SEARCHING FOR THE MAGIC BULLET: GROUND GEOPHYSICAL TECHNIQUES IN NORTHERN KIMBERLITE EXPLORATION

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Geophysical techniques have played a pivotal role in the discovery and development of diamond deposits in northern Canada. Since 1991, two diamond mines, several advanced development projects and scores of diamondiferous kimberlite pipes have been identified in a geological terrane once considered unlikely to host any economic diamond deposits. In the Slave Craton and surrounding regions, there are definite contrasts in physical properties between kimberlite intrusions and surrounding bedrock. Kimberlite commonly displays higher magnetic susceptibility, distinctive remnant magnetism, low electrical resistivity and lower density than surrounding rocks. In addition, the distinctive geometry of kimberlite pipes is reflected in geophysical responses which further facilitates target discrimination.

Geophysical explorations strategies reflect these physical property contrasts. Initial discoveries were made with total magnetic field and electromagnetic (EM) methods, reflecting the large contrast in magnetic susceptibility, remnant magnetism and lower electrical resistivity of kimberlite relative to surrounding rocks. In recent years, gravity, ground penetrating radar (GPR) and seismic methods have been introduced to exploit less intense physical property contrasts - particularly in heavily explored areas surrounding known deposits.

Helicopter total magnetic field and electromagnetic (HEM) surveys remain the most cost-effective first pass surveys in prospective areas. During the initial exploration in the early 1990's, ground total magnetic field and frequency domain electromagnetic (FDEM) surveys were virtually the sole techniques employed during follow-up surveys. Inevitably, the initially high rates of kimberlite discovery declined in the areas surrounding the original finds. Marginal magnetic and EM anomalies were all that remained to be tested and this spurred interest in the improvement of existing interpretation algorithms and in the application of additional complementary techniques to reduce the exploration risk. Gravity has become a popular third survey following the deployment of the Falcon (TM) airborne gravity gradiometer system by BHP Billiton in 1999 and improvements in ground techniques. Ground penetrating radar (GPR) has proven to be particularly useful in delineating kimberlite pipes following drill discovery and in exploring for kimberlite dykes in settings where indicator mineral trains indicate such targets are likely. Seismic methods have been tested for both reconnaissance and delineation but remain underemployed. Given the high cost of drilling in the North and the proven success of geophysical techniques in reducing exploration risk, it is likely that an increasingly diverse range of geophysical techniques and innovative interpretation techniques will continue to be applied in kimberlite exploration.

Improvements in ground magnetic survey techniques are almost entirely related to increases in field efficiencies through the application of GPS technology. Magnetometers equipped with differential GPS receivers are now available but critical operation navigation is still guided only by uncorrected GPS positioning. Given the critical importance of line separation in defining small kimberlite targets, GPS alone is not used by most operators. On the Barren Grounds where visibility is generally excellent, skeleton grids are often installed to permit operators to maintain alignment and uniform station spacing is approximated by pacing. True station locations are then recovered by GPS post processing. Some firms have experimented with towed GPS equipped magnetometers but this approach has been successful only in areas with unbroken topography.

Horizontal loop electromagnetic (HLEM) surveys remain the primary EM ground follow-up tool although some operators favour other techniques. Above the tree line, capacitive coupled resistivity (CCR) surveys can be performed rapidly and yield apparent resistivity data which correlate well with HEM resistivity data. Small-loop time domain EM (TDEM) soundings have been used to profile the electrical resistivity over kimberlite targets in order to decypher target geometry. A common source of ambiguity in kimberlite EM and resistivity investigations is the similarity in responses between kimberlite pipes and thick overburden deposits. Contoured stacked resistivity soundings can provide insight into the shape and vertical extent of resistivity anomalies, thereby facilitating discrimination between depth limited overburden sources and vertically persistent kimberlite targets.

Gravity surveys have been revolutionized by incremental improvements in several component technologies. GPS technology has made the greatest contribution by permitting accurate topographic leveling at a fraction of the cost of conventional leveling. Real time kinematic (RTK) carrier phase GPS surveys are particularly well suited to operations north of the tree line and provide elevations accurate to less than ± 2 cm over the distances encountered in small grids. The introduction of the automated gravimeter has greatly improved gravity survey accuracy, by removing operator effects from leveling and measurement operations. Finally, improvements in data processing algorithms have reduced errors in the application of terrain and bathymetry corrections. Accurate high resolution digital elevations models derived by combining existing topographic data and gravity survey elevation data are used as input to terrain correction algorithms that consider the gravity effect of each terrain element, thereby eliminating the inherent averaging errors in older methods. Finally, automated 3D gravity inversions yield target density models which provide sound insight into target geometry.

Ground penetrating radar (GPR) surveys are proving useful over both kimberlite pipes and dykes. In the Slave Craton, the high relative dielectric permittivity and low electrical resistivity of kimberlite relative to most country rocks generates distinctive signatures over many pipes. Unfortunately, the response of many flat-lying overburden deposits is similar to that of crater facies kimberlite in most settings and GPR surveys are not normally used as a primary diagnostic tool in exploring for pipes. They are very useful in delineating the surface extent of a pipe following an initial drill hole however. GPR surveys are proving most useful as primary tools in exploring for kimberlite dykes which can be readily discriminated from overburden sources by their distinctive signature in radargrams.

Seismic surveys have not been employed to a significant extent in kimberlite exploration but this may change as methods are adapted to improve target resolution and reduce acquisition costs. Experiments with refraction surveys indicate that kimberlite pipes can be discriminated from country rock on the basis of their seismic velocity but the utility of these surveys is hampered by the lack of sufficient velocity contrasts in greenstone. Reflection surveys have been conducted over known kimberlites and, at Snap Lake, have proven to be an effective means of mapping kimberlite dykes to depths in excess of 1000 m.

This paper will illustrate each method with case study results over known kimberlite pipes in the Slave Craton and adjacent districts.