KIMBERLITE WEATHERING AND ROLE FOR HYPERSPECTRAL SURVEYS IN THE SEARCH FOR DIAMONDS IN THE FLINDERS RANGES, SOUTH AUSTRALIA

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INTRODUCTION

Soil sampling by CRC LEME/PIRSA in May 2005 across spectral targets within the Ucocola Inlier, 33 km east of Terowie, outlined two new areas of weathered kimberlite defined by elevated levels of Ni, Cr and Nb. These represent the first reported kimberlite in South Australia found as the result of follow up of airborne spectral targets. They add to the growing list of newly discovered kimberlites within the Flinders Ranges and Nackara Arc exploration project areas of Flinders Diamonds Ltd (FDL). Between September 2004 and June 2005, FDL discovered 37 new kimberlite bodies through the use of airborne and ground magnetic surveys (Wills 2005b). Integration of hyperspectral surveys with the proven technique of low-level magnetics offers a means of locating and prioritising shallow kimberlite targets, including those with a subtle magnetic anomaly.

BACKGROUND

The Pine Creek kimberlite cluster near Pine Creek homestead, 33 km east of Terowie, has been the site of recent studies on kimberlite indicator mineral dispersion (Howard 2003a) and the use of spectral techniques for detection of kimberlite (Keeling *et al.* 2004). In March 2002, four hyperspectral survey lines, totalling 104 km, were acquired using the HyMap airborne spectrometer, configured for 126 spectral channels covering the spectral wavelength region 450 to 2500 nm, and flown at a pixel resolution of ca. 4.5 m (Figure 1). The spectral data were processed to highlight absorption features in the 2300 nm wavelength region to map Mg-rich minerals associated with weathered kimberlite.

