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GEOPHYSICAL EXPLORATION AT THE PINE POINT MINES LTD. ZINC-LEAD PROPERTY, NORTHWEST TERRITORIES, CANADA

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Abstract

Pine Point is a zinc-lead carbonate camp with about 40 known orebodies on the south shore of Great Slave Lake, Northwest Territories, Canada. The ore host is a Devonian barrier reef complex. The ore mineralogy consists, in order of relative abundance, of sphalerite, marcasite, galena, pyrite, and occasional pyrrhotite. The gangue consists of dolomite and calcite. Mineralization occurs as open-space filling in tectonically-prepared ground and solution-collapse structures. The area is mostly covered by glacial till and muskeg which averages 15 m in thickness.

In 1963, comparative tests of electromagnetic (EM), self-potential, and induced polarization (IP) methods clearly demonstrated that IP is the most powerful exploration tool for this district. EM is unsuccessful because of poor electrical continuity of the conducting minerals in the orebodies. In subsequent years, extensive induced polarization surveys resulted in the discovery of many of the Pine Point orebodies. The majority produce strong IP anomalies due to subcropping mineralization. There is often little or no coincident resistivity anomaly. The gradient array was commonly used at first, and, subsequently, improvements in instrumentation permitted the use of multiple separation arrays for better target detection and delineation. Exploration case histories and tests are discussed to emphasize particular aspects of exploration in Pine Point with the IP method. Gravity surveys respond to sinkholes and the larger, more massive orebodies. Magnetic surveys produce only weak anomalies from minor pyrrhotite which is sometimes associated with the ore. The seismic reflection method may be helpful in detecting collapse structures but is not a cost effective tool in comparison with the IP method. The background IP geologic noise level is very low but telluric noise is often severe. Careful analysis of the IP data aids in lithologic correlation studies.

Résumé

Pine Point est une région de carbonates minéralisés en plomb et zinc, comprenant environ 40 masses minéralisées situées le long de la côte sud du Grand lac des Esclaves, dans les Territoires du Nord-Ouest au Canada. La roche encaissante est un complexe dévonien de récif barrière. Le minerai se compose, par ordre d'abondance relative, de sphalérite, marcasite, galène, pyrite et parfois pyrrhotine. La gangue consiste en dolomie et calcite. La minéralisation se présente comme un remplissage de fissures dans un terrain fracturé et dans des structures d'effondrement par dissolution. La région est principalement couverte de dépôts glaciaires et de sol de marais, qui totalisent une épaisseur moyenne de 15 m.

En 1963, des essais comparatifs des méthodes électromagnétiques, de polarisation spontanée, et de polarisation provoquée ont montré clairement que la polarisation provoquée est l'outil d'exploration le plus efficace dans cette région. Les méthodes électromagnétiques ne donnent pas de résultats concluants à cause de la faible continuité électrique des minéraux conducteurs dans les corps minéralisés. Dans les années ultérieures, des levés détaillés de polarisation provoquée ont abouti à la découverte de plusieurs masses minéralisées à Pine Point. La plupart d'entre elles ont créé de fortes anomalies de polarisation provoquée, dues aux minéralisations proches de la surface. La désposition des électrodes suivant la méthode du gradient a d'abord été utilisée, puis, avec les perfectionnements de l'appareillage, un mode de disposition des électrodes suivant des lignes multiples a été adoptée, pour mieux déceler et localiser les corps minéralisés. Plusieurs exemples d'exploration et d'essais de prospection sont donner ici pour bien montrer les aspects particuliers de l'exploration pratiquée à Pine Point par la méthode de polarisation provoquée. Les levés gravimétriques enregistrent en particulier la présence de dolines et de corps minéralisés massifs et de grande taille. Les levés magnétiques enregistrent seulement de faibles anomalies dues à la présence de petites quantités de pyrrhotine parfois associée au minerai. La méthode de sismique réflexion peut aider à détecter les structures d'effondrement mais elle n'est pas rentable comparée à la méthode de la polarisation provoquée. Le bruit de fond résultant du milieu géologique est très faible en polarisation provoquée, mais le bruit tellurique est souvent gênant. L'analyse détaillée des données de la polarisation provoquée facilite la corrélation des niveaux lithologiques.

INTRODUCTION

The Pine Point zinc-lead district is located on the south shore of Great Slave Lake in Canada's Northwest Territories, approximately 800 km directly north of Edmonton, Alberta (Fig. 30.1). It is accessible by road and railroad and there is daily air service into the town of Pine Point with a present (1977) population of about 2000. The regional topographic relief is about 50 m and much of the area is swampy.

In 1898, the first few claims were staked by a local fur trader as a result of mining interest generated by prospectors en route to the Klondike gold fields of the Yukon. In 1926, a property examination by the Consolidated Mining and Smelting Company, now Cominco Ltd., revealed a geological similarity to the famous Tri-State zinc-lead district of southeastern Missouri, and an option was secured on some mineral claims. During the late 1940s, a large concession was acquired by Cominco enclosing the known mineralization. In 1951, Pine Point Mines Ltd. was formed to finance exploration on the property. A production decision was finally reached in 1963, after successful negotiations with the federal government for construction of a northern railway.

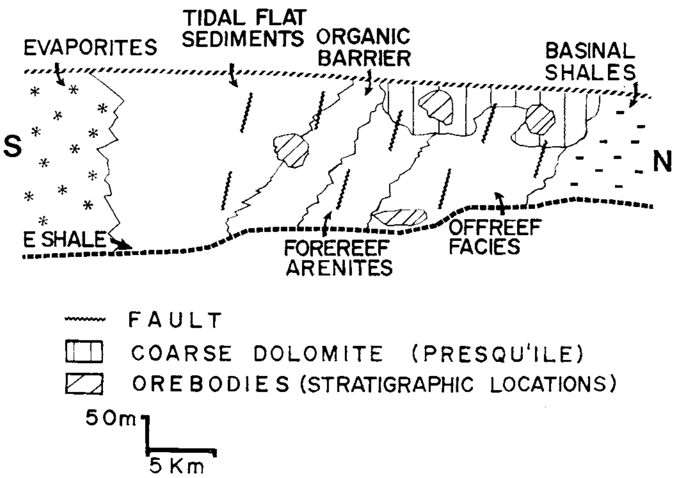

Figure 30.3. *Simplified geological cross-section of barrier complex. Note the exaggerated vertical scale.*

