The aeromagnetic discovery of kimberlites and sulphides at depths up to 200m.

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Introduction

In 1994 a kimberlite exploration program was initiated in the James Bay Lowlands of Northern Ontario, Canada. The area is covered by lakes and bogs on top of a Paleozoic sedimentary cover with no outcrop within hundreds of kilometres. Several kimberlites had been identified and a wide area search of more than 10,000 square kilometres was initiated to locate additional pipes. An aeromagnetic survey procedure, interpretation methodology, and drill siting procedure was designed to identify and test the interpreted kimberlite targets. Using the magnetic method alone, the program identified seven kimberlites at depths up to 150m, and six sulphide zones up to 200m below surface.

Location and geology

A map indicating the survey area is presented in figure 1. In this region the Archean basement is overlain by Paleozoic sediments that thicken from tens of metres at the western margin to hundreds of metres at the eastern margin. This sedimentary sequence is capped by glacial till, shallow lakes and muskeg. The nearest road access is from the town of Nakina, about 300 kilometres to the southwest. The kimberlite potential of the area was first confirmed by the discovery of a cluster of about eighteen pipes by Monopros, the Canadian exploration arm of DeBeers.

Figure 1 - Location Map

Aeromagnetic Survey Design

An aeromagnetic survey was carried out over the known kimberlites and confirmed that all had distinct magnetic signatures. The pipes were post Paleozoic in age and intruded the sedimentary section. Young magnetic intrusives, that penetrate hundreds of metres of non-magnetic cover are perhaps one of the easiest phenomena to detect. If the depth to the magnetic source of interest is significantly less than the depth to the background magnetic sources, they can be identified easily by their comparatively short wavelength characteristics. Figure 2 illustrates a series of magnetic profiles, at different heights, over one of the kimberlites which lies 10 to 20 metres below terrain. At 300 metres altitude, the kimberlite response is almost too small to be recognised. At 80 metres terrain clearance the magnetic amplitude is significant and the shorter wavelength characteristics are evident. The amplitude and frequency contrast become more emphatic at 30 metres altitude.

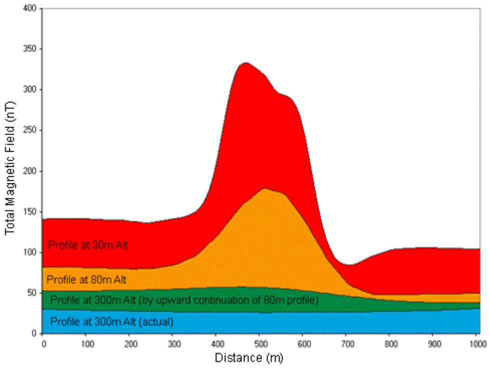


Figure 2 - Magnetic Profiles over a Shallow Kimberlite at Altitudes from 30m to 300m.

The first phase of the exploration program was a fixed-wing aeromagnetic survey at a terrain clearance of 80 metres and a line spacing of 400 metres. The terrain clearance was chosen as simply the lowest possible that was safely attainable. To coherently map magnetic sources, 100 metres below survey datum, the flight line spacing should be between 100 and 200 metres. A wider initial spacing of 400 metres was chosen for economic reasons, but with a technical rational. Using a vertical prism model, 200 metres in surface dimension, the profile response, over and 200 m. to the side of the prism was calculated. Both the profile directly over the prism and the one displaced to the side, were modelled. The calculated depth for the central profile was correctly estimated to be 100 m. below survey datum, or 20 m. below surface. The calculated depth for the displaced profile was 160 m. The magnitude of the error was considered manageable for the larger pipes in the areas of thicker sedimentary cover. In-fill flying to 200 or even 100 metre spacing was anticipated for zones, subsequently found to be of thinner cover, greater exploration potential and/or higher magnetic complexity.

