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Seismic Investigation of Selected Kimberlite Pipes in the Buffalo Head Hills Kimberlite Field, North-Central Alberta

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Forward (by D. Roy Eccles, Alberta Geological Survey)

In the mid 1990s, Robert Pryde with Alberta Energy Company (AEC; now EnCana Corporation), while exploring for hydrocarbons in the Red Earth Creek area along the east flank of the Buffalo Head Hills, determined that shallow high frequency magnetic anomalies were coincident with reflection seismic disruptions and suggested they were potential kimberlite pipe(s). AEC then sought and formed a joint venture with Ashton Mining of Canada Inc. and Pure Gold Resources Ltd., with Ashton as operator. In 1997, Ashton discovered kimberlites on the southeast flank of the Buffalo Head Hills and 38 kimberlitic pipes have been located in this region. A large percentage of the pipes at the Buffalo Head Hills are diamondiferous, with at least six of the kimberlites containing estimated grades of >3 carats per hundred tones (cpht) and one pipe (kimberlite K252) having preliminary mini-bulk sample grades of 55 cpht.

This Special Report/poster will make these previously unavailable seismic data over selected Buffalo Head Hills kimberlites public. In addition, the seismic images, together with integration of multiple datasets, will contribute to the development of a kimberlite emplacement model for northern Alberta intended to stimulate continued diamond exploration in Alberta.

Seismic Investigation of Selected Kimberlite Pipes in the Buffalo Head Hills Kimberlite Field, North-Central Alberta

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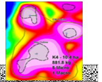
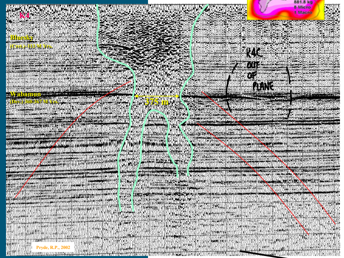
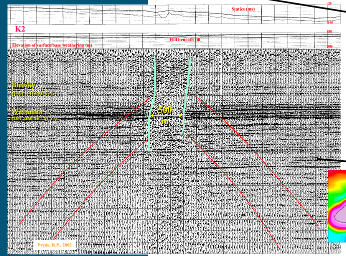
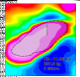
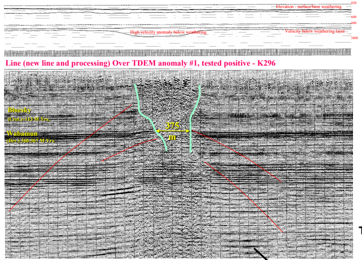




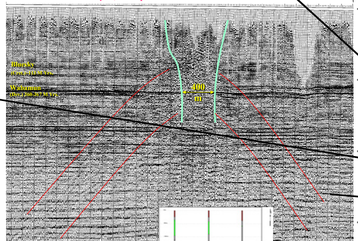


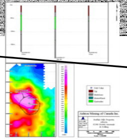


Line (new line and processing) Over TDEM anomaly #1, tested positive - K296



Line Over TDEM anomaly #5, tested positive - K300





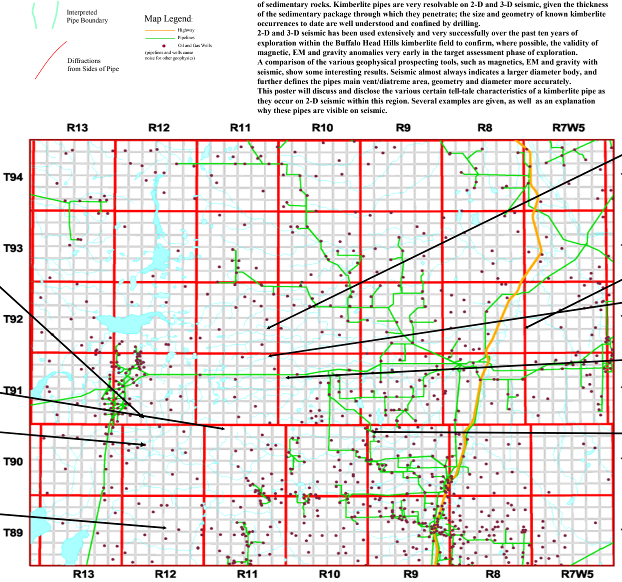
The province of Alberta is one of the richest petroleum regions on the Earth. As a result of exploration and development of this resource, the energy industry has created a significant proprietary and trade data seismic database that has remained extensively untapped for kimberlite exploration by diamond exploration companies.