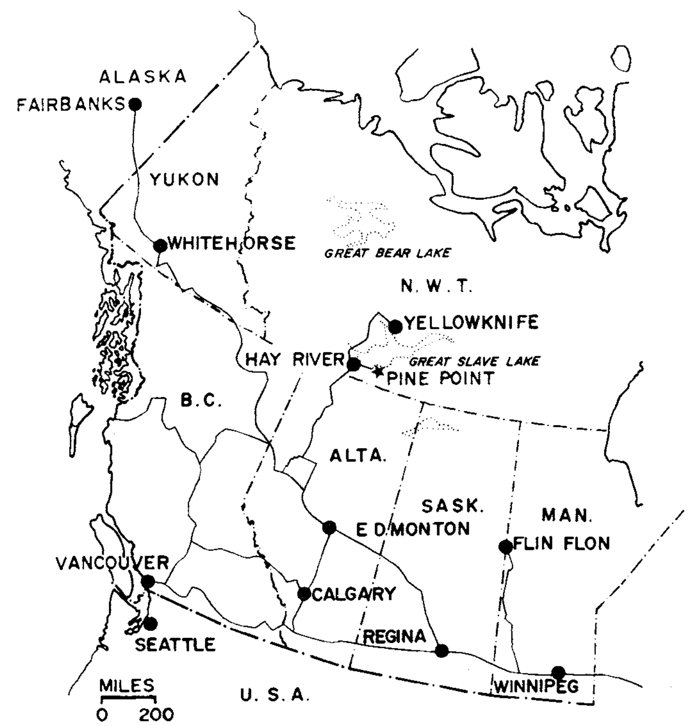

Figure 30.1. *Location map*

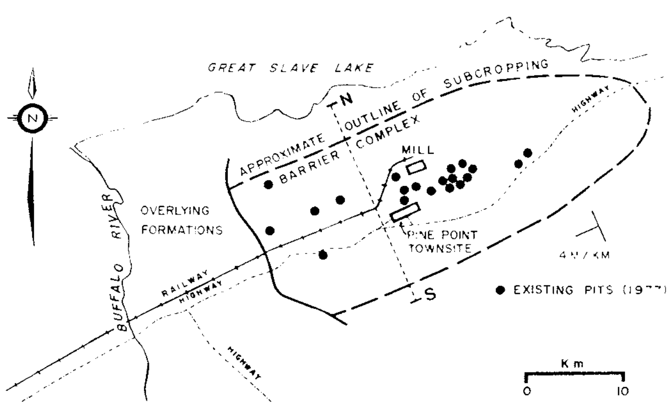

Figure 30.2. *Plan map of barrier complex and mining pits.*

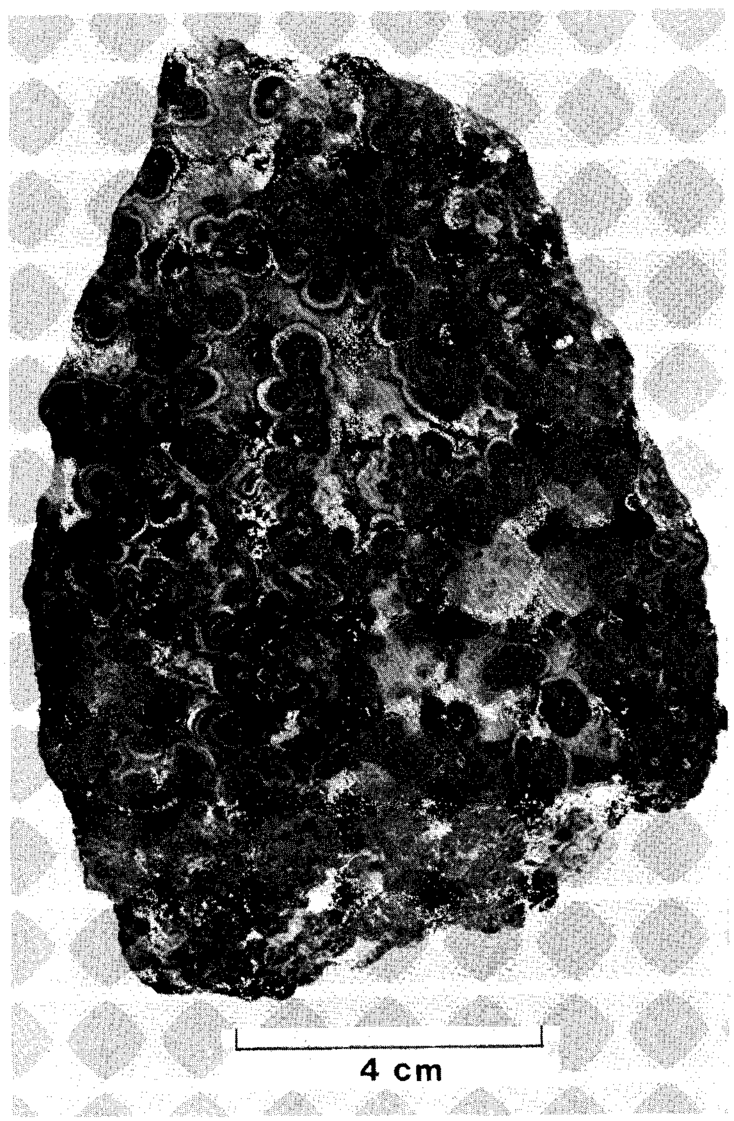

Figure 30.4. *Sample of sphalerite and galena mineralization in a dolomite gangue. (GSC 203492-I)*

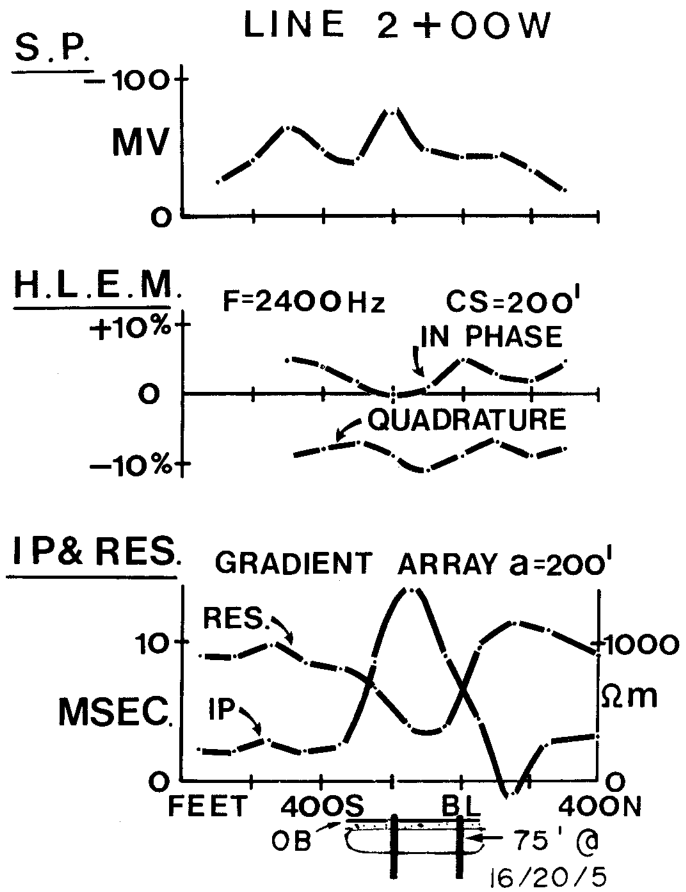

Figure 30.5. *Geophysical test profiles over orebody N-42, line 2+00W, 1963 (Huntec MK 1). Ore grade is in per cent Pb, Zn, and Fe.*

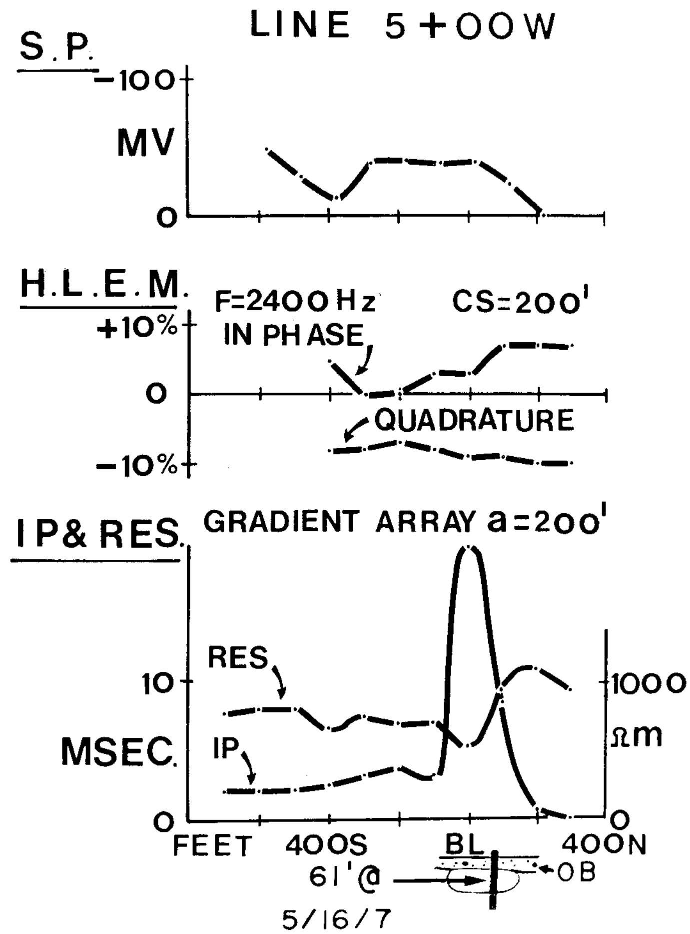

Figure 30.6. *Geophysical test profiles over orebody N-42, line 5+00W, 1963 (Huntec MK 1). Ore grade is in per cent Pb, Zn, and Fe.*

At this time, the company had 8.8 million tons of ore averaging 2.6% lead and 5.9% zinc in several orebodies which had been found by drilling. The induced polarization (IP) method which was first introduced to Pine Point in 1963, played a very important role in discovering more orebodies, and in significantly extending the ore reserves of the district. The total known ore is now about 74 million tons averaging 2.8% lead and 6.3% zinc in about 40 orebodies. About half of this ore has now (1977) been mined, mostly by open pit methods.

Previous articles have presented geophysical survey results in the Pine Point district, mainly IP, using time domain (Seigel et al., 1968; Paterson, 1972) and frequency domain (Hallof, 1972) methods. This paper describes the geophysical work done at Pine Point from an historical perspective, and discusses some geophysical aspects of particular interest.

GEOLOGY

The host of the zinc-lead mineralization is a Devonian barrier reef complex (Skall, 1975) which subcrops (i.e. outcrops below the overburden) on the south shore of Great Slave Lake, approximately as shown in Figure 30.2. The reef strikes east-northeast and dips about 4 metres per kilometre to the southwest, where it is overlain by more recent Devonian formations. The overburden consists of glacial drift and muskeg whose depth varies from about 5 to 30 m with an average of about 15 m over the area. Figure 30.2 shows the location of the pits which now exist on the property. Sulphide mineralization subcropped in all but one of the orebodies shown here.