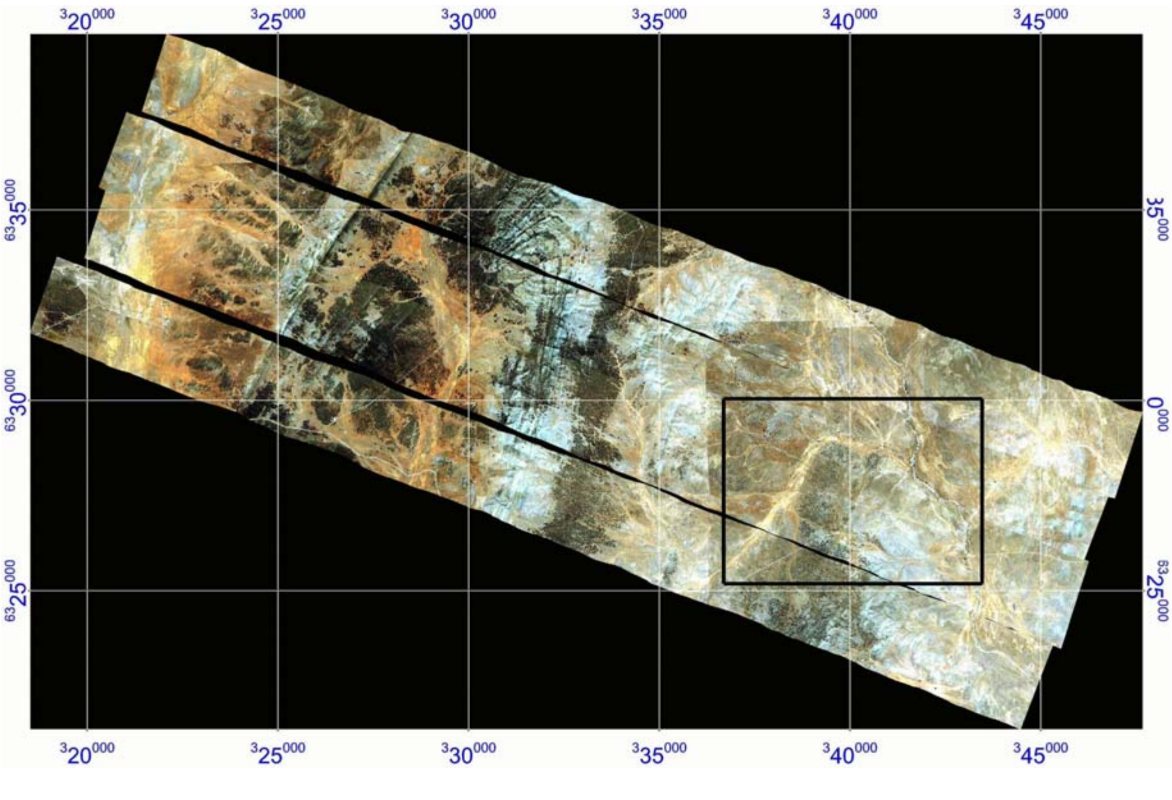

Figure 1: Pine Creek kimberlite HyMap spectral survey, composite of 4 flight lines coloured by channels in the visible range at 648.5 nm (red), 556.4 nm (green) and 479.9 nm (blue).

The resultant images showed spectral anomalies that correlated with known kimberlite An42 and two smaller diatremes at Calcutteroo, northwest of Pine Creek. They also identified broad anomalous zones within the Ucocola Inlier and a small number of minor targets in other areas covered by the survey. Field inspection of selected sites, during 2004, indicated a high proportion of spectral anomalies were due to dolomite or Mg clays developed on pedogenic or bedrock carbonate (Keeling *et al*. 2004). Consequently, further regional hyperspectral surveys for kimberlite in the area were not recommended and FDL continued with airborne magnetic surveys for their regional coverage and follow-up ground magnetics to define drill targets. These surveys have proved highly successful in locating new kimberlite bodies in the district (Wills 2005a) and led to the introduction in June 2005 of a new "Helimag" survey capable of 1 m width resolution when towed at a height of 30 m above the ground (Wills 2005b). The soil geochemistry project over spectral anomalies was initiated following a review of the weathering mineralogy and spectral response of kimberlite at Pine Creek and some refinements in processing the airborne spectral data.

GEOLOGY

Kimberlites at Pine Creek were intruded into an open dome structure in folded Neoproterozoic sedimentary rocks comprised of tillite, sandstone, siltstone and dolomitic shale of Umberatana Group sediments of the Adelaide Geosyncline (Figure 2). Prior to 2002, the Pine Creek kimberlite cluster was defined by a main diatreme (An42), of some 6.3 hectares, and a kimberlite dyke (An58) both located through indicator mineral surveys in the 1970s; a buried kimberlite diatreme (An65) and dyke (An68) discovered by Dampier Mining Ltd by drill testing magnetic features (BHP Exploration, 1981). A third diatreme (An43) was located during recent field investigation of indicator mineral dispersion (Howard 2003a) (Figure 2). An42, generally referred to as 'the Pine Creek kimberlite' is the main diatreme in the cluster and is situated within fine-grained, crystalline marble and calcareous quartzite that are locally deformed and occupy the core of the dome. The host rocks are possible equivalents of Curdimurka Subgroup sediments emplaced as a diapir along zones of structural weakness (Cowley & Preiss 1997). Kimberlite emplacement was during the Jurassic period at around 174 Ma (K-Ar date on phlogopite; Stracke 1979). What remains is believed to represent the root zone of the diatreme with some 1,700 m of kimberlite stripped by erosion since emplacement (Colchester 1980). Samples of unweathered kimberlite are composed of macrocrysts of olivine, monticellite and phlogopite in a groundmass of olivine, monticellite, phlogopite, perovskite, clinopyroxene, anatase, apatite and opaques (Howard 2003b).

