3C-3D seismic survey over high-angle intrusives: A physical modelling study

Jill Belisle

INTRODUCTION

Kimberlites and lamproites are the only known economically significant sources of diamonds. These small carrot-shaped volcanic pipes originate from ultramafic material in the upper mantle and often occur in clusters of up to forty pipes. They serve as transportation mechanisms, carrying diamond xenocrysts from deep within the earth to the near-surface.

Gravity, magnetic, resistivity, and electromagnetic surveying have all been used in diamond exploration, primarily in the attempt to locate kimberlites. However, because of the size, geometry, and composition of these features, no single method has proven to be successful. Due to their lack of dependence on strike and their complete wavefield sampling, 3C-3D seismic surveys have tremendous potential for detailed imaging of three-dimensional bodies. Therefore, it is possible that this method will be successful in delineating high-angle intrusives, such as kimberlite and lamproite pipes, which have sharp contrasts in acoustic impedance with surrounding rock.

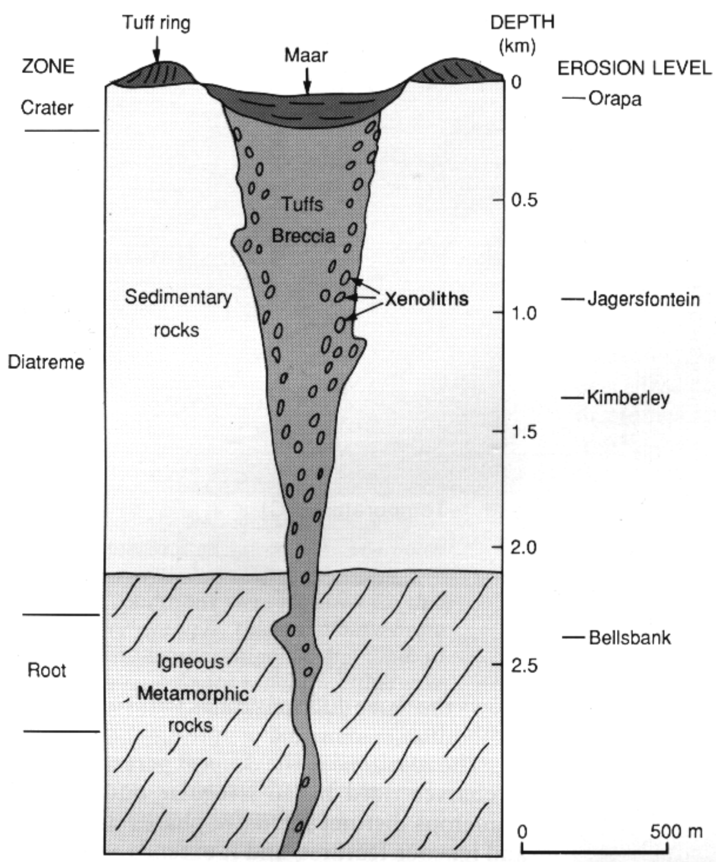

Figure 1: Model of a Kimberlite (adapted from Hawthorne, 1975)

GEOMETRY OF KIMBERLITE PIPES

Kimberlite pipes have a vertical axis and are characteristically conical in shape, with the edges sloping downward and inward at an average angle of 82 ˚. They tend to range from 0.1 km to 5 km in diameter, and from 0.4 km to 1 km in depth. The typical geometrical properties of kimberlites are illustrated in Figure 1. In this case, a surface diameter of 300 m has been used, with the diameter decreasing as the edges slope at 82˚ to the horizontal.

PRESENT GEOPHYSICAL METHODS

Various methods are used to locate kimberlite and lamproite pipes for the purpose of diamond exploration. However, due to the variability of the geophysical response, single method has been successful. Such variability arises from alteration, weathering, erosion, depth, chemical composition, and porosity of the feature.

The gravity method is useful in that crustal material is less dense than mantle material, yielding gravity lows in the areas of thicker crust which favour kimberlite formation. It is also possible to obtain gravity lows over kimberlites, but this requires thick upper weathered layers. If the feature has been eroded to fresh kimberlite, the local anomaly will be a gravity high.

Magnetics, and particularly aeromagnetics, has been the most cost-effective and one of the most widely used methods of exploration. Because of the abundance of magnetic minerals in kimberlite, large anomalies are common. However interference due to remanent magnetization is also common.

Airborne electromagnetics and resistivity have been very successful in distinguishing the conductive clays of the weathered kimberlite from a resistive host rock. However, these methods are relatively expensive and tend to be used in conjunction with ground magnetics.

Radiometrics is another method which is used; but because the amount of potassium present in kimberlite is highly variable, the level of contrast which is necessary to distinguish it from the surrounding rock is not always obtained.

PROPOSAL

In order to physically simulate a feature, such as a kimberlite pipe, whose seismic velocity increases with depth, a velocity-graded model will be constructed. This will be accomplished using synthetic rock in combination with other experimentally determined materials, which will serve to increase and decrease seismic velocities as required. The geometry of the model will follow that of Figure 1.

The 3C-3D survey over the physical model of a kimberlite pipe will be run using an elastic physical modelling apparatus. This computer-controlled experiment will be appropriately and accurately scaled using a distance scale of 1:10 000, such that measurements are in meters, and a sample rate of 100 nanoseconds, which will scale to a field sample rate of 1 millisecond. Both P- and S-waves will be measured using source and receiver transducers which will allow for nine-component acquisition.

SUMMARY

There is tremendous potential for 3C-3D seismic surveys to delineate the edges and allow for accurate determination of the subsurface properties of high-angle intrusive bodies, such as kimberlite and lamproite pipes. With 3-C sources and 3-C receivers (nine-component coverage), the full wave field will be sampled and better images acquired due to the additional detail from the horizontal components and the S-wave properties. As a result, more accurate evaluations of the features will be made.

REFERENCES

Buckle, J. and G. Paleolog, 1993, The geophysical response of kimberlite pipes - C.I.M.M./D.I.A.N.D. diamond exploration short course: Calgary, Dighem Surveys and Processing Inc.

Gallant, E.V., D.C. Lawton, R.J. Brown, and R.R. Stewart, 1994, Physical Modelling Update: CREWES Research Report, v.6

Hawthorne, J.B., 1975, Model of a kimberlite pipe: Physics and Chemistry of the Earth, v.9, Oxford,. Pergamon Press, p.1-16

Kirkley, M.B., J. J. Gurney, and A.A. Levinson, 1991, Age, origin, and emplacement of diamonds: Scientific advances in the last decade: Gems & Gemology, v.27, no.1, p.2-25

McNae, J., 1995, Applications of geophysics for detection an exploration of kimberlites and lamproites: Journal of Geochemical Exploration, v.53, p.213-243

Stewart, R.R., 1994, The present and promise of P-S seismic exploration: CREWES Research Report, v.6