In cross-section, the reef exhibits the major characteristics of a clastic reef complex as shown in Figure 30.3. The environmental facies encountered from south to north are evaporites, tidal flat sediments, organic barrier, forereef arenite facies, offreef facies, and basinal marine shales. Note that there is a vertical exaggeration of 100 in Figure 30.3. The development of the barrier reef during the Devonian was accompanied by a greater rate of sedimentation in the evaporite basin to the south. This was at least partly responsible for faulting and fracturing within the reef complex, parallel to the strike of the reef. Later, these fractures served as conduits for magnesium-rich fluids which dolomitized parts of the reef to a coarse, vuggy dolomite, referred to locally as the Presqu'ile facies.

The tectonic activity acted as ground preparation for the deposition of Mississippi Valley-type deposits. There is a vast supply of sulphur in the evaporite basin to the south. Sources of metals are postulated to be the basinal shales to the north, the carbonate pile itself, or some other deeper source. Within the reef complex, the porous carbonate rocks allow easy migration of metal brines and sulphur-bearing solutions.

The prime requirement for the formation of the ores is the availability of open spaces in the rock for precipitation of sulphides. At Pine Point, the main causes of open spaces are: a) karsting and solution breccias which developed during marine regressions; b) faulting and fracturing and especially the intersection of fault zones; and c) dolomitization which produces a rock with high porosity. Traps created by pinch outs and facies changes also play a role in ore deposition. Figure 30.3 shows the original stratigraphic positions of four major, partially-eroded, subcropping orebodies.

Most of the orebodies can be subdivided into two basic shapes: massive orebodies which are roughly equidimensional and tend to have a somewhat higher grade, and tabular orebodies which are restricted vertically and extend horizontally either in one horizontal direction (run type) or two horizontal directions (blanket type).

The ore mineralogy is simple. It consists of crystalline and colloform sphalerite, marcasite, galena, pyrite, and occasional pyrrhotite. The zinc to lead ratio averages about two to one, and varies widely for different orebodies. The gangue consists of calcite and dolomite. A typical sample of ore is shown in Figure 30.4, where galena mineralization is surrounded by colloform sphalerite and the gangue is dolomite. A common physical property of the ore is the lack of electrical continuity of the conducting minerals: galena, pyrite and marcasite. In Figure 30.4, the galena is surrounded by sphalerite which is a nonconductive and nonpolarizable mineral. Generally, however, the conducting paths are interrupted by calcite and dolomite gangue. This explains why the orebodies do not respond to standard electromagnetic exploration methods.

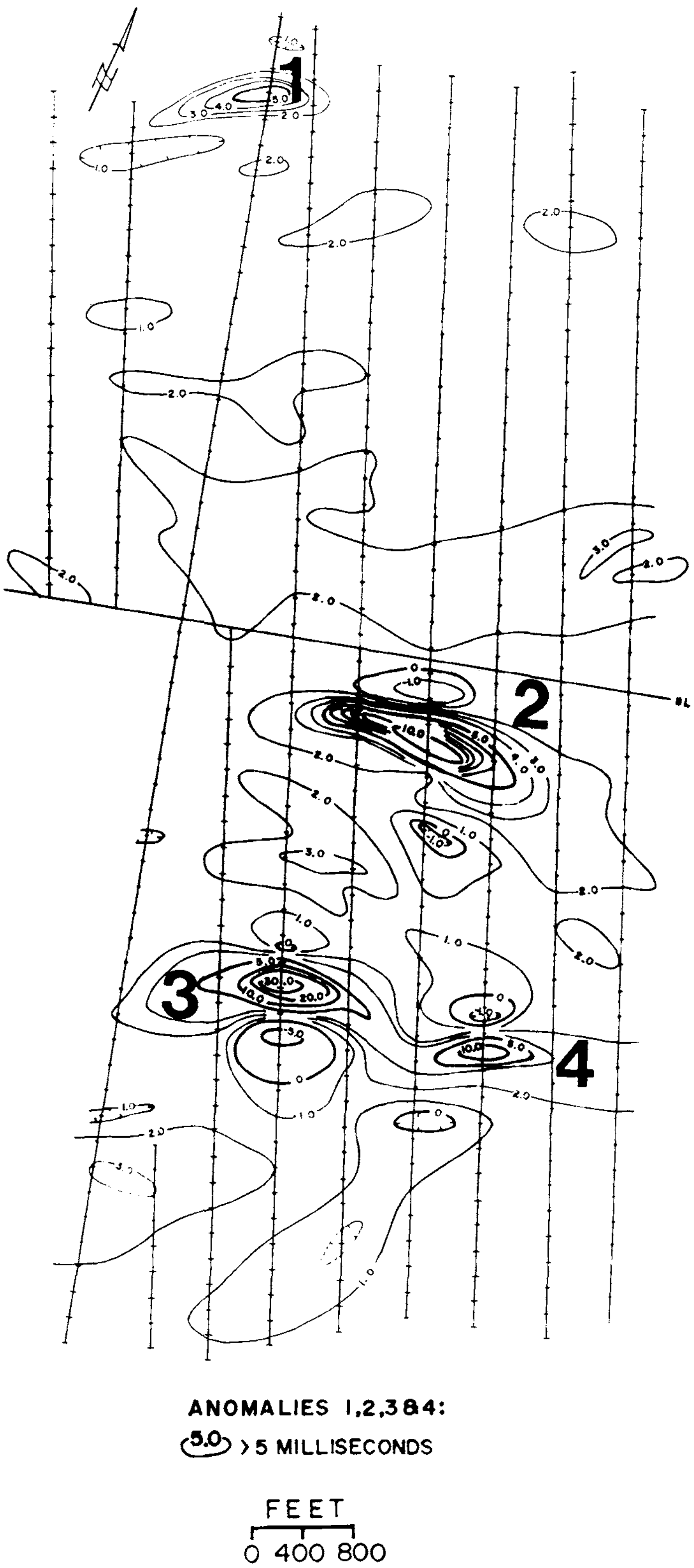

Figure 30.7. *Chargeability contour map of 1964 gradient-array IP survey (Huntec MK 1).*

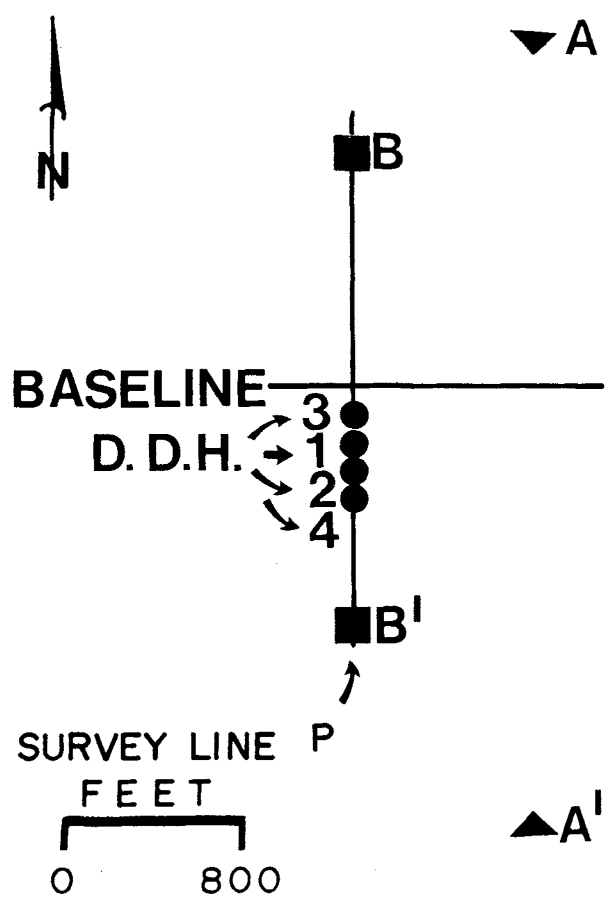

Figure 30.8. *Plan of mineralized holes on line P and positions of current electrodes (AA' and BB') for gradient-array survey on line P.*

GEOPHYSICS

First Geophysical Tests

Comprehensive geophysical tests were performed during the spring of 1963. Hunting Survey Corporation Limited was contracted to carry out tests of self-potential, electromagnetic, and induced polarization geophysical methods over orebody N-42. The results of these tests on two lines three hundred feet (91 m) apart are shown in Figures 30.5 and 30.6. Representative sections through the orebody are drawn to scale at the bottom of these figures. The station interval for the data points is 100 feet (30 m).

The self-potential results shown at the top of Figure 30.5 show moderate activity on both lines. However, there is no anomaly which could be attributed to mineralization.

For the horizontal-loop electromagnetic (HLEM) data, a coil separation of 200 feet (61 m) and a frequency of 2400 Hz were used. There is possibly a weak quadrature anomaly near the base line on line 2W (Fig. 30.5) where a drillhole has a high grade 75-foot (23 m) intersection of 16% Pb/20% Zn/5% Fe. On line 5W (Fig. 30.6) however, there is no evidence of an EM anomaly over the orebody. Further reconnaissance work with EM produced weak anomalies similar to that on line 2W and these correlated well with swampy ground. Seigel (1968) showed Turam results over the Pyramid No. One orebody which confirm the lack of response to electromagnetic methods.