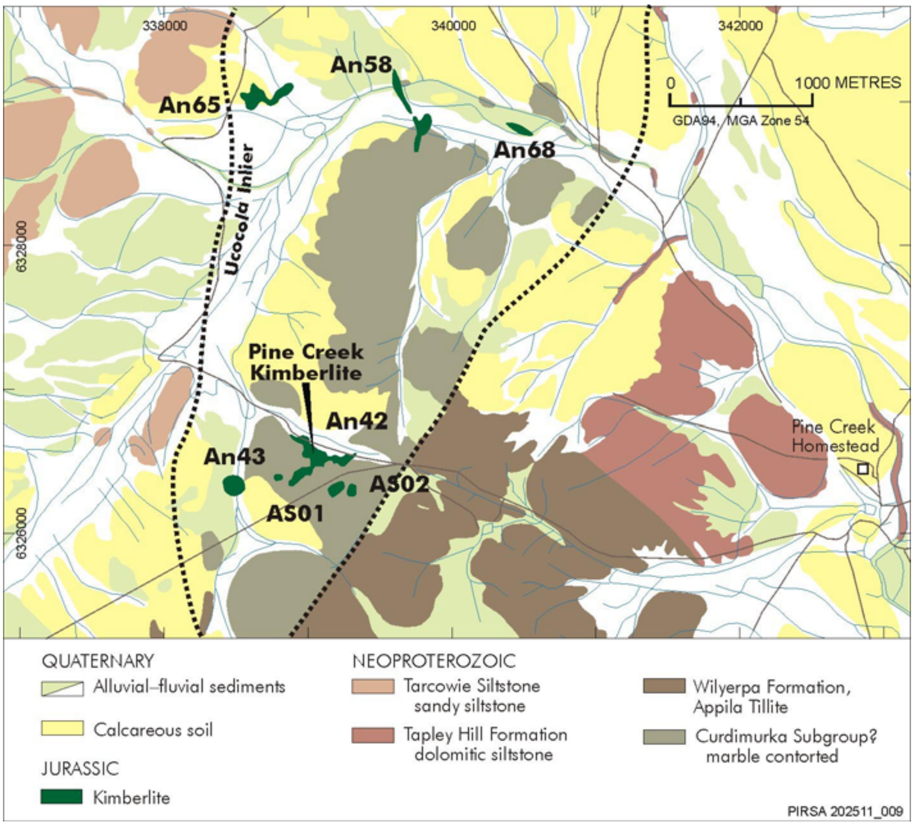

Figure 2: Geology of the Ucocola Inlier and location of kimberlites of the Pine Creek kimberlite cluster.

KIMBERLITE WEATHERING AND SPECTRAL CHARACTERISTICS

Alteration of kimberlite immediately after emplacement is common, resulting in extensive serpentinisation of olivine and monticellite via reaction with meteoric and ground waters. Rapid emplacement and cooling of kimberlite or lamproite limits the development of alteration haloes in the surrounding country rock. The high CO_2 content of magmatic fluids can result in widespread calcite crystallisation during early alteration. Clinopyroxene is altered to chlorite and continued supergene weathering of kimberlite generates a series of alteration products that include talc, vermiculite, dolomite and Mg-Fe smectite, which under intense or prolonged weathering are reduced to kaolin and Fe oxy-hydroxides (Figure 3). Highly weathered terrains with deep kaolin profiles are therefore unlikely to preserve sufficient MgOH minerals at the surface to be diagnostic of kimberlite. Early and intermediate alteration products of primary silicate minerals are potentially the most useful for surface spectral mapping, especially where these contrast with predominantly AlOH mineralogy in adjacent country rock. The spectral absorption characteristics of a variety of minerals found in altered kimberlite are shown in Figure 4. These have in common a strong absorption feature in the 2300-2330 nm wavelength range.

