides were to

be found in the vicinity of the mine. This information allowed them to close the mine without incurring any additional exploration expenses.

In closing I would like to reiterate that all geophysical surveys have boundary conditions that dictate what a survey will or will not find. Knowing these boundary conditions is necessary if the exploration professional is to evaluate a property effectively with geophysics. Before you spend money on a geophysical survey take the time to identify the boundary conditions through the development of a thorough survey plan.

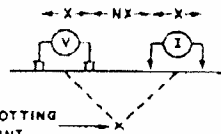




INDUCED POLARIZATION  
and  
RESISTIVITY RESULTS

SULPHIDE-BEARING SCHIST ZONE  
Hemlo Area, Ontario

DIPOLE-DIPOLE  
ELECTRODE CONFIGURATION



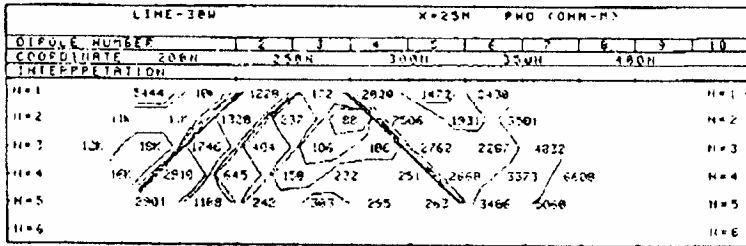
SURFACE PROJECTION  
OF ANOMALOUS ZONE  
DEFINITE —————  
PROBABLE .....  
POSSIBLE - - - - -

FREQUENCY - 1.0HZ

NOTE - CONTOURS AT  
LOGARITHMIC INTERVALS  
1, -1.5, -2, -3, -5, -7.5, -10

Phase IP pseudosection Hemlo Area; Line 30W, X=50 m

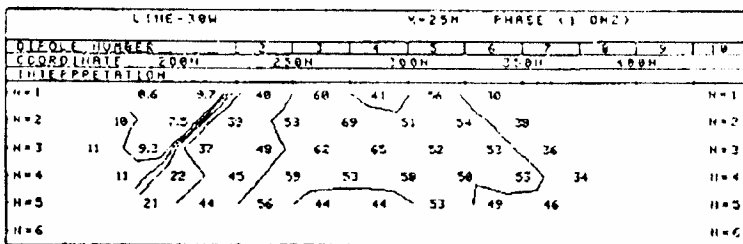
FIGURE 3



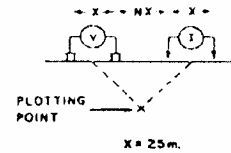
INDUCED POLARIZATION  
and  
RESISTIVITY RESULTS

SULPHIDE-BEARING SCHIST ZONE  
Hemlo Area, Ontario

LINE NO - 30W



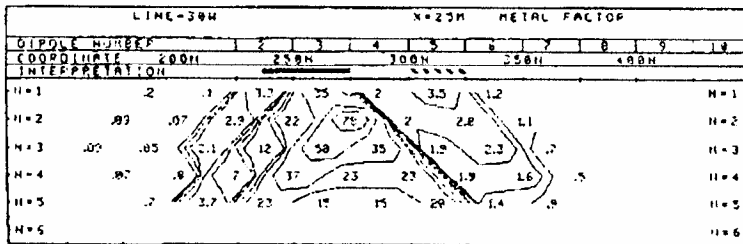
DIPOLE-DIPOLE  
ELECTRODE CONFIGURATION



SURFACE PROJECTION  
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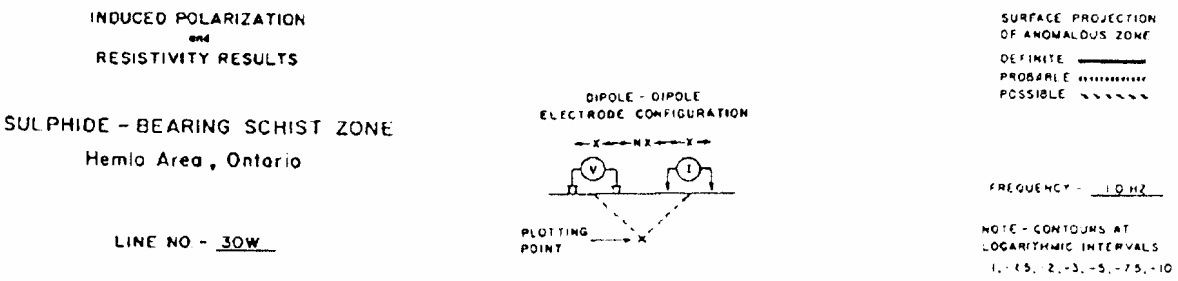
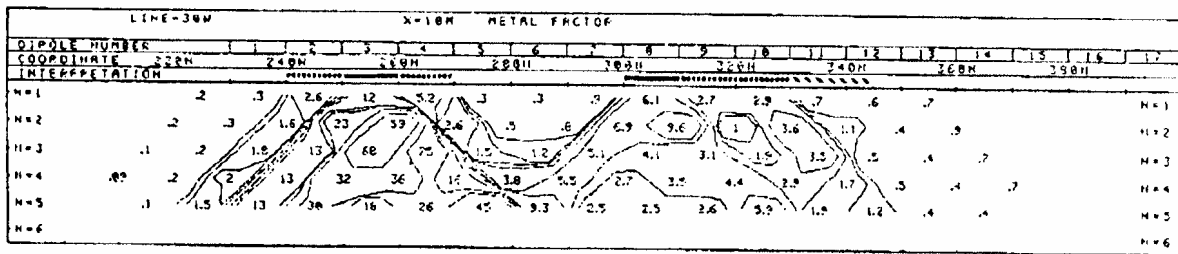
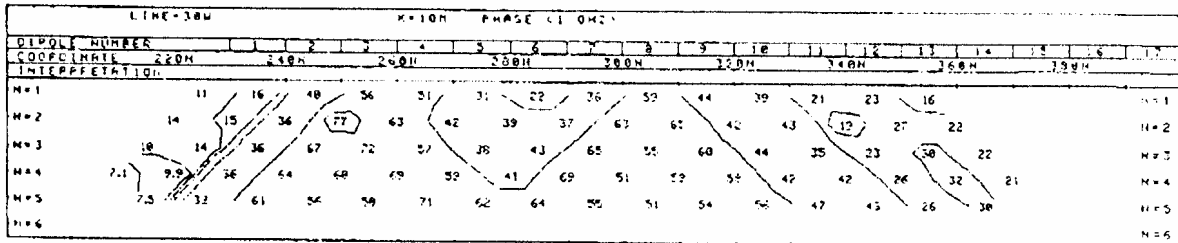
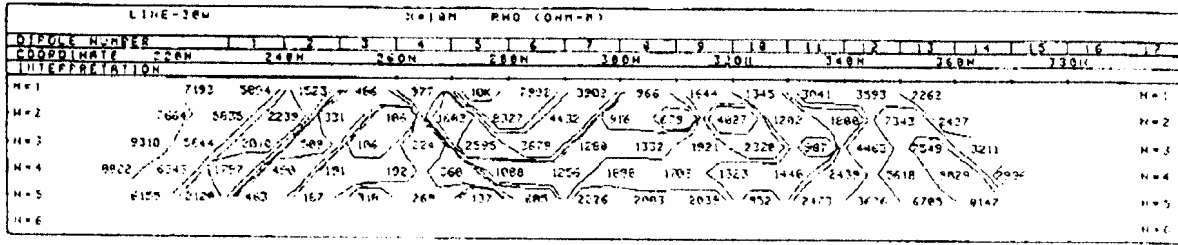
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NOTE - CONTOURS AT  
LOGARITHMIC INTERVALS  
1, .15, .2, .3, .5, .75, .10