The IP data in Figures 30.5 and 30.6* were acquired using a gradient array with a potential electrode spacing of 200 feet (61 m). It is evident that strong chargeability anomalies coincide directly with the orebody on both lines. The background chargeability level is between 2-3 ms and is remarkably flat; thus, the anomalies are about seven times background. A distinct resistivity low occurs on line 2W where a drillhole shows a combined lead-iron grade of 21%. On line 5W, where the combined lead-iron grade is only about 12%, a weak resistivity anomaly is only barely detectable over the background variations.

Initial High Success Rate

The geophysical test of 1963 marked the beginning of a new exploration era at Pine Point. The following year, about 250 line miles of time-domain gradient-array IP were surveyed. Figure 30.7 shows an example of IP discoveries made during the extraordinarily high success period experienced during 1964. The lines are about 500 feet (152 m) apart. There are four chargeability anomalies with amplitudes greater than 5 ms. Each is caused by an orebody.

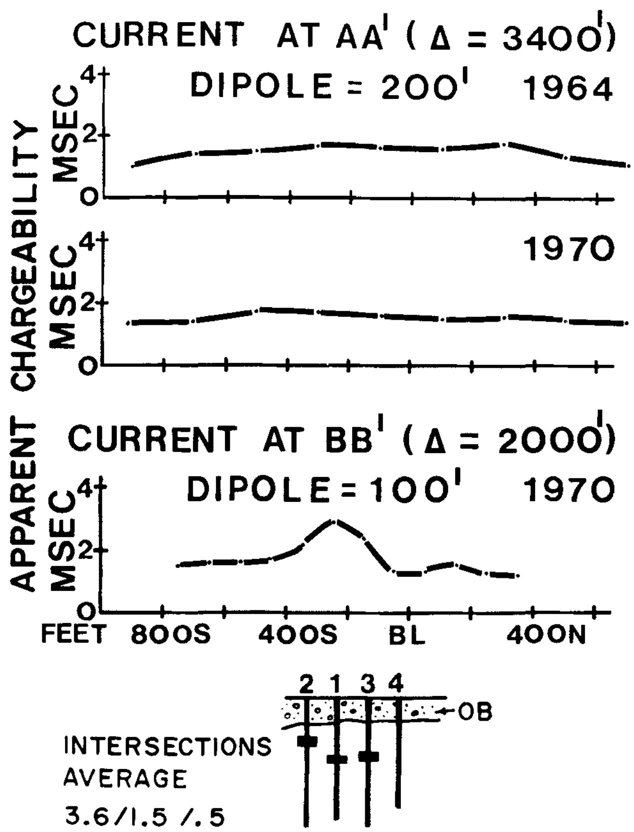

Figure 30.9. *Gradient-array IP profiles obtained in 1964 and 1970 on line P (Huntec MK 1). Δ is the current electrode separation. Grade is in per cent Pb, Zn, and Fe.*

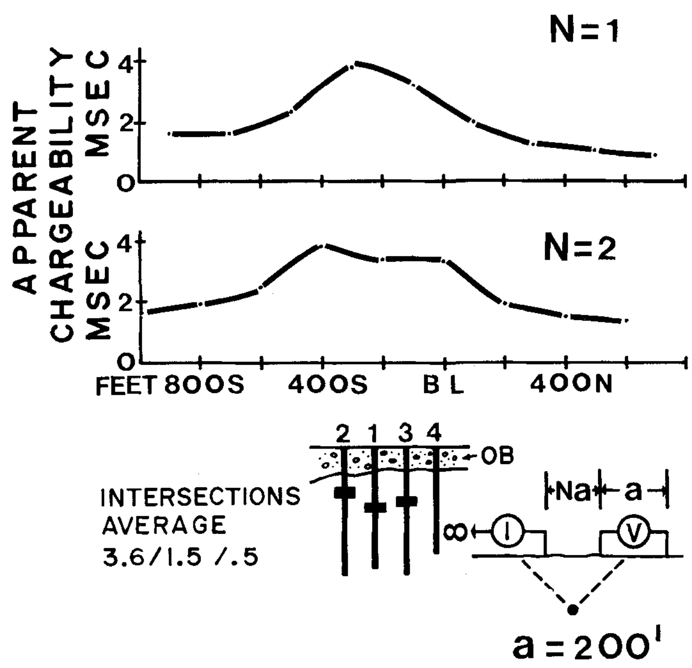

Figure 30.10. *Pole-dipole array IP profiles on line P (Huntec MK 1). Grade is in per cent Pb, Zn, and Fe.*

* In figure captions denoting "Huntec MK 1", the data were acquired with a Huntec MK 1 time-domain receiver which integrates the secondary voltage from 15 ms to 415 ms after cessation of the 2 s ON current pulse. This is then normalized to the received voltage of the current pulse. The chargeability units are therefore mvolts-second per volt or, simply ms. In figure captions denoting "Huntec MK 3", the data were acquired with a Huntec MK 3 time domain receiver which integrates the secondary voltage from 120 ms to 1020 ms after cessation of a 2 s ON current pulse.

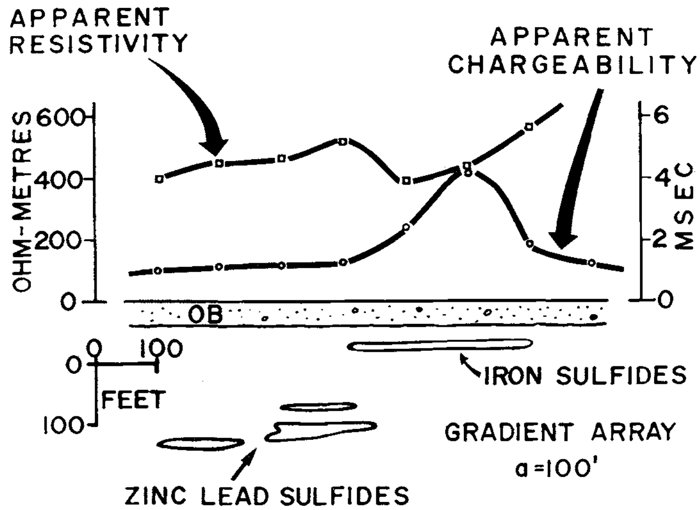

Figure 30.11. Example of an indirect discovery using time-domain IP on line M (Huntec MK-1) showing apparent resistivity and chargeability profiles. OB is overburden.

Note the very low variation in background level of chargeability; this is typical for much of the Pine Point district. The anomaly in the centre of Figure 30.7 is the N42 orebody on which the first IP tests were carried out. It had been previously found by grid drilling. The other three orebodies occurred nearby within areas which had been previously tested with drillholes spaced roughly 1000 feet (305 m) apart. However, none had intersected the orebodies. They were discovered directly as a result of the survey shown in Figure 30.7, actually within a few days of each other.

Advantages of Multi-separation Arrays

The high success rate of the early surveys eventually slowed down with the completion of the drill testing of all obvious anomalies; experimentation then began to determine more diagnostic survey parameters for ore delineation. The following example illustrates a field experiment where the target consisted of short mineralized intersections along line P with grades of about 3.6% Pb/1.5% Zn/0.5% Fe in three holes 100 feet (30 m) apart. They are shown in plan in Figure 30.8 and in section in Figures 30.9 and 30.10. The upper profile in Figure 30.9 is a 1964 gradient-array survey with a potential electrode separation of 200 feet (61 m). The current electrodes were located at A and A', 3400 feet (1034 m) apart and 800 feet (244 m) away from the survey line. There is no indication of an anomaly to hint at the mineralization. As shown in the centre profile, the survey was repeated in 1970, using the identical parameters and the results were essentially the same. For the lower profile in Figure 30.9, the current electrodes were moved to B and B', directly on the survey line, 2000 feet (610 m) apart, and the potential electrode spacing was reduced to 100 feet (30 m). As can be seen on Figure 30.9, this electrode configuration produced a definite anomaly coincident with the mineralization. However, surveying large areas with such small electrode spacings and survey blocks is costly.

Next, a two-separation pole-dipole array was tried with an electrode spacing of 200 feet (61 m). The resultant anomaly shown in Figure 30.10 is stronger and more definite than that obtained with the gradient array. On second separation (N=2), the expected double peaking of the anomaly with the strongest peak on the side of the current electrode can be seen. Such field tests showed that, here at least, multi-separation arrays are better focused for the detection of weak mineralization than the gradient array. Also, they make it easier to interpret the depth and the lateral limits of polarizable sources. The multi-separation arrays became practical with improvements in instrumentation in both time domain and frequency domain methods, which allowed measurements of the lower signal levels at higher separations.