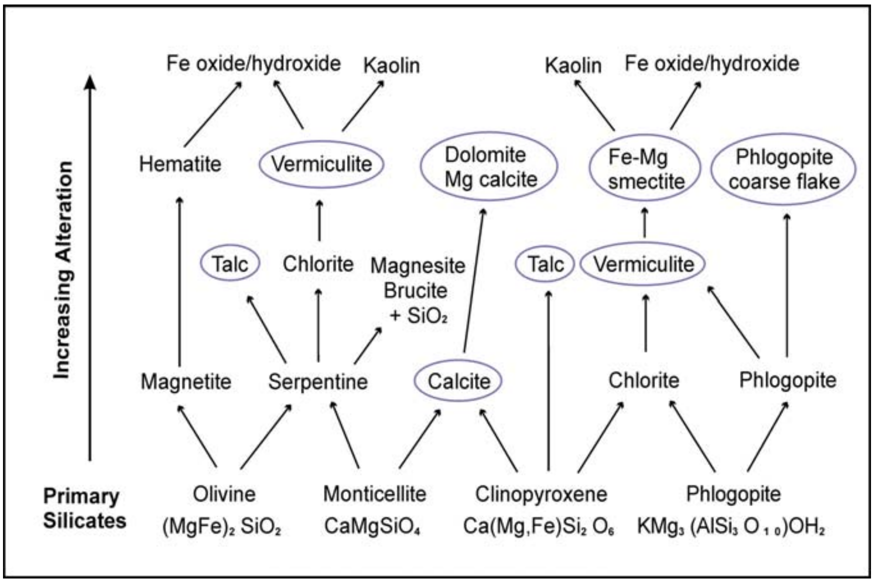

Figure 3: Pine Creek kimberlite. Possible alteration pathways and secondary mineral phases formed during supergene alteration of primary silicate minerals. Minerals present at the near surface of kimberlite diatreme An42 are circled.

A study of the weathered profile in kimberlite An42 showed calcite and dolomite are co-dominant phases in the upper profile, with minor vermiculite and ferruginous saponite (Fe-Mg smectite), and trace phlogopite and talc (XRD results in Keeling *et al.* 2004). Serpentine minerals were not encountered until around 36 m depth (Howard 2003a). Fe-Mg smectite and fine-grained vermiculite partially coat coarser mineral grains and therefore dominate the spectral response. Coarse flakes of phlogopite resist weathering and are observed in the soil but make up < 5% by volume and were not detected in the spectra of bulk surface samples. Fine-grained phlogopite is altered to vermiculite and Mg-smectite. Smectite from weathered kimberlite An42 shows an absorption feature at wavelength 2303–2309 nm that is intermediate between nontronite (Fe-smectite) and saponite (Mg-smectite) (Keeling *et al*. 2004). Surficial sediments in the area incorporate substantial amounts of exotic aeolian inputs of dominantly fine-grained quartz, kaolin and Al-rich smectite. These accumulate in hollows and drainage depressions to dilute any dispersion from weathered kimberlite and consequently even thin (< 0.2 m) aeolian, fluvial or alluvial cover effectively masks underlying kimberlite to surface spectral techniques.

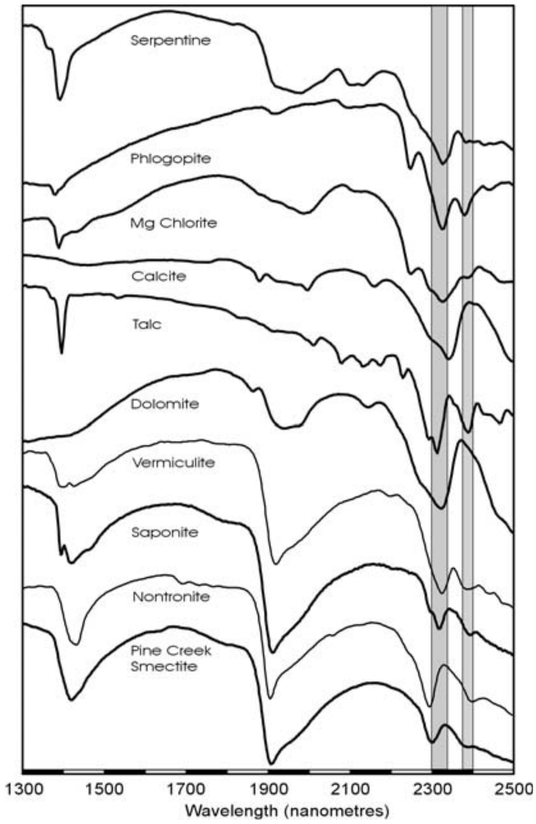

Figure 4: Short-wave infrared (SWIR) spectra of minerals associated with kimberlite weathering. Absorption features at wavelengths 2300-2330 nm and 2390 nm are highlighted.