Phase IP pseudosection Hemlo Area; Line 30 W, X=25 m

Figure 4



Phase IP pseudosection Hemlo Area; Line 30 W, X = 10 m

Figure 5

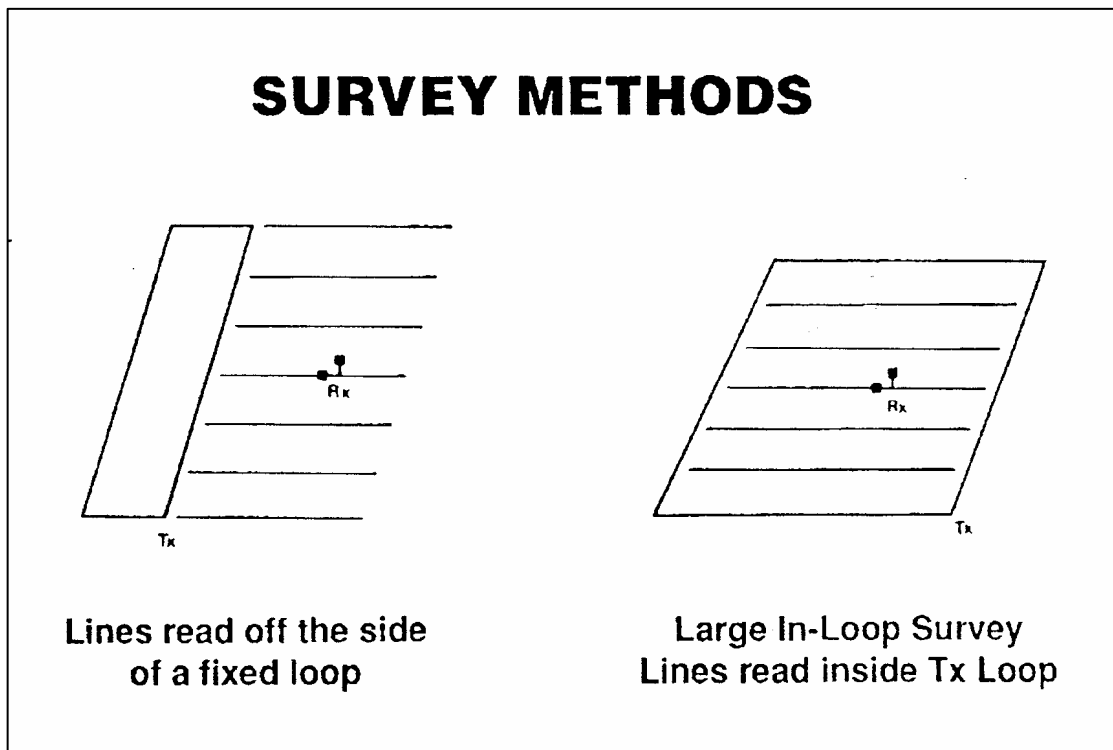
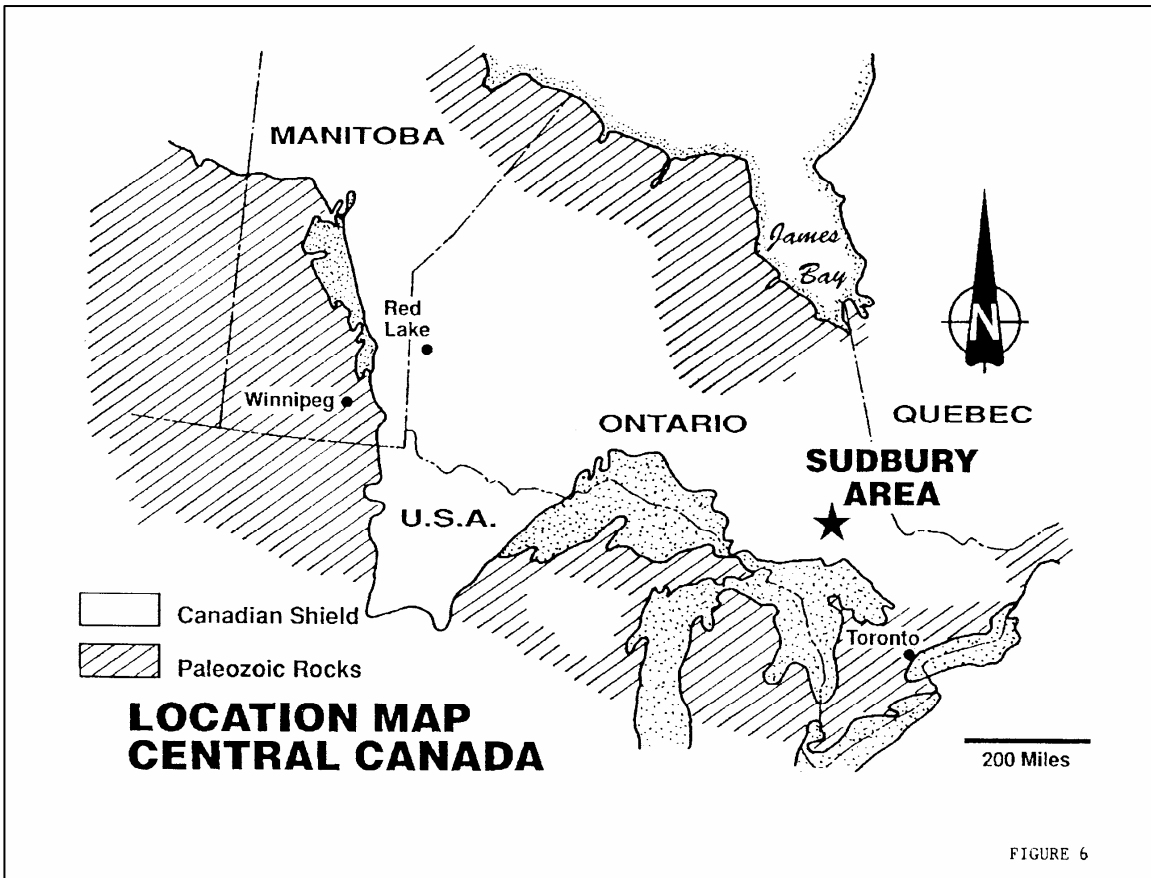