Example of an Indirect Discovery

The examples previously discussed demonstrate the ideal one-to-one correlation between IP anomalies and economic mineralization. Actually, during the initial 1963 and 1964 surveys, such correlation was very common and everyone expected the first hole drilled into an anomaly to intersect an orebody. In some cases, however, IP anomalies led to discoveries indirectly and this section describes an example of this.

In Figure 30.11, the iron sulphides nearly subcrop whereas the zinc-lead sulphides are deeper. The data on line M are from a gradient-array IP survey with a potential electrode spacing of 100 feet (30 m). A weak but definite anomaly coincides directly with the iron sulphide mineralization. The first drillhole confirmed the source of this anomaly. However, due to favourable geological indicators, drilling continued and economic mineralization was eventually found. Careful analysis of the detailed IP data can aid in guiding drilling in the search for hidden economic mineralization.

IP Anomaly Over a Small, Massive, Shallow Orebody

The larger orebodies at Pine Point may be discovered relatively easily with multi-separation IP surveys, especially if they are at or near subcrop. The smaller orebodies, however, offer a little more challenge and this example illustrates the discovery of a small massive-type orebody which is a very difficult drill target. On a property the size of Pine Point, there are many drillholes with interesting intersections of mineralization and it is difficult to decide which ones to follow-up first. Diamond-drill hole (DDH) A

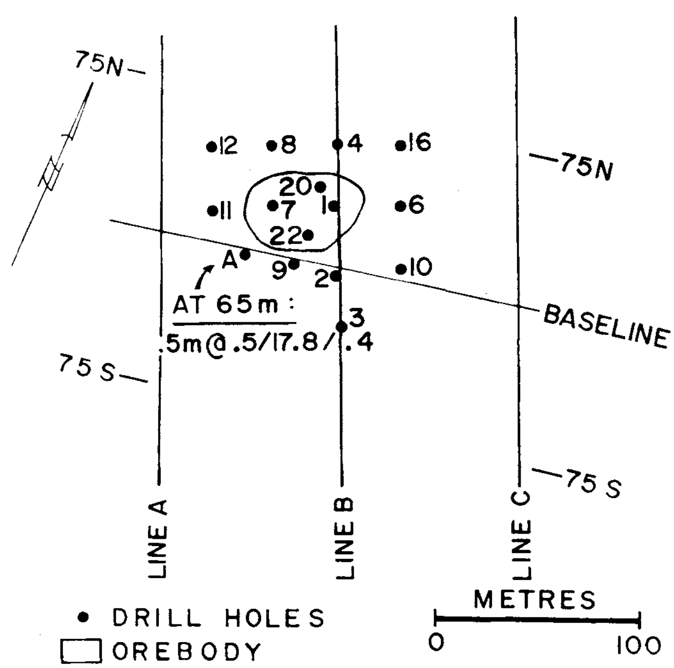

Figure 30.12. Plan of orebody R, drillholes, and IP lines.

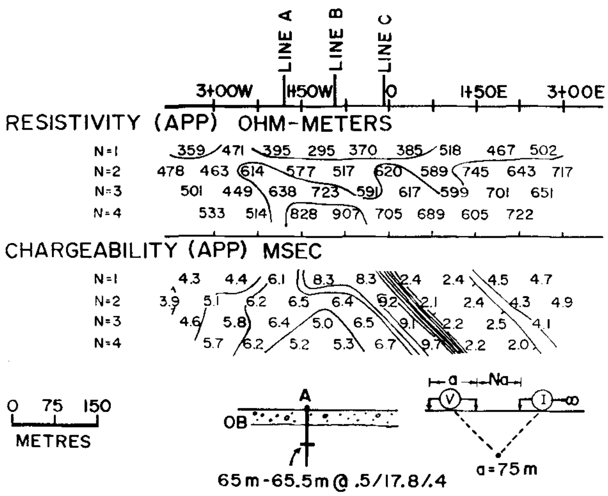

Figure 30.13. *IP-resistivity data obtained on baseline of orebody R using pole-dipole array (Huntec MK 3). Grade is in per cent Pb, Zn, and Fe.*

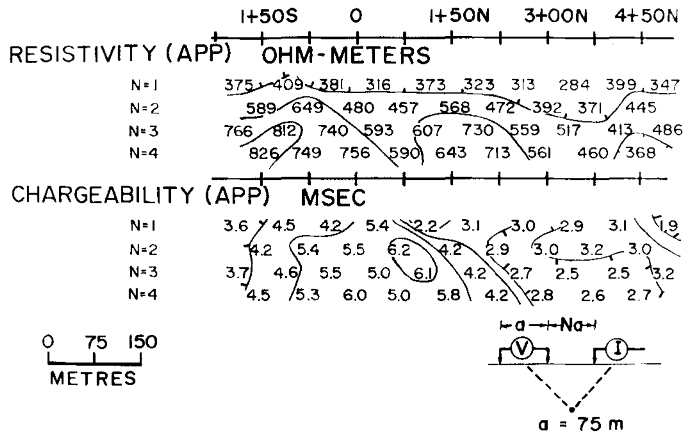

Figure 30.15. *IP-resistivity data obtained on line C of orebody R (Huntec MK 3).*

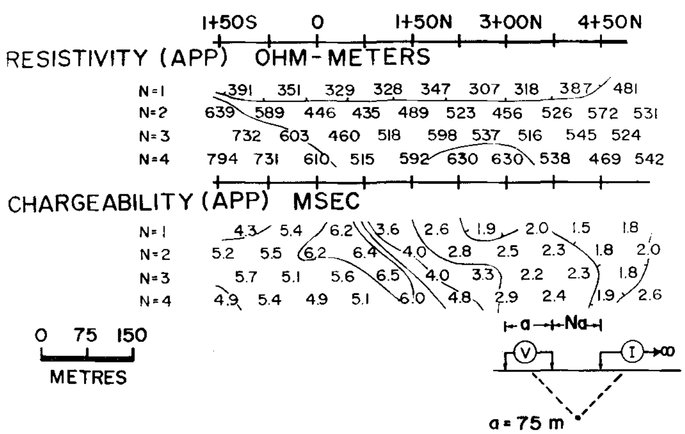

Figure 30.14. *IP-resistivity data obtained on line A of orebody R (Huntec MK 3).*

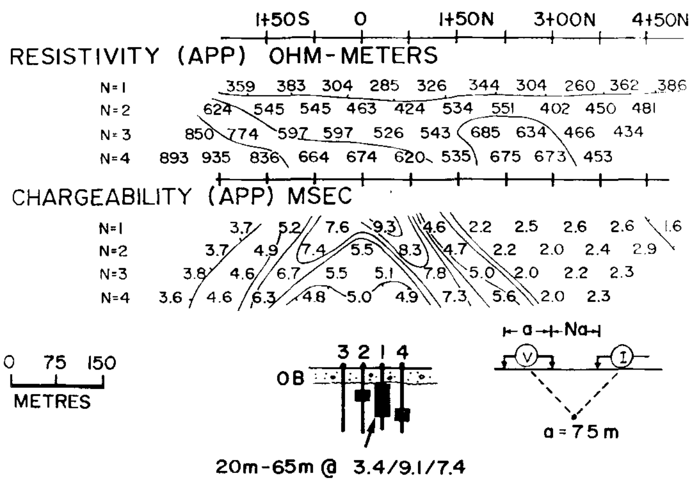

Figure 30.16. *IP-resistivity data obtained on line B of orebody R (Huntec MK 3). Grade is in per cent Pb, Zn, and Fe.*

located near orebody R as shown in Figure 30.12 is typical. At a depth of 65 m, it intersected 0.5 m with a grade of 0.5% Pb/17.8% Zn/0.4% Fe. The base line was surveyed with a pole-dipole IP array and the results are shown in Figure 30.13 in pseudosection form. The pole (moving current electrode) is to the right and the electrode spacing is 75 m. The top pseudosection shows apparent resistivity data while the bottom shows the apparent chargeability data. DDH A with its intersection is shown at the bottom of Figure 30.13. An IP anomaly is evident and it has a few important characteristics. First, the shape of the anomaly indicates a shallow source. However, the strongest chargeabilities do not occur on first separation (N=1) as might be expected. Instead, the strongest chargeabilities occur at separations of N=2, 3 and 4, on the pole-side "pant-leg" of the anomaly, the highest being 9.7 ms. Second, the mineralized intersection in DDH A does not explain the high chargeabilities of over 9 ms. Third, the centre of the anomaly is displaced from DDH A. An anomaly with these characteristics, that is, a shape indicating a shallow source but with the strongest chargeabilities occurring on higher separations, is recognized as evidence of a subcropping body of polarizable material which is just off the survey line to one side or the other.

Subsequently, lines A, B, and C which are about 100 m apart, were surveyed. Figure 30.14 shows the data obtained on line A. There is an apparent chargeability high of greater than six ms in a background of about two ms and it has a poorly developed anomaly shape. The anomaly is centred just north of the baseline.