Kimberlite pipes within the Buffalo Head Hills region of north-central Alberta pierce a 1600 m section of sedimentary rocks. Kimberlite pipes are very resolvable on 2-D and 3-D seismic, given the thickness of the sedimentary package through which they penetrate; the size and geometry of known kimberlite occurrences to date are well understood and confined by drilling.

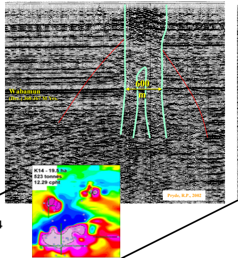
2-D and 3-D seismic has been used extensively and very successfully over the past ten years of exploration within the Buffalo Head Hills kimberlite field to confirm, where possible, the validity of magnetic, EM and gravity anomalies very early in the target assessment phase of exploration.

A comparison of the various geophysical prospecting tools, such as magnetics, EM and gravity with seismic, show some interesting results. Seismic almost always indicates a larger diameter body, and further defines the pipes main vent/diatreme area, geometry and diameter more accurately.

This poster will discuss and disclose the various certain tell-tale characteristics of a kimberlite pipe as they occur on 2-D seismic within this region. Several examples are given, as well as an explanation why these pipes are visible on seismic.



K14



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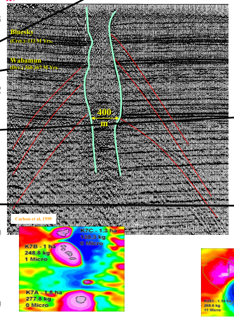

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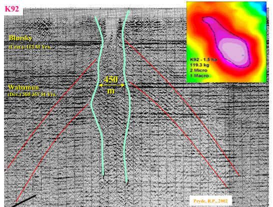
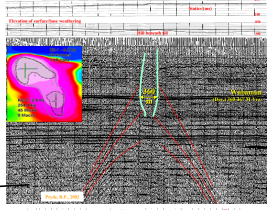
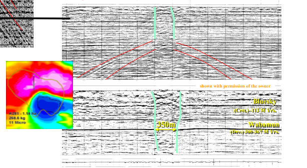


K6b/BH270



BH 281



Character of Kimberlite Pipes on Petroleum Industry Seismic Data

This poster gives examples of seismic data known to represent kimberlite pipes in north-central Alberta's Buffalo Head Hills kimberlite field.

Kimberlite pipes appear on seismic as sharp-bounded non-reflective zones. The sides of the pipes are generally too steep to be imaged, because steeply dipping interfaces do not reflect energy back to the surface. The interface of the sedimentary strata with the pipe wall scatters energy and thus produces diffractions. These diffractions are observed on structural (common midpoint) stacks, which are early processing results where the recorded energy is plotted beneath the midpoint between sources and receivers. The common processing technique of "migration" of the energy to its correct location in space will collapse these diffractions to points where the strata are cut off. Migrated stacks are the most common way of looking at 2-D seismic lines.

These pipes have often been mistaken for noise zones and were often muted out (manually removed) by petroleum industry seismic processors. No obvious cause of a noise zone (e.g., a lake or swamp) will exist over a good quality seismic pipe anomaly. Possible noise zone sources can be investigated on the observer's notes and survey notes for the seismic lines. A typical noise zone will appear more diffuse; it will have less defined bounds and contain some weaker reflections within it, even shallow in the section.