Figure 7

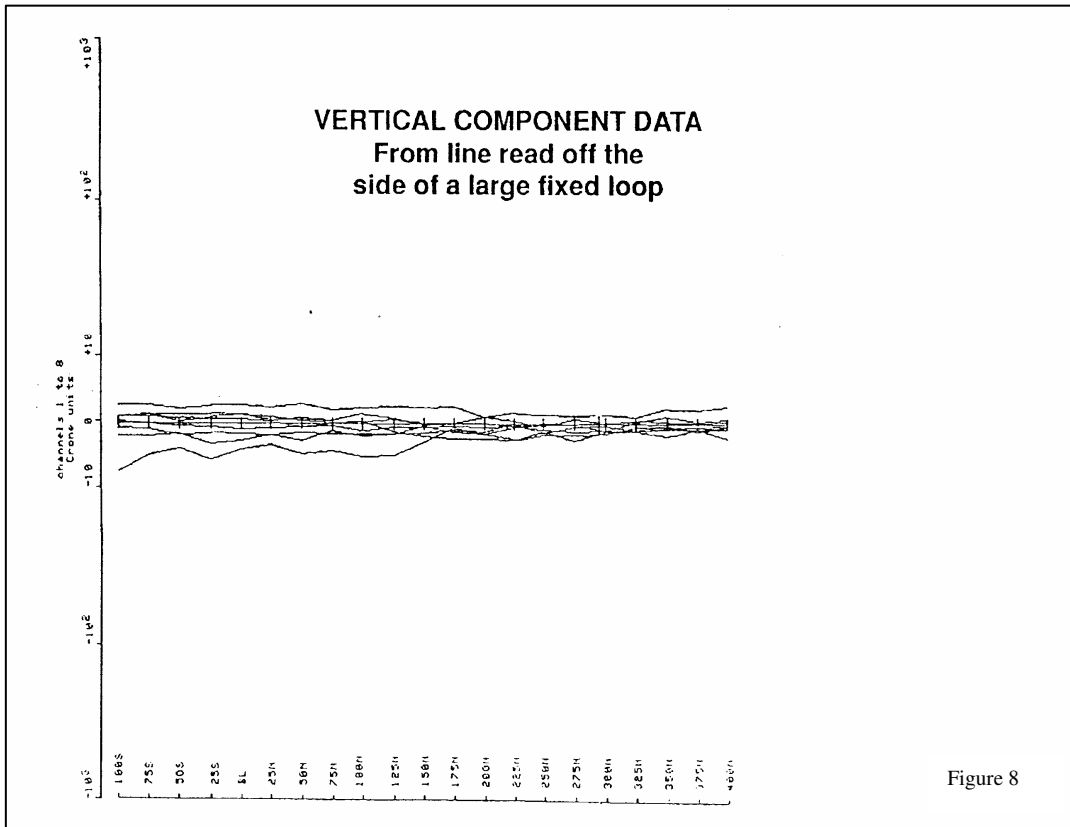


Figure 8

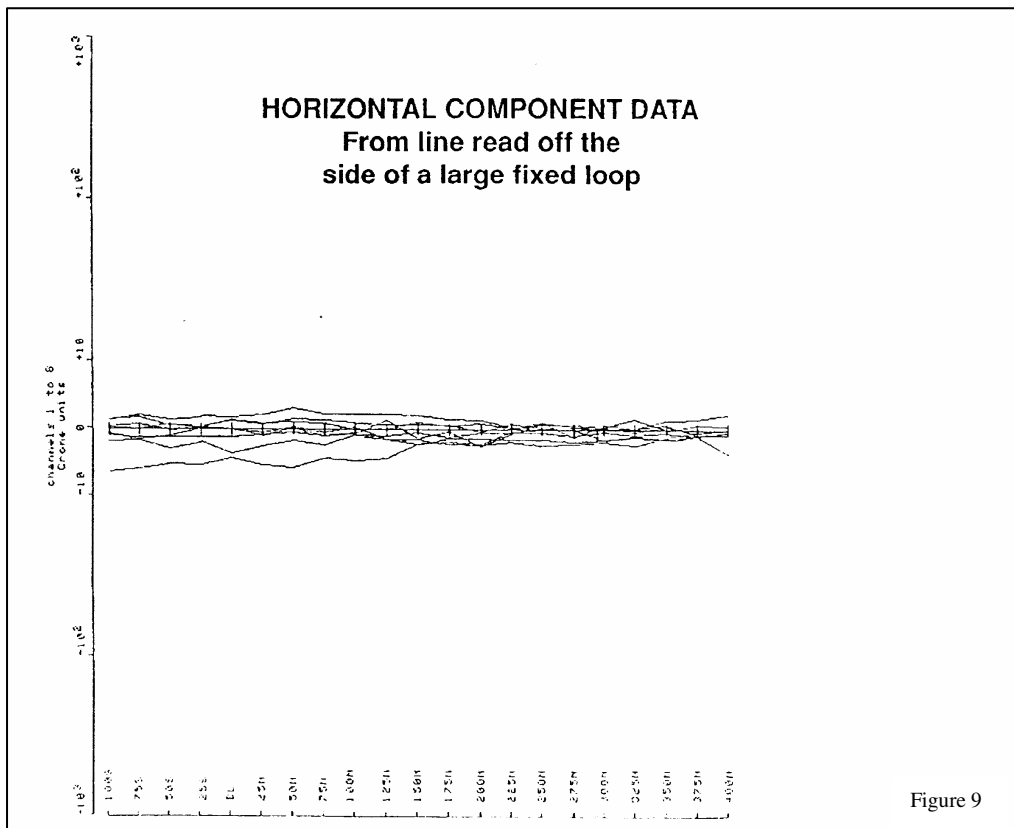


Figure 9

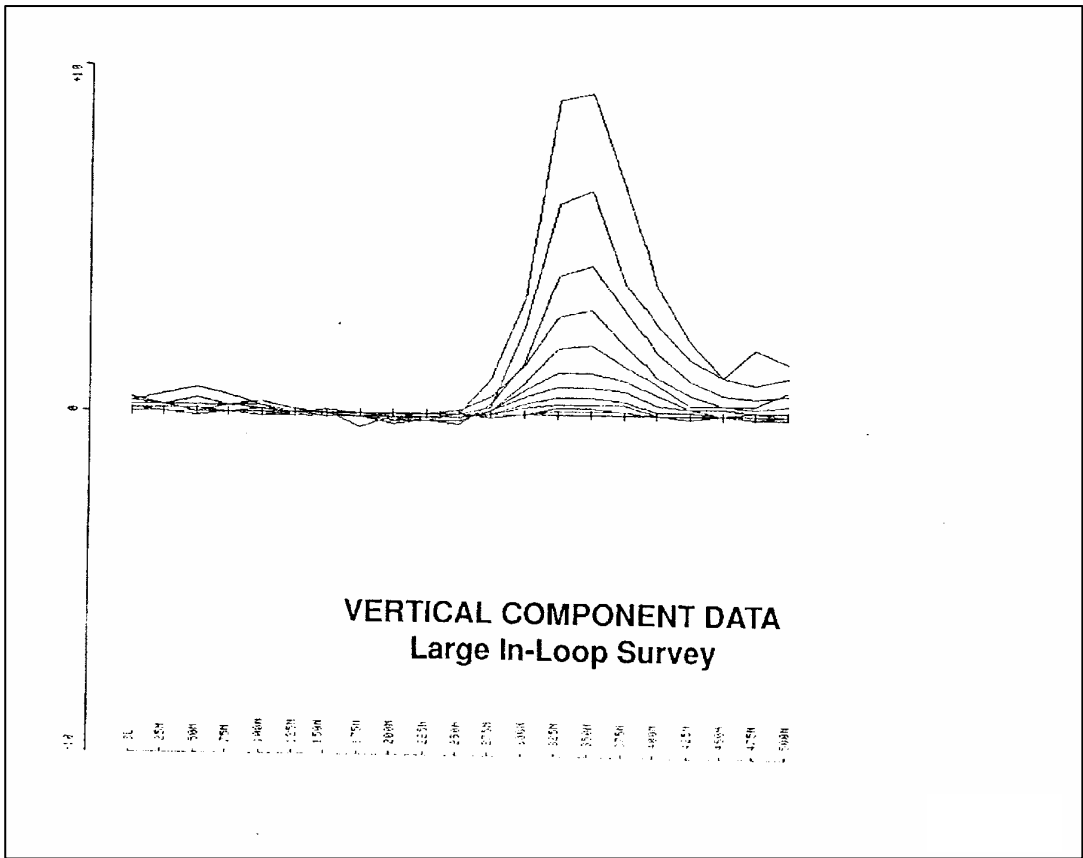