Figure 30.15 shows the IP-resistivity data obtained on line C. The results are similar to those obtained on line A, that is, a broad region of moderate chargeability with the highest readings on second and third separations. Figure 30.16 shows the IP-resistivity data obtained on line B, the centre line. This is a typical Pine Point IP anomaly over subcropping mineralization with the pole-dipole array. The anomaly shape indicates a shallow source with the strongest chargeability value occurring on first separation, on the pole side, and with the chargeability amplitudes decaying down each "pant-leg" of the anomaly from 9.3 to 7.3 ms. Note that there is no significant apparent resistivity anomaly coincident with the IP anomaly on this line. It is apparent that line B passes directly over the polarizable source. DDH 1 intersected 45 metres of mineralization grading 3.4% Pb/9.1% Zn/7.4% Fe at subcrop. Subsequent drilling outlined a small but high grade orebody whose horizontal dimension along line B was less than 60 m.

An example such as this shows that IP is a very practical tool for finding orebodies of small lateral dimensions at Pine Point. Geological exploration through drilling is useful to define areas of good potential. However, when it comes to pinpointing the target for drilling, IP is the more cost-effective exploration tool.

Example of Lithologic Correlation

So far, the discussion has been mainly concerned with the location of IP anomalies and their subsequent drilling to discover economic mineralization. Another use for the geophysical data is in lithologic correlation studies. Figure 30.17 shows a pseudosection of apparent resistivity, chargeability, and metal factor* data on line N. A pole-dipole array was used, the pole being to the north. The electrode spacing was 75 m. One can easily pick out two different regions from these data. In the northern half of the section, both the apparent resistivity and chargeability data appear to indicate a two-layer earth, while, in the southern half, a halfspace appears to be a more appropriate model. In the northern region, there is a good positive correlation between the apparent resistivity and chargeability data which would lead one to suspect that the variations observed in these data are due to the same geological units. Because of this positive correlation, the metal factor data acts as a filter of the layer effect.

In the northern region, an average of the apparent resistivities and chargeabilities from A to B, denoted in Figure 30.17, for each separation, yields the values shown in Figure 30.18. Figure 30.18 also shows a simple two-layer resistivity and chargeability model which gives a reasonable fit with the observed data. The thickness of the top layer in the numerical model is 80 m.

A correlation with drillhole information (Fig. 30.19) shows that the high resistivity and chargeability layer may be explained by a facies which could be described as a fine, sucrosic, and argillaceous dolomite with poorly developed bedding. The high resistivity is most likely the result of poorer permeability and the higher chargeability is probably a function of the clay and iron content in this facies.

Limits of Detectability and Usefulness of the Induced Polarization Method in Pine Point

The following two examples demonstrate the limits of detectability of the IP method at Pine Point.

In the first, hole no. 1 (Fig. 30.20) was drilled in an area of favourable geology and intersected 56 feet (17 m) grading 3.5% Pb/6.4% Zn/7.6% Fe at a depth to top of 203 feet (62 m). However, 16 more holes were drilled on a grid of 100 feet (30 m) and no sulphides were intersected. A 4-separation pole-dipole IP survey was carried out on line L and the data presented in Figure 30.21, with the drill intersection shown at the bottom. The background in chargeability is about 1.8 ms and a weak anomaly with a peak of 2.8 ms, only 1 ms above background, occurs on second separation. Note that the contour interval is only 0.25 ms. From the shape and amplitude of this anomaly, one can safely conclude that it is caused by the mineralization found in DDH 1 at a depth of 200 feet (61 m). This is a good field example for demonstrating how small a target can be detected at moderate depths in areas of very low background variations in chargeability.

The second example demonstrates how the effectiveness of the IP method drops off completely when the orebody contains no significant amounts of the conducting minerals – galena, marcasite, and pyrite. Figure 30.22 shows an IP and apparent resistivity pseudosection over a "run-type" orebody which passes under line S and consists mostly of sphalerite which does not produce an IP effect. The electrode interval chosen for this test survey was only 25 m in an attempt to optimize the detection and resolution of this shallow orebody which is at a depth of 30-40 m. There is no anomaly coinciding with the ore zone. This can be explained by the grade of combined conducting sulphides of lead and iron which is only about 1.3%, and not significantly anomalous in this particular area of the property. Thus the only possibility of mapping the extension of the ore zone is by studying its relation to patterns in the goephysical data.

The Gravity Method

After IP, the next logical geophysical tool to use is gravity. Seigel (1968) quoted densities of 2.65 and 3.95 gm/cc for the host limestone and ore in the Pyramid orebody. There has been no attempt to further establish rock densities, however, because of the widely varying relative amounts of sphalerite, galena and pyrite from one orebody to the other. The densities of these minerals are 3.7, 7.5 and 5.0 respectively. Also, the degree of porosity can vary significantly in the host rock in the vicinity of an orebody. The following examples will attempt to show the advantages and limitations of the gravity method.

Figure 30.23 shows the residual Bouguer gravity and IP data over orebody A. There is a chargeability anomaly of about 10 ms above background within a broad region of low apparent resistivities of about 100 ohm-metres. Coincident with the IP high is a residual Bouguer gravity anomaly of 0.5 mgals. There is obviously very little doubt that these anomalies are due to underlying mineralization. One of the most interesting holes drilled on this orebody intersected 72 feet (22 m) of ore grading 8.9% Pb/17.5% Zn/13.4% Fe. Orebody A has 3.5 million tons of ore grading 4.2% Pb and 9.5% Zn. This example illustrates that gravity data form an excellent complement to the IP data. The gravity method responds not only to the conductive ore minerals but also to sphalerite and may therefore indicate concentrations of zinc ore which do not show up on the IP data.

Figure 30.24 shows IP and gravity data over a sinkhole on line U. Sinkholes occur very frequently at Pine Point and are usually filled with sand, gravel, granite boulders, and limestone breccia whose average density might therefore be expected to be less than the host limestones and dolomites. This sinkhole is characterized by a moderate chargeability anomaly of about 4 ms above background and resistivity anomaly of 200 ohm-metres below background. The residual gravity data show a weak negative anomaly of 0.4 mgals. Two holes did not intersect solid bedrock after drilling about 150 feet (46 m) in an area where the overburden thickness is known from nearby drilling to be about 40 feet (12 m).

The last two examples suggest that it is entirely logical to conclude that, given an IP anomaly, a coincident positive gravity anomaly indicates mineralization while a negative gravity anomaly indicates a sinkhole. Figure 30.25 demonstrates the danger of being restricted by any model,

* Metal factor is defined herein as apparent chargeability divided by apparent resistivity, multiplied by 1000.

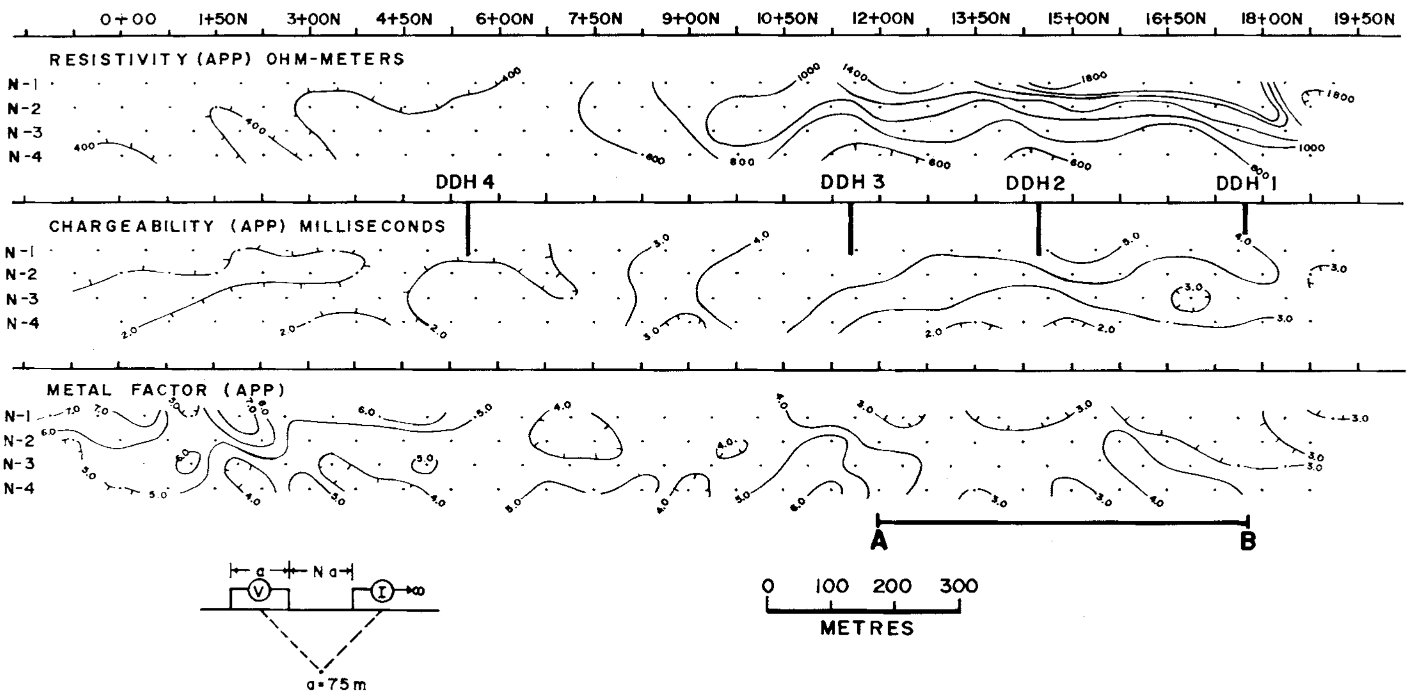

Figure 30.17. IP-resistivity data obtained on line N (Huntec MK 3).