In the Buffalo Head Hills region, kimberlite pipes are more resistant to weathering than the surrounding Cretaceous strata into which they intrude. As a result, some pipes are topographic hills; subsequently, some of these hills were covered by till in the last glaciation. These 'hills beneath the till' can be seen in the 'refraction statics' processing of the seismic data. The first arrival of energy on each seismic shot is analyzed to determine the geometry of the near surface, so that the image can be adjusted for the slowest, most shallow weathered layer (till in this case). The results of this analysis are often plotted at the top of archived seismic sections, where lines plotting both the surface elevation and the base of this weathered layer are shown. The 'hills beneath the till' show up as a thinning of the weathered layer, with solid rock existing a small distance beneath the surface. Another parameter calculated from this refraction statics process, and sometimes plotted on seismic lines, is the velocity of the rock below the weathered layer. Here, kimberlite typically has a higher velocity than the surrounding strata, and so will show up in such a plot as a higher velocity area.

In summary, look for sharp-bounded non-reflective zones, diffractions (on structural stacks) from the walls of the pipes, hills or high velocity anomalies beneath the till, and no other reasonable explanation for the lack of reflectivity.

Implications of These Examples for the Geometry of Northern Alberta Kimberlite Pipes

These seismic images provide some significant constraints on the geometry of kimberlite pipes in northern Alberta. The sections clearly image intrusions that are 350 m to 600 m across at the strong Wabamun Formation reflection. This formation varies in depth from over 700 m in the west to around 400 m in the eastern part of the Buffalo Head Hills area (each trace on the seismic section represents 12.5 m or more laterally).

The edges of the intrusions are also outlined by the diffractions. Thus, these images show pipe geometry that maintains a cylindrical to "gently" conical (carrot like) shape for more than 1000 m into the ground (well past the Wabamun Formation reflection) and maintain significant width to those depths (see dimension labels on sections).

The fact that an intrusion is imaged at all on seismic to significant depth shows that these pipes have width in the order of hundreds of metres, as seismic data have a limited lateral resolution and will not see features only tens of metres across. On unmigrated data, the lateral resolution limit is the "Fresnel zone" (Yilmaz, 1987), calculated as

$$r = (v/2)(t/f)^{1/2}$$

Where v is the velocity of rock above, t the two-way time to point and f is the dominant frequency at the point.

Now, for example, the Wabamun Formation is about 700 m below the surface in the vicinity of K296 and K300 kimberlite pipes. Average velocity above the Wabamun is about 2250 m/s, and on this older seismic data the dominant frequency is no more than 50 Hz. The two-way travel time is 0.65 seconds, and the Fresnel zone radius calculates to 130 m. Thus, the diffractions from either edge of the pipes would begin to run together if they were much less that 130 m wide at this depth, and it would be difficult to image the pipes. The image of the pipes is quite visible, and therefore, the pipes are estimated to be 375 and 400 m wide.

Note that migrating the data tends to collapse the Fresnel zone to approximately the dominant wavelength $\lambda = v/f$ (Stolt and Benson, 1986; at about 45 m in the above example). However, it can be difficult to recognize pipes in noisy data, without the aide of diffractions to draw the eye and define the pipe edge, as reflectors may have some weak areas just due to noise.

Seismic lateral resolution deteriorates with depth as well, as velocity tends to increase with depth and frequency decreases with depth. Thus, there comes a point farther into the earth where the width of the pipes become less than the lateral resolution limit, and the stratigraphic reflectors will not be clearly broken by the pipes. This lack of resolving the intrusions at these greater depths does not mean the pipes are not there, just that they are narrower than the Fresnel zone. For example, near the K296 and K300 kimberlites, the Precambrian basement is at 1760 m and 1.1 seconds; the average velocity above would now be 3130 m/s and the dominant frequency may be only 40 Hz. The Fresnel zone radius now calculates to 260 m and any pipe narrower than this will be obscured.

Summary

Seismic data clearly image intrusions in the Buffalo Head Hills region that have been proven to be kimberlite via advanced exploration. Hence, it is possible the plethora of seismic data throughout Alberta be re-interpreted with diamond exploration in mind.

The geometry of these intrusions is shown to resemble pipe- or carrot-like intrusions with significant width (hundreds of metres) at depth. This technique can, therefore, assist diamond exploration companies in modelling the tonnage and grade of a potential deposit.

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