Figure 10

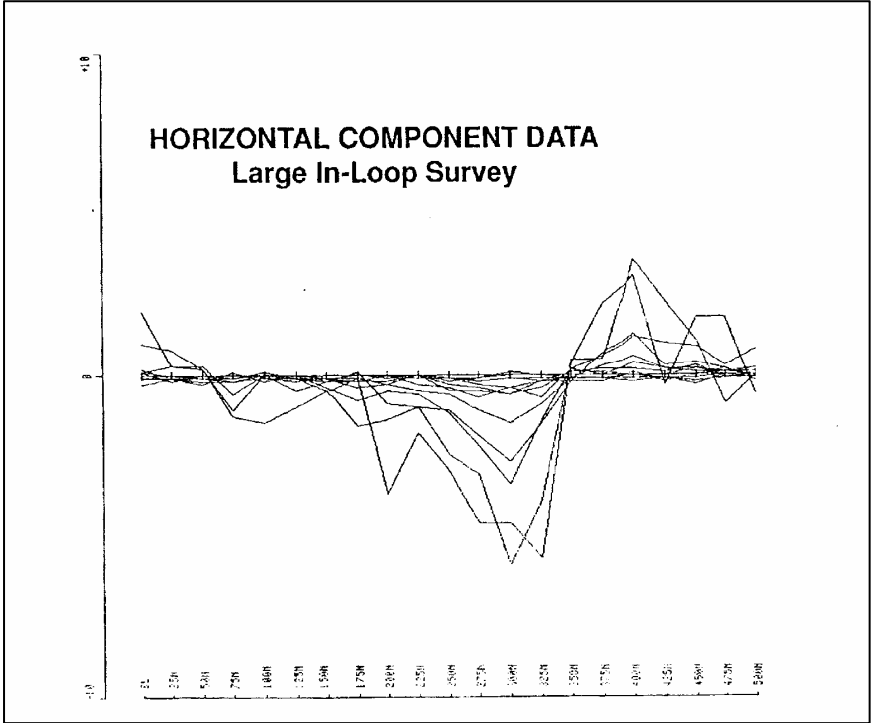
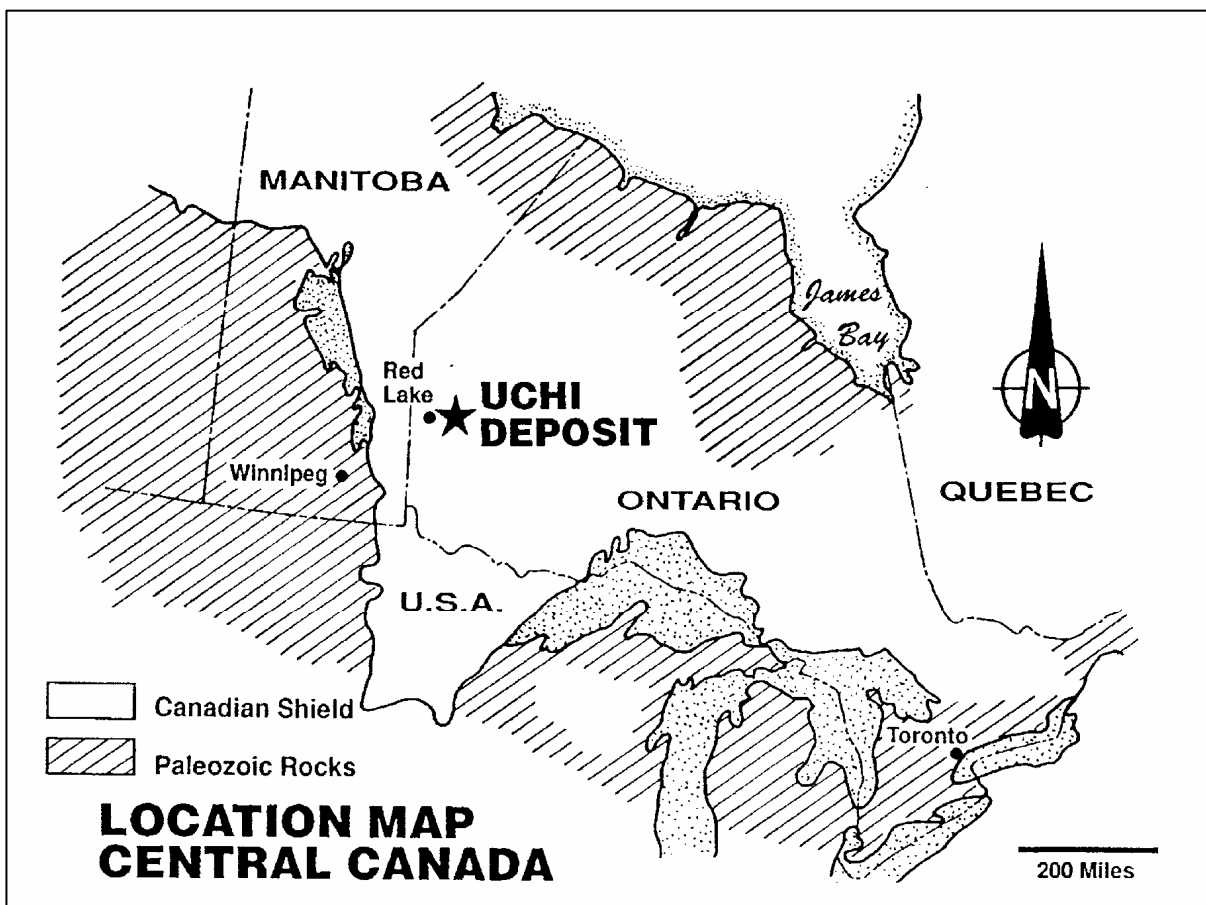
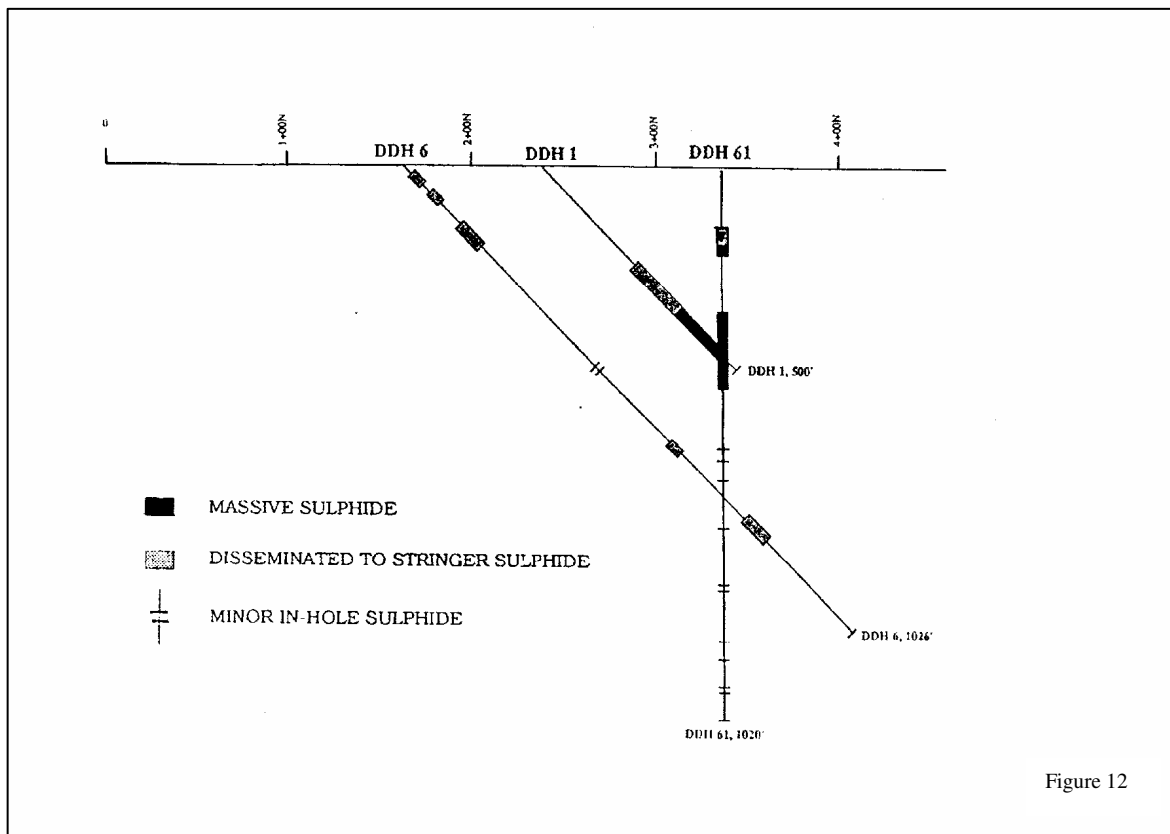