The second phase of the program was to obtain detailed magnetic information in preparation for final target selection and drill siting. The remote location of the area and the large distances between target sites made the logistics for ground survey difficult and very expensive. A procedure to replace ground survey with detailed magnetic mapping by helicopter was devised. The limited tree cover permitted a magnetic sensor to be towed at 30 metres terrain clearance. A GPS antenna was mounted on the towed bird and after differential GPS correction, the geophysical measurements could be located with about 5 metre accuracy. Sites identified by the fixed-wing survey, that warranted closer inspection, were surveyed with the helicopter system at 100 m. line spacing. These detailed survey blocks were typically about one square kilometre in size unless several anomalies of interest could be conveniently grouped together into a larger block. In anticipation of work on the ground by geologists and drillers, a ground marker was placed at each site prior to the detailed survey. The helicopter pilot would land the survey bird at the mark and record a GPS value that could be differentially corrected and presented on the detailed aeromagnetic map. This ground reference point permitted ground work to proceed without further GPS reliance, and possible misuse, yet have an accurate tie to the airborne data and geographic coordinates.

The third phase was the actual drill test of selected anomalies. The centre of the magnetic anomaly would be located in terms of metres north and east of the site marker. A magnetic profile would be run along this central profile and at least one to either side. These ground magnetic profiles could be chained, marked and recorded in a single visit to the site. The principal profile of the ground survey would be used for final magnetic modelling to permit the drill collar to be defined relative to the marked lines and stations on the ground.

Anomaly Selection

The anomaly identification process is relatively straightforward for the kimberlite pipes penetrating the sedimentary cover. The fixed-wing aeromagnetic data was studied in contour and profile form for indications of shallow sources. Visual identification of such responses was followed by profile modelling using a 2.5 D model. Since the targets of interest were smaller than the 400 metre line spacing, the strike length was indeterminate and, for consistency of approach, was simply set equal to the modelled width. If the depth modelled was sufficiently indicative of a shallow source the response was flagged for more detailed mapping. Figure 3 illustrates a comparison of the magnetic response of the fixed-wing data and detailed helicopter magnetic data over one of the shallow kimberlite pipes in the area. The clearly defined, near surface magnetic source contrasts sharply with the deeper source magnetic background variations, and is easily identified. The glacial till overlying the Paleozoic sediments can also contain magnetic material and can produce a small but measurable response. It is suspected that some karsts have been filled with glacial gravels and that the volume and thickness in such cases can produce a significant magnetic response.

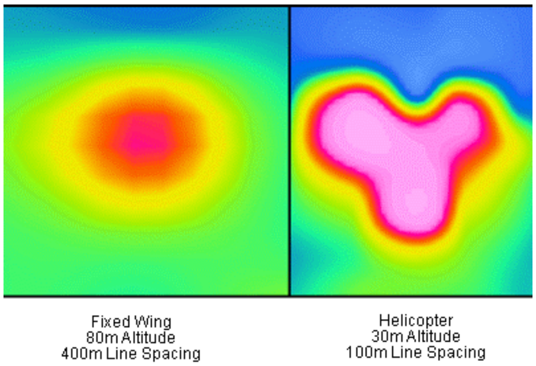
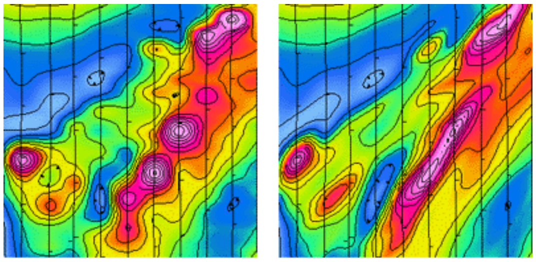


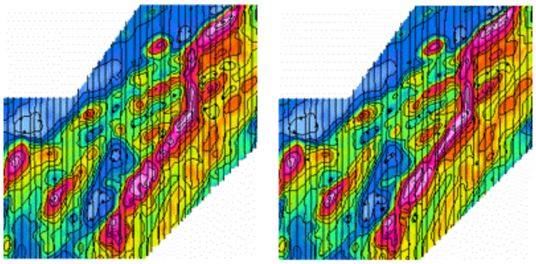
Figure 3 - Comparison of Magnetic Response, Fixed-Wing and Helicopter, over a Shallow Kimberlite

Kimberlite pipes are typically steeply dipping, with surface dimensions of several hundred metres. A diameter of 400 metres or more is considered large; less than 100 metres, small. On a continental or crustal scale there can be preferred trends and regions for their emplacement. The location of the pipes is little influenced by the host geology and at larger scale their location typically bears little relation to the surface geology. It is this non-conformance that can often help the interpreter recognize the magnetic response of a kimberlite intrusive. In the western sector of the survey area, the basement depth decreased and the line to line coherence of the data was marginal. An interactive interpolation process referred to as SI-GRID or strike-interpretive gridding was developed to allow the interpreter to influence the grid interpolation process and interactively assess whether certain anomalies were truly isolated events or simply isolations implied by the interpolation process. An example of this process is presented in figure 4 in which the conventional interpolation is presented together with an SI-GRID interpolation for both the fixed-wing and helicopter survey of the same area.