The semi-arid climate and generally open vegetation cover in this region of the Flinders Ranges combined with neotectonic activity, weathering and erosion, provide apparent excellent conditions for spectral mapping of weathered kimberlite in both residual and erosional landform situations. The reality is that the targets are typically small and the presence of any sediment cover restricts detection at the surface. Direct detection of kimberlite is possible as evidenced by spectral anomalies over An42 and the Calcutteroo diatremes. The spectral response at these sites is due primarily to Fe-Mg smectite and dolomite, enhanced somewhat by surface disturbance from previous exploration activity.

Further processing of spectral anomalies in the Ucocola Inlier by P Hausknecht of HyVista Corporation resolved a spectral subset based on variation in the shape of the 2300 nm absorption feature and the presence of a small absorption band at 2390 nm. This subset correlated closely with the An42 diatreme, provided more tightly constrained targets, and appeared to discriminate against those due to Mg carbonate. In May 2005, two target sites south of the Pine Creek road were tested using a manually operated power auger to sample weathered rock at 0.5 to 1.0 m depth. Some 30 holes were completed at an average spacing of 10 m. Pressed powder samples were analysed by XRF, and kimberlite identified from elevated levels of Ni, Cr and Nb, above threshold values determined in earlier surveys (Hough & Morris 1989, Howard 2003b). The results show probable kimberlite intersected at two sites: AS01; and AS02, on line 3 (Figures 5 and 2). These sites are programmed to be tested in future backhoe bulk sampling for micro-diamonds by FDL.

The lack of success on lines 1 and 2 was investigated. Areas of weathered, shallow carbonate bedrock in the Ucocola Inlier develop smectite clay in residual soils that shows similar spectral characteristics to that from weathered kimberlite. The clay, combined with dolomite adds to the pattern of 2300 nm wavelength anomalies observed in the Ucocola Inlier. Differentiation based on the shape of the 2300 nm feature and the presence of an absorption band at 2390 nm highlights the more clay-rich areas and areas where talc is concentrated (distinct absorption feature at 2390 nm, see Figure 4). Such a response is not specific to kimberlite and also maps increased talc content in the carbonate. Here, talc in carbonate may be an alteration phase spatially related to kimberlite intrusion, but this remains to be proven.

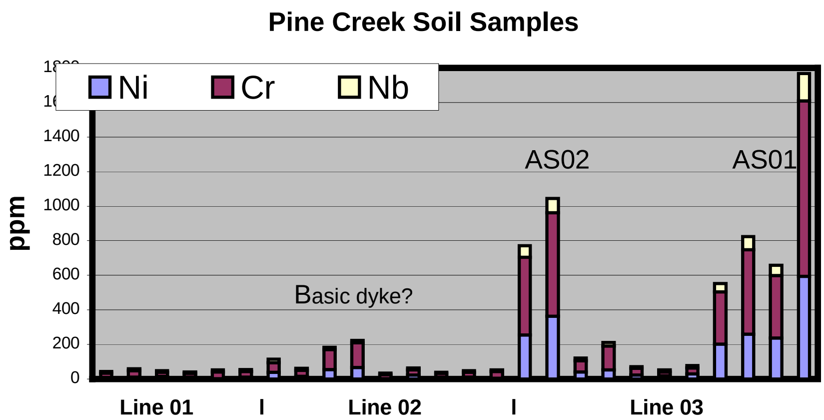

Figure 5: Summary of soil geochemistry over spectral anomalies with kimberlite AS01 and AS02 identified from elevated Ni, Cr and Nb.

ROLE FOR SPECTRAL SURVEYS

Subsequent to the soil sampling it was shown that the newly detected kimberlites AS01 and AS02 fit with subtle magnetic highs that had not been investigated in previous exploration. The combination of spectral MgOH anomalies overlain on total magnetic intensity (Figure 6) offers a tool to prioritise those magnetic features that have associated Mg-rich minerals at the surface. In this instance, spectral mapping has the advantage of identifying magnetic features that can be tested by shallow surface methods and pinpoints the spatial location by virtue of being able to produce a photographic image of the land surface. Restricting spectral surveys to areas of high interest, as identified from magnetic surveys, would limit the additional cost required for another airborne survey over the same ground. The combined technique offers a means of prioritising subtle spectral or magnetic features that might otherwise be overlooked.