Figure 11



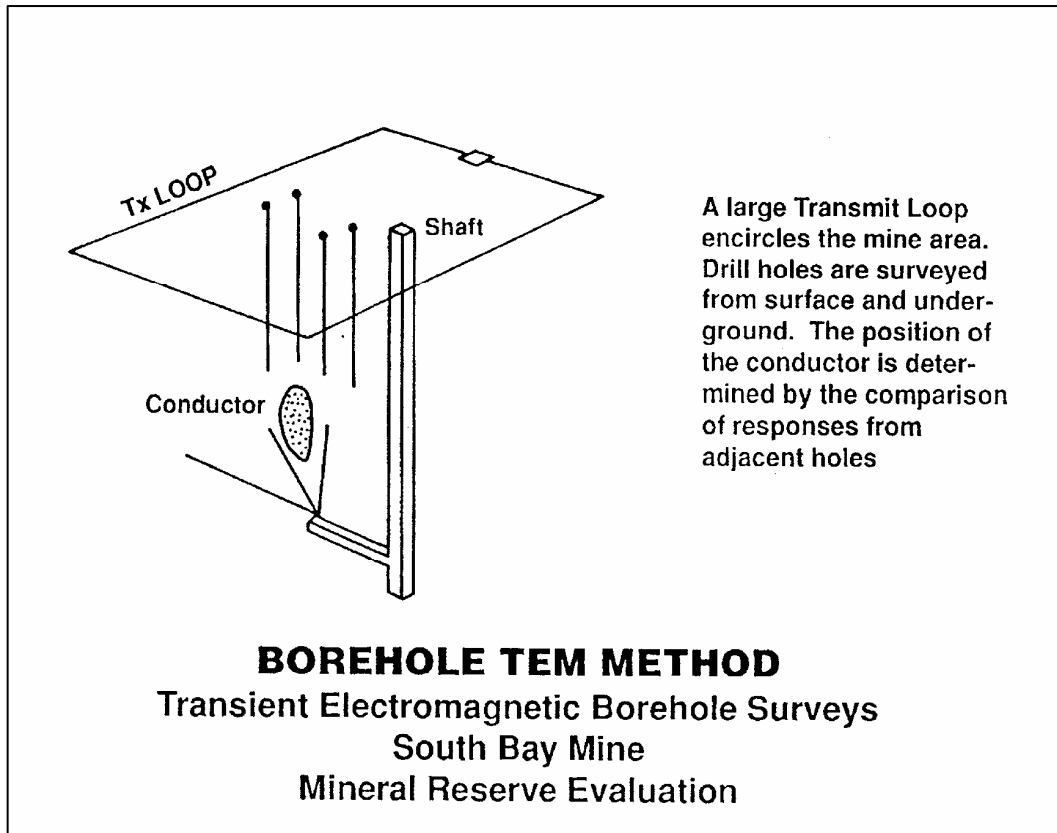


Figure 14

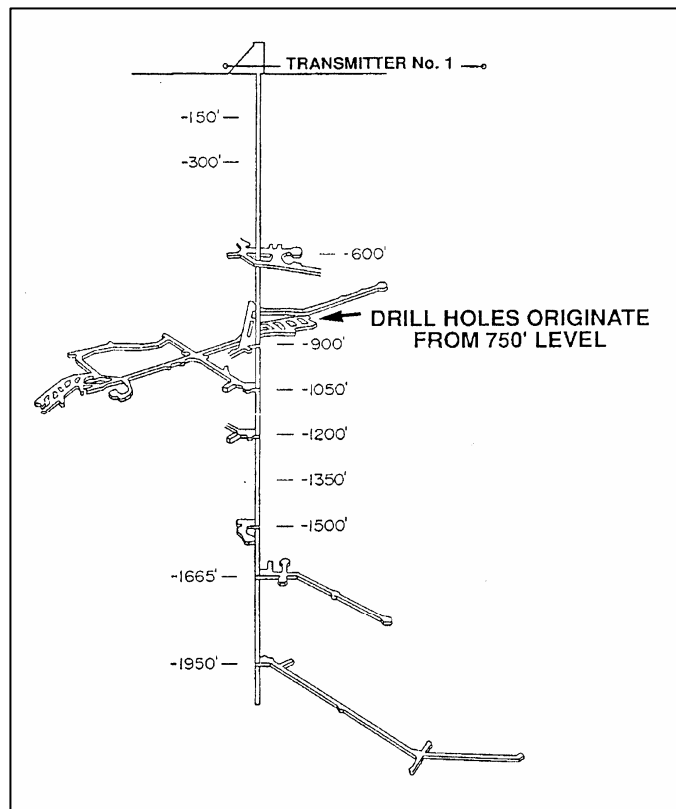


Figure 15