(NORTH HALF)

		SEPARATION	OBSERVED AVERAGE (AtoB)	TWO-LAYER MODEL
APPARENT RESISTIVITY (OHM-METERS)		N = 1	1635	1635
		N = 2	1105	1115
		N = 3	850	795
		N = 4	625	640
APPARENT CHARGEABILITY (MSEC)		N = 1	4.5	4.6
		N = 2	3.9	3.8
		N = 3	3.1	3.0
		N = 4	2.4	2.5

TWO-LAYER MODEL

ρ_1 = 2000 Ω m, m = 5 MSEC, 80 m

ρ_2 = 475 Ω m, m = 2.1 MSEC

Figure 30.18. Model fitting of IP-resistivity data obtained on line N.

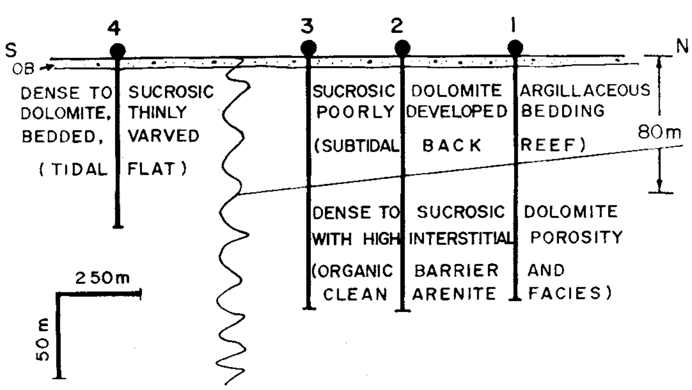

Figure 30.19. Geological cross-section of line N.

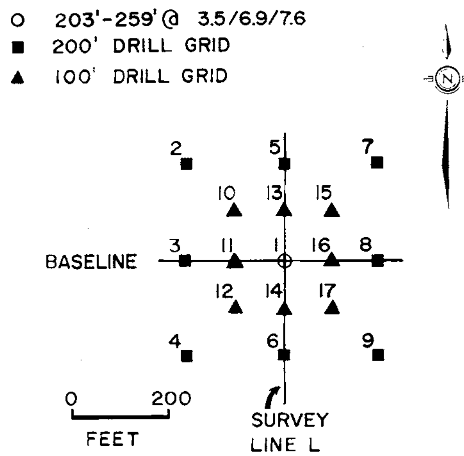

Figure 30.20. Plan of drillholes in the vicinity of line L.

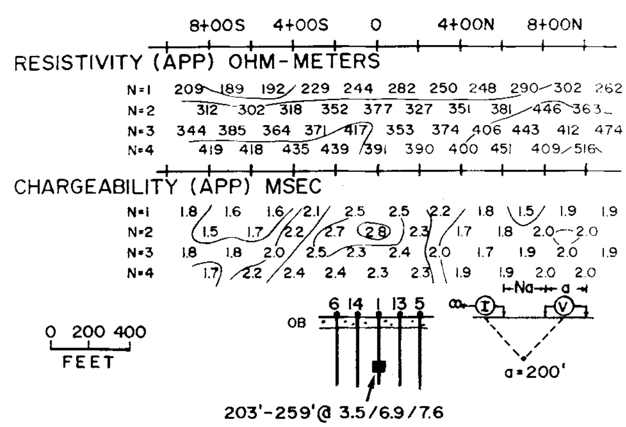

Figure 30.21. Time-domain IP-resistivity data on line L over deep and localized mineralized intersection (Huntec MK 3). Grade is in per cent Pb, Zn, and Fe.

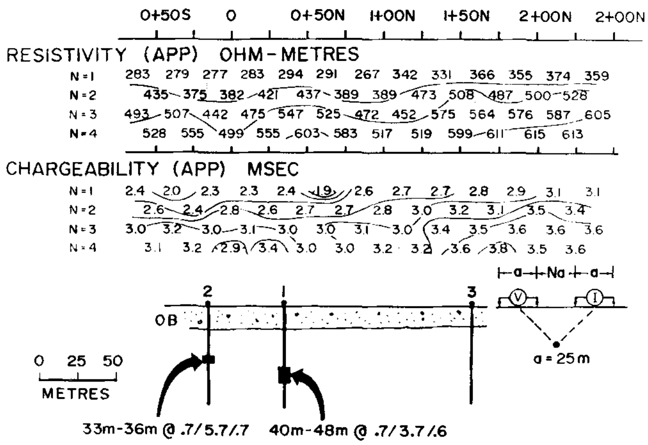

Figure 30.22. *Time-domain IP-resistivity data on line S over run-type orebody consisting mostly of sphalerite (Huntec MK 3). Grade is in per cent Pb, Zn, and Fe.*

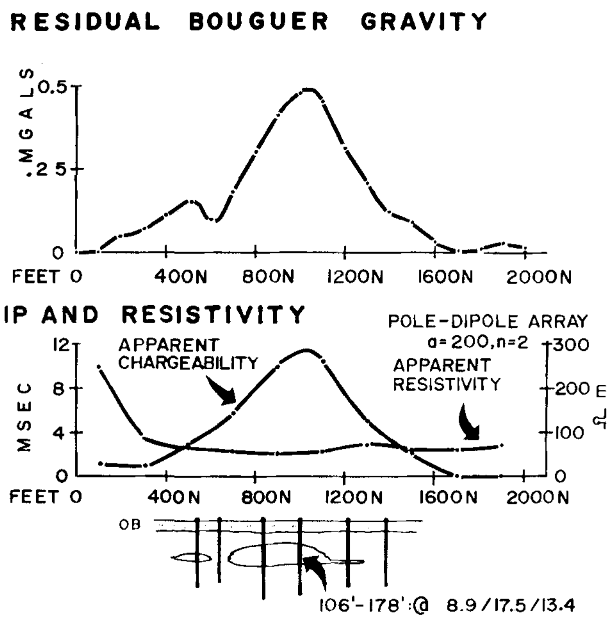

Figure 30.23. *Time-domain IP-resistivity and Bouguer gravity data over orebody A (Huntec MK 1). Grade is in per cent Pb, Zn, and Fe.*

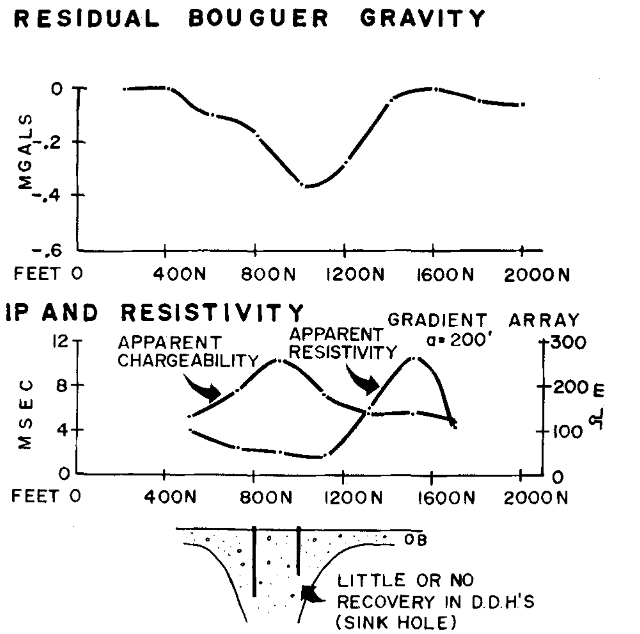

Figure 30.24. *Time-domain IP-resistivity and Bouguer gravity data over a sinkhole on line U (Huntec MK 1).*