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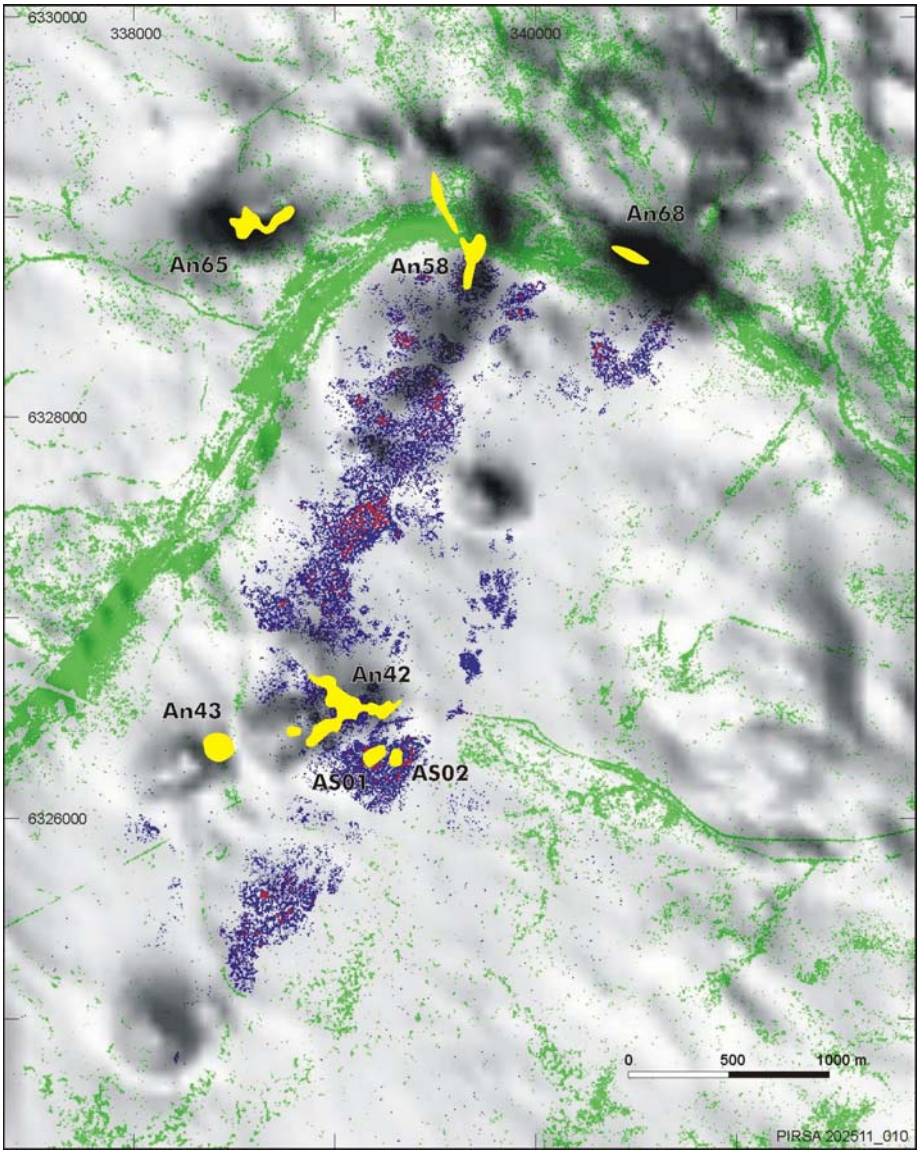

Figure 6: Spectral mapping overlain on grey-scale TMI for the same area. Red – strong 2300 nm wavelength absorber (Mg-Fe smectite ± talc); Blue – weaker 2300 nm absorber (smectite and dolomite); Green - bare ground with dominant Al-OH (Al-smectite and kaolin).

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