Conventional Grid of Fixed Wing Data

SI-Grid of Fixed Wing Data



Conventional Grid of Helimag Data

SI-Grid of Helimag Data

Figure 4 - SI-GRID Comparison

Within the survey area several unique isolated magnetic responses were noted. Their modelled dimensions were in the 200 metre range and their susceptibility was comparable to that of confirmed kimberlites in the area. Unlike the known kimberlites, their interpreted depth did not indicate a source at surface but one within the basement. The most promising of these magnetic isolations, illustrated in figure 5 was selected for drill testing. The modelled depth was 130 metres below surface and kimberlite was confirmed at a depth of 131 metres. This confirmation of kimberlites that both predated and postdated the Paleozoic sedimentary cover introduced a new dimension to the exploration program. These older pipes, capped by a thick layer of limestone and dolomite, are inaccessible to heavy mineral or geochemical exploration techniques as well as airborne electromagnetic methods. The prospect of identifying additional deep kimberlites within the Archean basement, using magnetics alone, presented a geophysical challenge with interesting and rewarding results.

The interpretation methodology was modified to focus not only on the shallow targets but also those within the magnetic basement. In typical Archean terrain there are numerous possible geologic phenomenon, of 100 to 400 metre scale, that can create a magnetic anomaly. A number of factors were used to identify prospective targets. The first step was visual identification of responses that were consistent with a magnetic source with length and width dimensions less than 500 m. This selection was further refined by a largely qualitative assessment of contrast with the surrounding magnetic/geologic characteristics. Priority was given to those anomalies that were most out of context relative to the surrounding trends and patterns. Each selected response was modelled to estimate depth, dip, width and susceptibility. Those anomalies with moderate susceptibility, in line with values established for other kimberlites in the area, were favoured. As well, widths in excess of 100 metres were favoured not only because larger pipes were preferred but also because a wider modelled width gave more confidence to the estimate of susceptibility. If a magnetic source is narrow, a susceptibility-width product may be well determined but the width and susceptibility as independent parameters are poorly determined. Dips greater than 45 degrees were considered acceptable but shallower angles were assigned low priority.

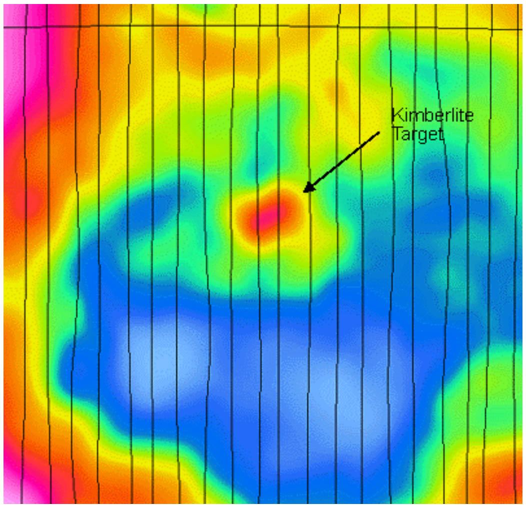


Figure 5 - Magnetic Response of a Kimberlite at 130m depth. Fixed-wing Survey 80m alt., 200m line spacing.

The philosophy of this anomaly selection process was to focus on those magnetic responses that magnetically indicated the highest probability of a kimberlite source. It was intentionally biased toward the characteristics of those already discovered in the area. There may very well be other classes of equally significant pipes within the area, with magnetic attributes different than those favoured; however, the practical consideration of cost requires a focused approach.

