## SPECTRAL REFLECTANCE FEATURES OF KIMBERLITES AND CARBONATITES: THE KEY TO REMOTE SENSING FOR EXPLORATION

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Recent advances in the spectral and spatial resolution of airborne and spaceborne multispectral scanning devices provide new opportunities for using remote sensing techniques in kimberlite and carbonatite exploration. To evaluate their remote sensing potential, laboratory diffuse reflectance spectra were recorded in the 0.4-jum to 2.5-jum wavelength range for naturally weathered surfaces of kimberlites from southern Africa and for carbonatites from South Africa and North America. Mineralogy was confirmed by petrographic and/or x-ray diffraction analysis.

Characteristic absorption features of minerals are derived from either electronic or vibrational processes. The principal electronic processes result from energy level transitions in a crystal field or from the formation of valence and conduction energy bands. In the near-infrared range, vibrational processes yield overtones and combination tones of the fundamental modes of anion groups and water.

The spectrum of a relatively fresh dark kimberlite, fine grained hardebank (sample 1, Figure 1), contrasts with that of a weathered light green kimberlite (sample 2). Spectral contrast is reduced by the presence of finely disseminated opaque minerals so that features are often obscured in dark kimberlite samples.



Fig. 1. Sample (1); kimberlite "hardebank", Doornkloof Mine, South Africa (2); kimberlite, Williamson Mine, South Africa (3); "Granny Smith" nodule (Ti-Cr diopside), Kampfersdam, South Africa (4); Cr-diopside nodule, Kampfersdam, South Africa (5); Lherzolite, Monestery Mine, South Africa (6); garnet-rich nodule, Orapa, Botswana. Spectra are displaced vertically.

Bands near 1.4 µm are due to the first overtone of the hydroxyl fundamental; the presence of bands at both 1.4 µm and 1.9 µm is diagnostic of water. Features near 2.32 and 2.38 µm are caused by MgOH stretching and bending modes. The spectrum of sample (1) is common to many kimberlites and absorption bands can be attributed to a small amount of serpentine. Features exhibited by the sample (2) spectrum can be assigned to saponite, a weathering product of olivine and pyroxene. The broad band centered near 1.0 µm is due to ferrous iron in a spin allowed transition in the octahedral field. Weak features between 0.4 µm to 0.5 µm are caused also by crystal field transitions of ferrous iron. Magnesium olivine strongly predominates in kimberlites, but the presence of only a small amount of iron will produce these features.

The features near 0.45  $\mu$ m and 0.65  $\mu$ m as displayed in the spectrum of sample (3), the "Granny Smith" nodule (Ti-Cr diopside), are due to ferrous iron but chromium also contributes to these absorption bands. The spectrum of sample (4), chrome-diopside, has a similar shape. These spectra display broad iron bands near 1.0  $\mu$ m, due to ferrous iron of diopside which occurs in the M<sub>(1)</sub> octahedral site. The minima of the ferrous iron feature in the lherzolite, sample (5), is shifted to a shorter wavelength due to iron occupancy of the M<sub>(2)</sub> site of enstatite (Burns, 1970). Typically garnet-rich samples (sample 6) display a broad iron feature centered near 1.28  $\mu$ m not 1.0  $\mu$ m, due to eight fold co-ordinated ferrous iron in pyrope (Bancroft et al., 1967). Serpentinization and/or kelyphitization is the cause of the 0H, MgOH and H<sub>2</sub>O bands. As garnet and chrome-diopside are both indicator minerals in kimberlite prospecting, their spectral properties may be significant in exploration, especially in aerial surveys of desert regions.



Fig. 2, Sample (7); sövite, Bear Paw Mountains, Montana, USA (8); sövite, Mountain Pass, California, USA (9); rauhaugite, McCloskey;s Field, Quebec, Canada (10); rauhaugite, Glenover Complex, South Africa. Spectra are displaced vertically.

Carbonatites may have a higher reflectivity and may display more intense absorption bands than kimberlites. Near-infrared features of carbonatites are due to carboxyl-group vibrational processes, with the 2.34-um band at a slightly longer wavelength than the 2.32 um MgOH feature. Some samples display a series of sharp. narrow bands between 0.5 µm and 0.9 µm caused by electronic transitions of neodymium (Rowan et al, in press). In sovite sample (7) (Figure 2), enriched in the mineral burbankite, neodymium causes the bands at 0.52, 0.58, 0.74, 0.80 and 0.87 um. Carbonatites containing as little as 100 ppm neodymium display these bands, if they are not obscured by spectrally opaque minerals. Whole rock analysis of the McCloskey's Field, Quebec, coarse-grained carbonatite (sample 8) gives 180 ppm neodymium. Except for samarium other rare earth elements do not exhibit absorption bands, because of their unsuitable electronic configuration and/or low concentrations. The spectrum of sample (8) (20% bastnaesite) displays not only neodymium features but also prominent bands between 1.0 um and 1.7 um due to samarium. A broad double absorption band centered near 1.0 µm and 1.25 µm is conspicuous in some rauhaugite samples and is due to ferrous iron substituting in the dolomite lattice, (sample 9). The presence of this feature in rock spectra in combination with carboxyl and neodymium bands is diagnostic of carbonatite. Finely disseminated magnetite in carbonatite will quench the rare earth, ferrous iron and carboxyl spectral features as demonstrated in the South African rauhaugite spectrum (sample 10).

We have successfully used a portable spectrometer in field studies at the Iron Hill, Colorado carbonate complex to map the distribution of rare-earth-rich phases on the basis of observation of neodymium absorption bands. Remote exploration of kimberlites and carbonatites however is dependent on the occurrence of spectral and spatial contrast with country rock. Distinctively shaped discordant bodies in the appropriate tectonic setting should be identifiable. Serpentine-rich kimberlites that intrude basalt, granite or most sedimentary rock can be spectrally discriminated. Differences in soil development due to contrasting weathering resistance between kimberlite and country rock will result in remotely detectable vegetation differences. Carbonatite may be remotely discriminated because the frequently associated alkalic igneous rocks are spectrally featureless. An airborne high-resolution spectroradiometer has distinguished both carbonate and neodymium spectral features in flights over the Mountain Pass, California carbonatite complex (Kingston and Rowan, 1986). Flightlines that recorded intense neodymium absorption spectra were juxtaposed on those recording anomalous carbonate features and were used to outline the rare-earth-enriched sectors of the carbonatite complex.

A new generation of high-resolution airborne imaging spectrometers offers substantial potential for exploration. The NASA imaging spectrometer will soon be operational, acquiring data from a U-2 aircraft in 160 spectral channels from 0.4 to 2.5 µm, and having a ground resolution of 15 m. Spectral features of iron, hydroxyl, carboxyl and rare earth elements will be detectable at this resolution.

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