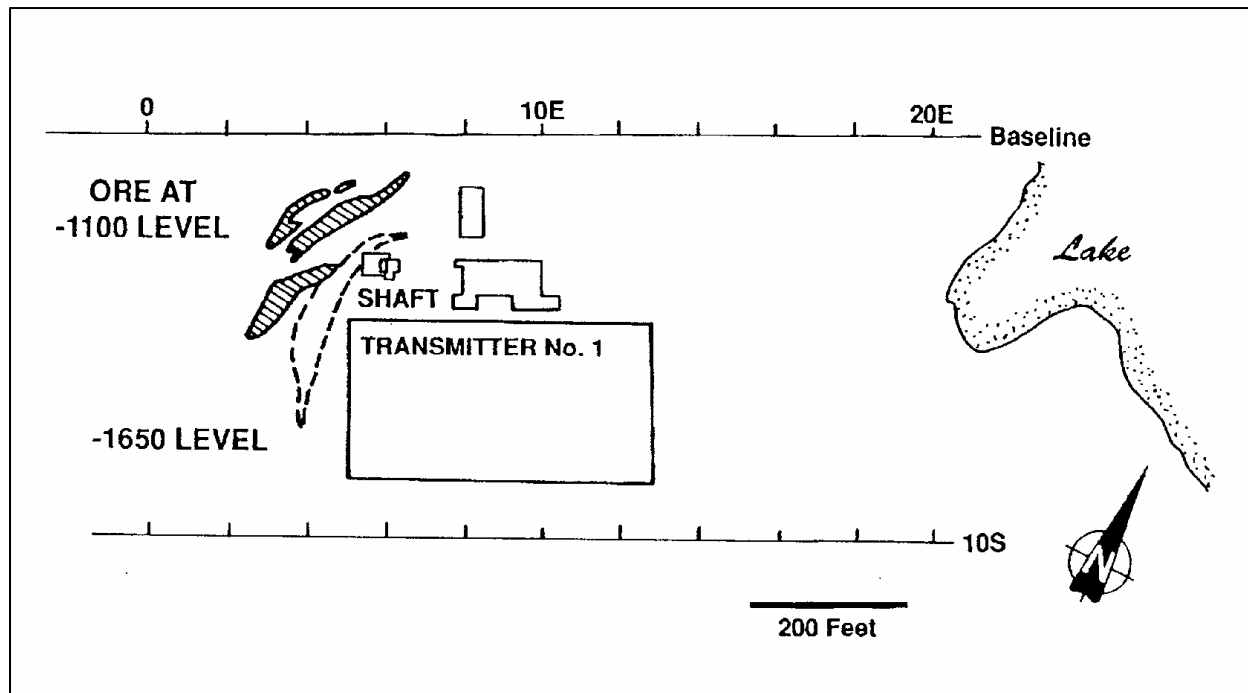


Figure 16

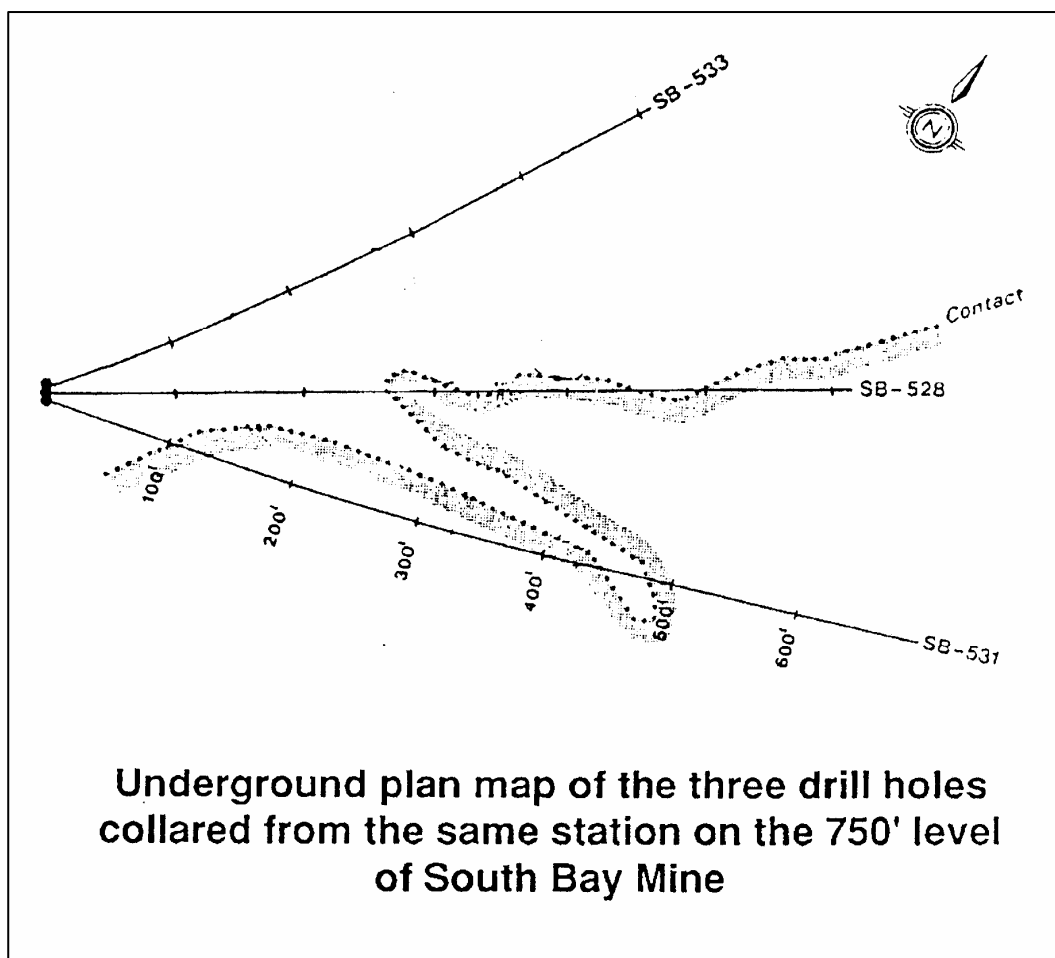


Figure 17