Drill Site Determination:

With no confirmation of depth to basement for 100 kilometres, or more, in any direction, the magnetic data provided the only means of establishing basement depth. Whether the source was at, below or above the Archean basement and whether there was significant basement topography was unknown. In consideration of these uncertainties and practical caution concerning the accuracy of magnetic modelling results, care was necessary in planning a diamond drill hole. The associated high cost made it important that the magnetic target be identified with a single hole. For this reason, angled holes were not considered since an error in properly estimating the source depth would lead to overshooting the target or drilling a much longer hole than needed.

The accuracy of the interpreted target width and centre must also be carefully considered. Should the pipe be only 50 metres in width, at a depth of 200 metres, one has to not only position the drill within a 25 metre radius but also consider that an error of 7 degrees from vertical will lead to a 25 metre offset at depth. The apparent dip of the modelled target is also a consideration. The expectation for a kimberlite pipe is near vertical and should the dip be off vertical one must decide if this is the reality, or due to an influence from an adjacent anomaly, a modelling error or an indication of remanent magnetization. The answer cannot be confirmed in advance but testing different solutions based on different scenarios can help identify the safest target location. Our adopted procedure was to carry out first a free fit using the IGRF magnetic inclination and declination for the area. If the estimated dip was significantly off vertical the model dip was constrained and other parameters forced to adapt. Often a small change in the base line slope and level provided the desired result. In some instances remnant magnetization was strongly suspected and to accommodate this unknown remnant component, the inclination of the inducing field was simply modified to render a fit that produced a near vertical dip. An equally good fit to the profile curvature could often be produced by these alternative solutions. Figure 6 illustrates the free fit and a forced result for comparison. In practice one can use the alternate model solutions to define a location on the body surface, common to the various solutions, and thus a more confident drilling target.

The discoveries and their significance:

A total of 36 anomalies within the 10,000 square kilometre area were drilled to identify the source of the magnetic anomaly. Seven were confirmed as kimberlite at depths ranging from 30 to 150 metres below surface. Two of these kimberlites had significant diamond content and are still being evaluated for commercial potential. Thirteen sites were attributed to gneissic rock, one to a gravel filled karst, and one hole was abandoned at 251 metres. The remaining fourteen sites encountered volcanic rock which at 4 locations contained disseminated sulphides with minor gold and at two other sites hosted massive sulphides at depths up to 203 metres and with drill intersections as great as 50 metres.

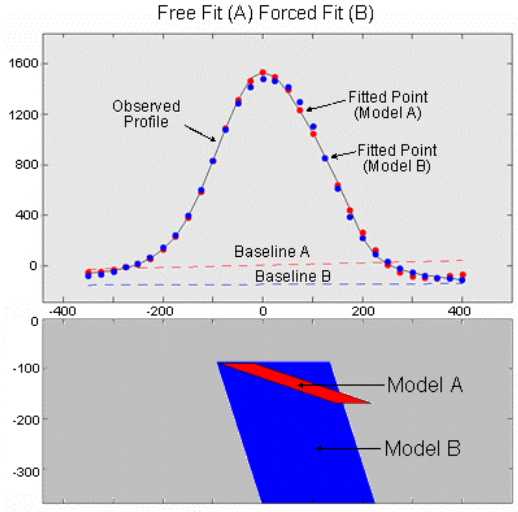


Figure 6 - Free Fit and Forced Model Solutions

At 13 of the 36 sites drilled, mineralization of potential economic interest, was identified, sometimes at significant depth. Mineral deposits are anomalies within the earth's crust and are often only hundreds of metres in size. The aeromagnetic method provides a tool for identifying magnetic anomalies of these dimensions near surface and at considerable depth. Perhaps unfortunately, large areas of the world have regional magnetic coverage at one kilometre spacing or greater and elevations of 150 metres or greater. Such data does not have the resolution necessary to resolve anomalies associated with most mineral deposits. This widespread source of low resolution data has prevented many exploration geologists from recognizing the full exploration potential of high resolution magnetic data. At the present time, considerable exploration activity is being directed towards deeper targets in established mining areas and the magnetic method could make a significant contribution.

Acknowledgements:

The exploration program was conceived by D.A. MacFadyen, who recognized the benefits of aeromagnetic survey for kimberlite exploration in the 1960's. Spider and KWG Resources deserve special credit for their courage to undertake such an ambitious and geophysically dependent exploration program.