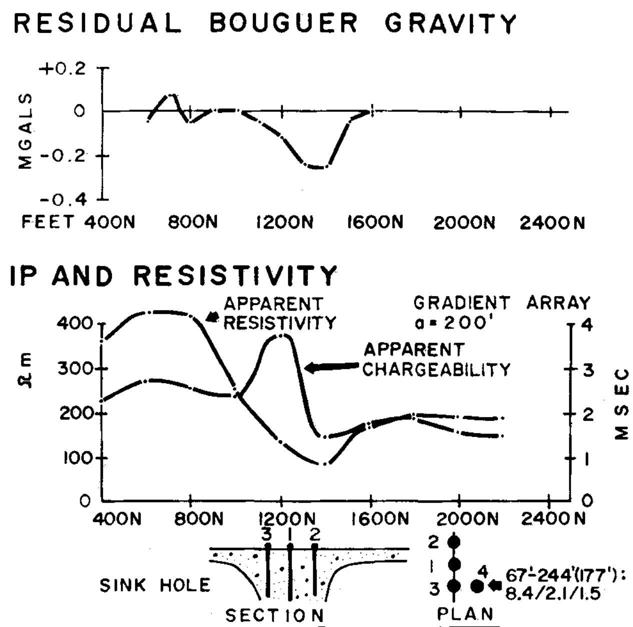

Figure 30.25. *Time-domain IP-resistivity and Bouguer gravity data over a sinkhole and nearby orebody W (Huntec MK 1). Grade is in per cent Pb, Zn, and Fe.*

even one as simple as that just described. In Figure 30.25, there is a chargeability anomaly of about 2 ms above background, a resistivity anomaly of about 300 ohm-metres below background and a negative residual gravity anomaly of 0.2 mgals. As might be expected, the three drillholes shown in section intersected sinkhole material down to about 150 feet. Drillhole no. 4, however, shown in plan view and only 100 feet (30 m) to the east of the other three, intersected 177 feet grading 8.4% Pb/2.1% Zn/1.5% Fe. Further drilling outlined a small orebody adjacent to the sinkhole. The drilling was guided by that part of the chargeability anomaly which was intermediate in amplitude between background and the peak over the sinkhole in the remainder of this survey area. Actually, in this case, the gravity data were acquired on a test basis after all drilling was completed.

A moderate amount of exploration experience using gravity has shown that most anomalies were due to varying overburden thickness. Therefore, to be truly effective, gravity surveying should be accompanied by refraction seismic surveying to determine the variations in overburden thickness in order to apply terrain corrections to the gravity data. However, this considerably lowers the cost-effectiveness of the gravity method in reconnaissance surveys at Pine Point in comparison with the IP technique and may not be feasible for general use.

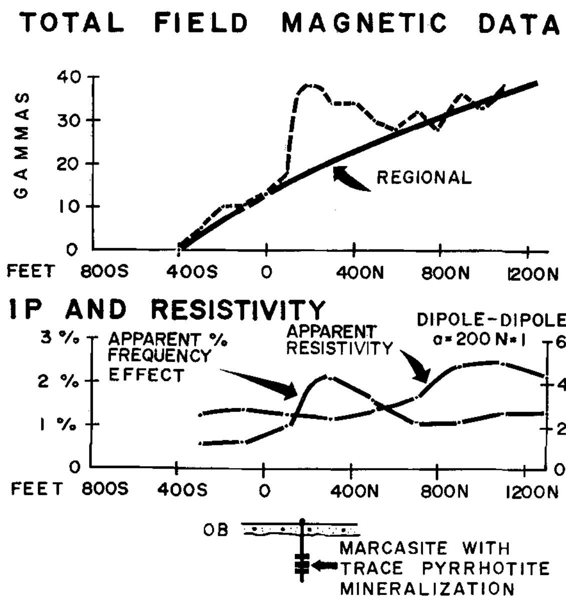

Figure 30.26. Frequency-domain IP-resistivity and magnetic data over iron sulphide deposit on line Y (McPhar P660, 0.3-5 Hz).

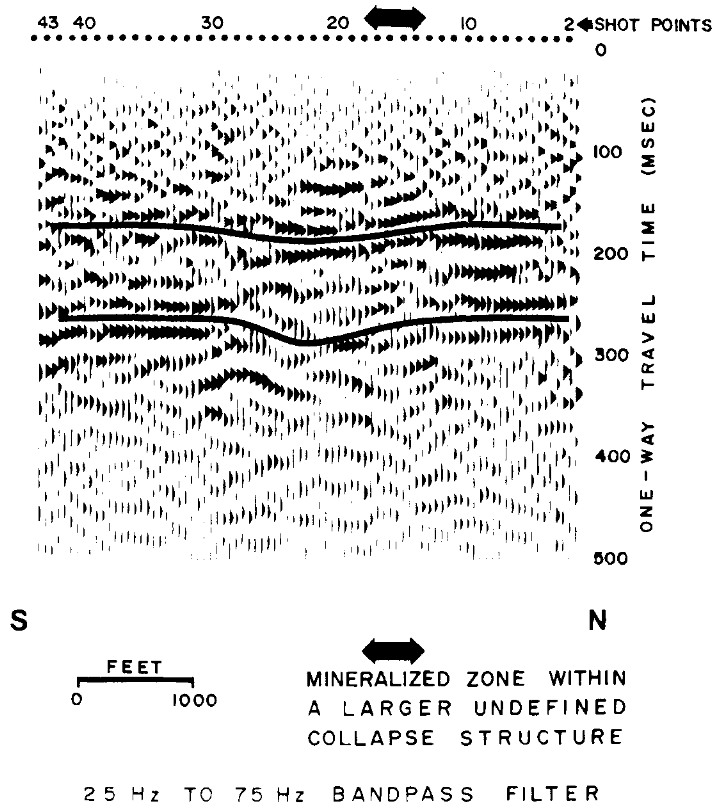

Figure 30.27. Reflection seismic data over orebody A. Shot spacing = 110 feet (34 m). Group offset = 1320 feet (402 m).

The Magnetic Method

Small amounts of pyrrhotite, the magnetic iron sulphide, are sometimes found with pyrite and marcasite mineralization which, in turn, occur with the ore. Figure 30.26 shows frequency-domain, IP-resistivity and magnetic profiles over one extremity of a noneconomic deposit consisting mainly of barren iron sulphides. The frequency-domain IP results were obtained using a McPhar P660 system. Of the holes drilled into this deposit, the drill hole shown had the highest concentration of pyrrhotite. Coincident with the IP anomaly is a magnetic anomaly of about 20 gammas which was confirmed by repeating the survey. However, since Pine Point is in the auroral zone, the area is subjected to severe magnetic storm activity, and since only a 20 gamma anomaly was obtained over a deposit with higher amounts of pyrrhotite than usual, it is unlikely that the magnetic method can be a significant exploration tool at Pine Point in comparison with IP.

The Reflection Seismic Method

Some experimentation has been carried out with the seismic reflection method in order to determine its possible usefulness as a mapping tool, a direct ore finder, and to find disturbances in the bedrock such as faults and collapse structures which may lead to mineralization. Figure 30.27 shows a seismic section on a line which passes over orebody A whose lateral extent is shown by the thick arrow. The orebody is contained within a large area of collapse. The data were processed with a 25-75 Hz bandpass filter. Several good reflections appear at the ends of the line and there is a definite depression from shot points 13 to 27. The shallowest continuous reflection appears at a one-way travel time of about 160 ms and this definitely puts it below the ore zone. It is possible that the depression in the reflected events is a velocity slow down anomaly; that is, reflections from deeper horizons were slowed down in passing through a region of lower velocity in the collapsed area surrounding the mineralization. However, Figure 30.27 shows the best results of the experiment. The remaining seismic data acquired during the test were not as encouraging.

It is possible that very high resolution seismic reflection surveys such as those carried out for nuclear site investigation may be more successful. Again, however, the cost effectiveness of such surveys would not compare with that of the IP method on the Pine Point Mines property.

CONCLUSIONS

Most of the Pine Point Mississippi Valley-type deposits contain sufficiently high concentrations of the conducting minerals galena, marcasite, and pyrite, to be good IP targets. The poor electrical continuity in bulk is a common characteristic of these ores and explains why the orebodies do not respond to standard electromagnetic methods. The chargeability anomalies produced by the ore are usually of the order of 10 ms (although chargeability values in excess of 30 ms were observed in one case). This is not very large when one considers that normal background variations in chargeability in many volcanic terranes are often as high as this. Therefore, the success of the IP method at Pine Point depends largely on the very low and uniform chargeability of the host limestones and dolomites. Weak variations in the chargeability can be measured which can sometimes be correlated to the lithology. Production surveying is however often hindered by high telluric activity since Pine Point is in the auroral zone. The gravity method is useful as a complementary tool especially in anomaly detailing, and responds to sphalerite mineralization which is not polarizable. At the present time, EM, magnetic and seismic methods appear to have little application as direct ore-finding tools in comparison with the IP method. Thus, the IP method is by far the most cost-effective geophysical exploration tool on the Pine Point Mines property.

ACKNOWLEDGMENTS

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