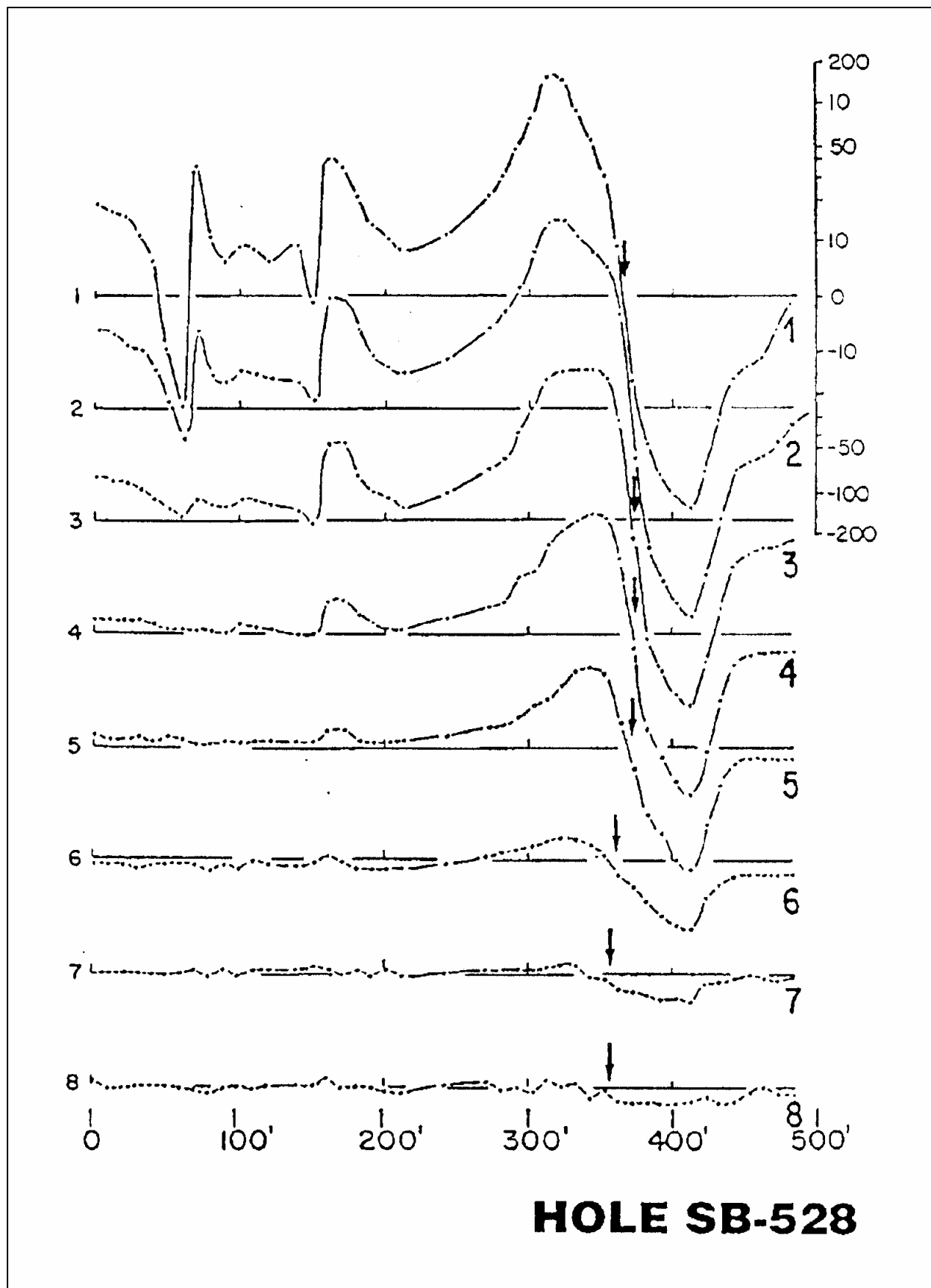


Figure 18

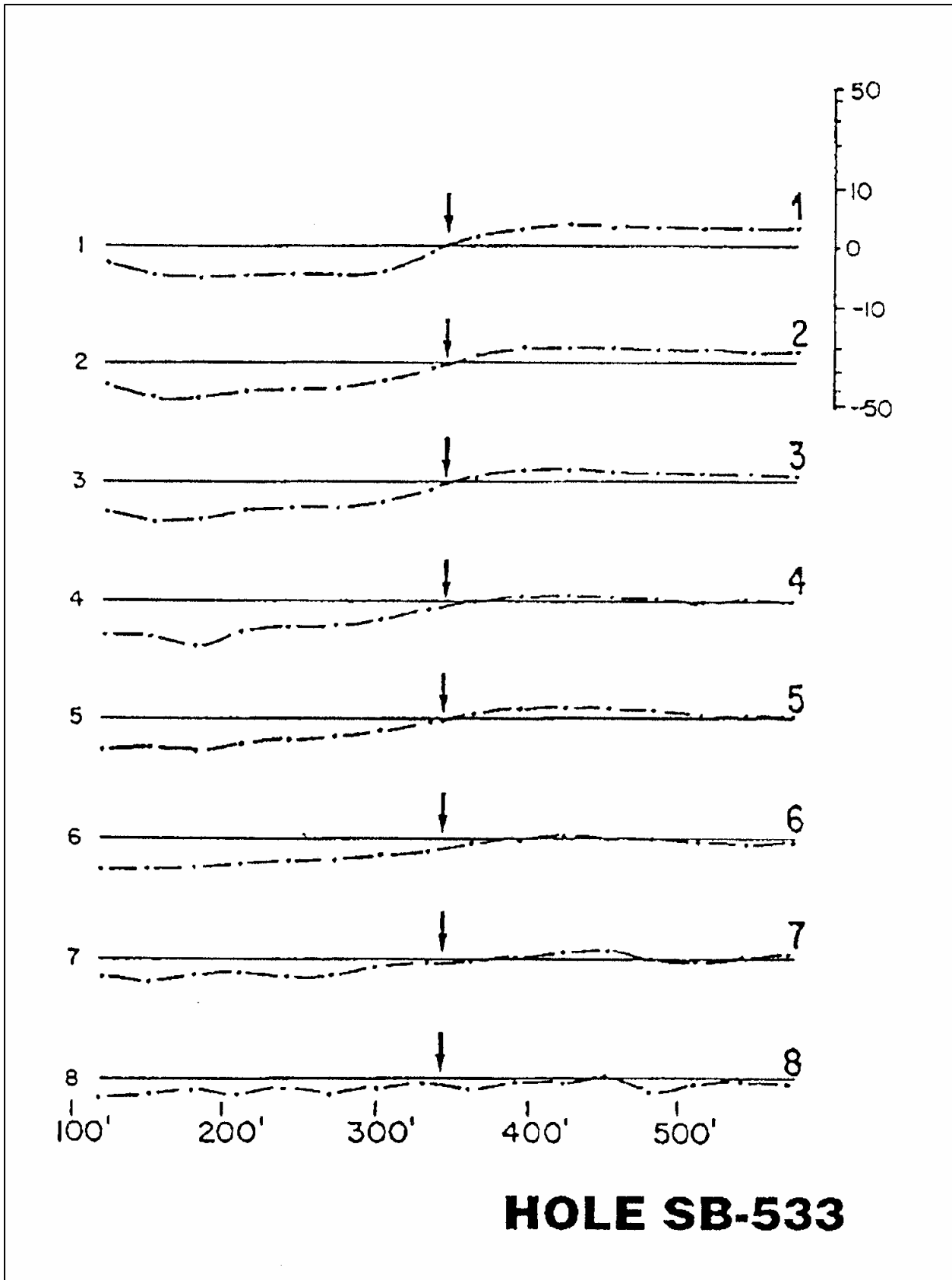


Figure 19

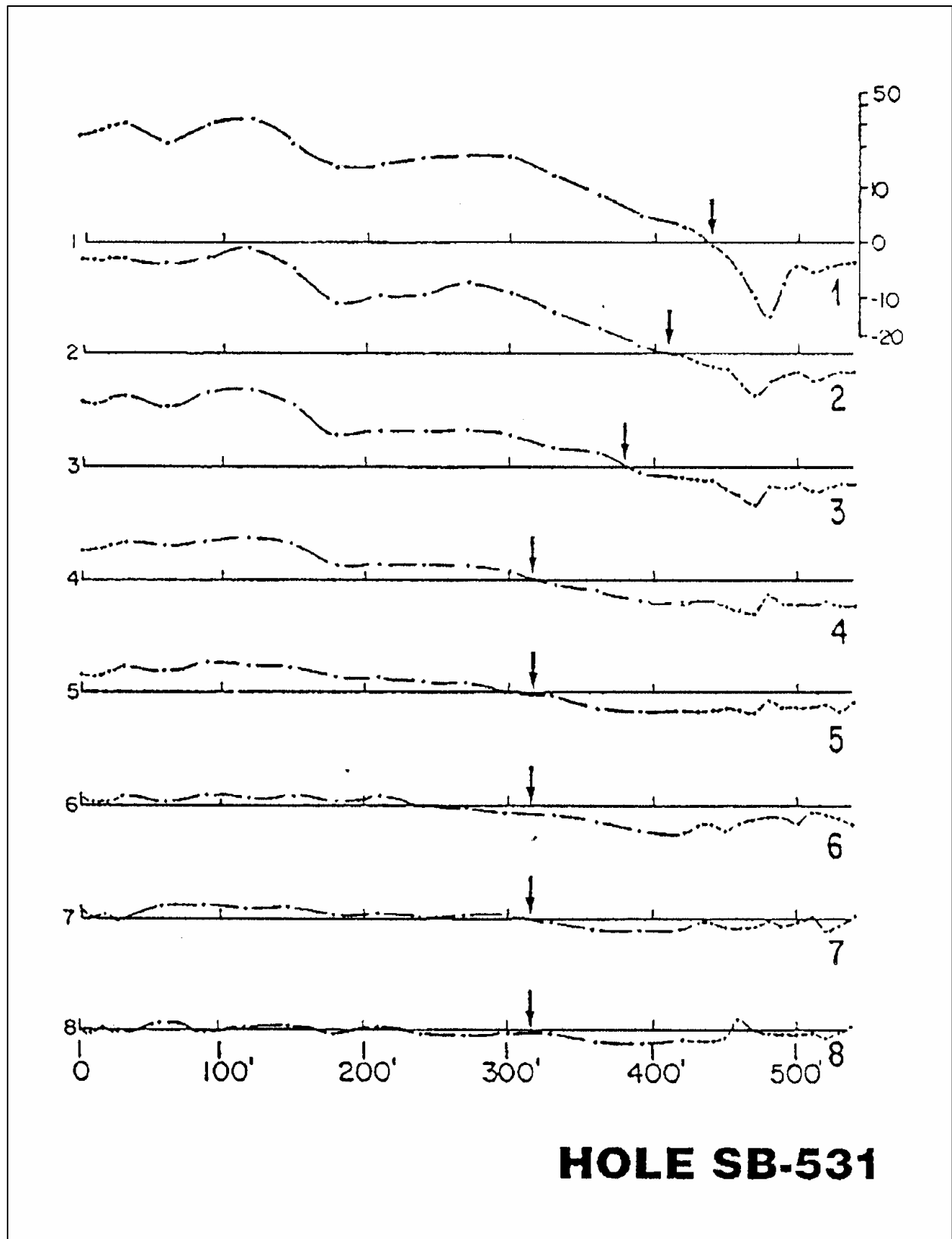
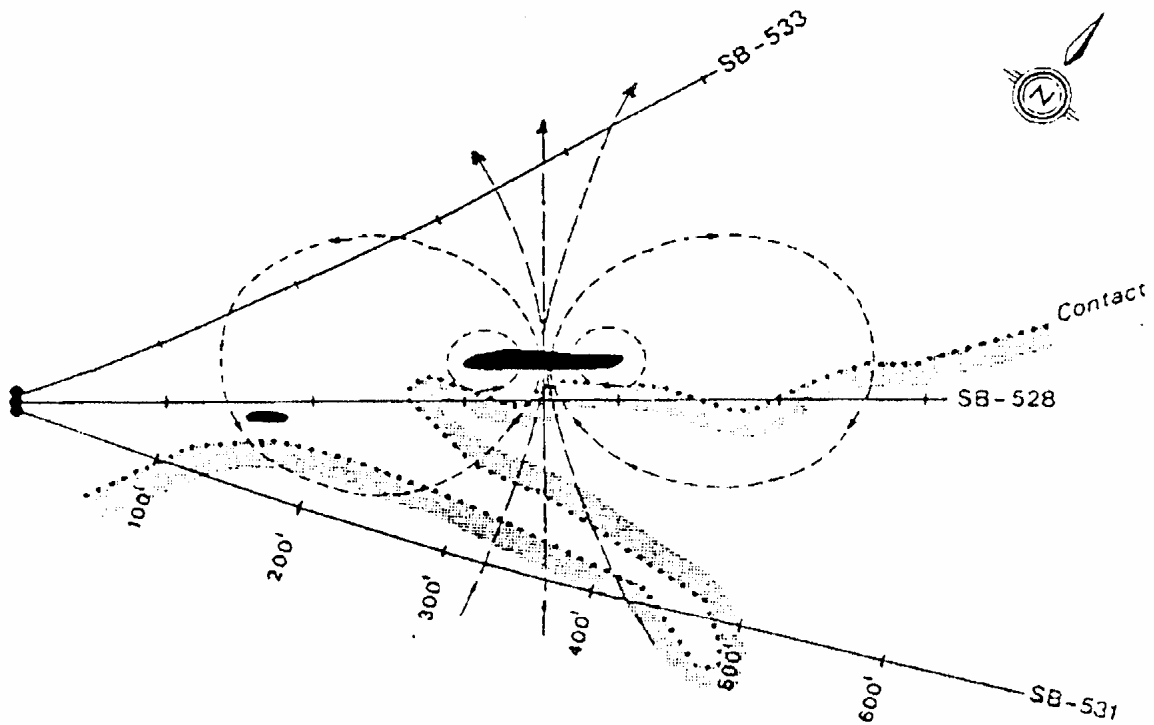


Figure 20



**Interpreted Conductor Location**