AIRBORNE HYPERSPECTRAL SURVEY AND KIMBERLITE DETECTION IN THE TEROWIE DISTRICT, SOUTH AUSTRALIA

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INTRODUCTION

The 1969 discovery of diamond indicator minerals near Terowie by DeBeers subsidiary Stockdale Prospecting Ltd. led to the discovery, in 1971, of a substantial kimberlite diatreme, over 6.3 hectares, near Pine Creek homestead, 33 km east of Terowie. While the Pine Creek kimberlite proved to be barren of diamonds, several smaller diatremes and kimberlite dykes were located in the district including a swarm of diamond-bearing kimberlite dykes near Eurelia, from which bulk sampling recovered 163 micro-diamonds totalling 1.46 carats (Muggeridge 2001). The semi-arid rangeland of the Pine Creek site was included by DeBeers in early trials in the use of ground (1992) and airborne (1997) spectral techniques to map kimberlite (Hussey 1998). Although data from the airborne trials have not been placed in the public domain they were regarded as encouraging (Hussey 1998) and have been made available for related research (e.g., Lewis *et al.* 2000). In March 2002, PIRSA/CRCLEME took the opportunity to reacquire hyperspectral data over the Pine Creek kimberlite using HyVista Corporation's HyMap airborne scanner, deployed at the time to map magnesite near Port Pirie and carbonate host to zinc silicate mineralisation at Beltana in the Flinders Ranges. This paper examines the application of hyperspectral surveys to kimberlite detection in the Terowie area in the context of local basement geology and regolith, kimberlite mineralogy that gives a spectral response in the visible to near infrared, and company exploration objectives.

GEOLOGY

The Pine Creek kimberlite cluster was 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 1). The main diatreme is hosted by contorted fine-grained, crystalline marble of possible diapiric origin, termed the Ucocola Inlier, that forms an infaulted core of older rocks, possibly Curdimurka Subgroup (Cowley & Preiss 1997). Samples of unweathered kimberlite are composed of macrocrysts of olivine, monticellite and phlogophite in a groundmass of olivine, monticellite, phlogophite, perovskite, clinopyroxene, anatase, apatite and opaques (Howard 2003b). Near-surface kimberlite is weathered to mostly Mg-clay and carbonate. While rocky outcrop is present in the area, shallow calcareous soil is widely developed on erosional bedrock landforms, and depositional regolith as alluvial and fluvial sediments of variable thickness forms an extensive blanket within areas of present and palaeo-drainage (Figure 1).

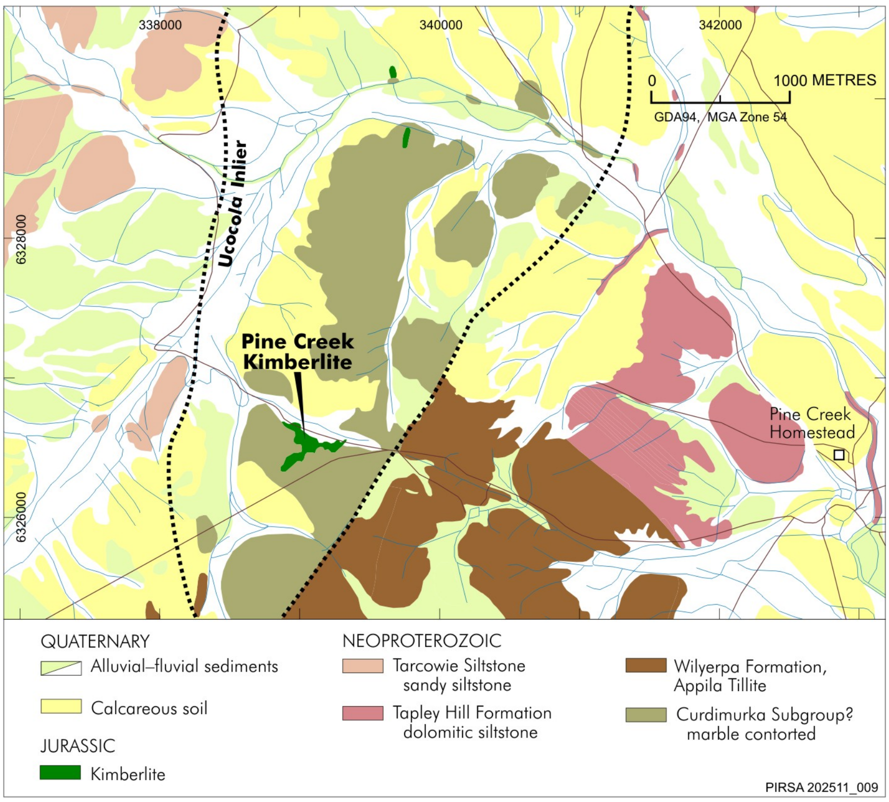

Figure 1: Basement and regolith geology of the Pine Creek kimberlite locality adapted from detailed regional mapping by Cowley & Preiss (1997) for the Burra 1:250,000 map sheet area.

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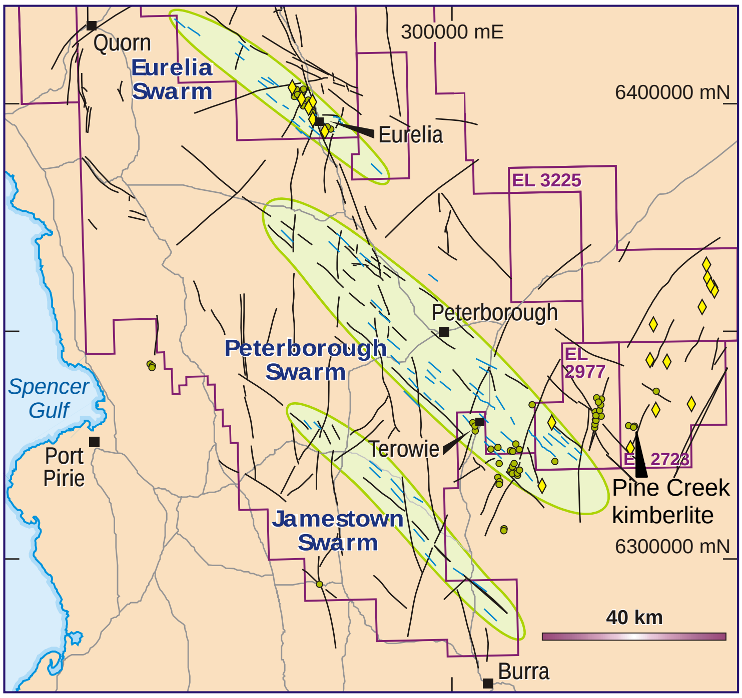
Kimberlite was emplacemed at Pine Creek in the Jurassic at around 174 Ma (K-Ar date on phlogopite). What remains is believed to represent the root zone of the diatreme with ca. 1,700 m of kimberlite stripped by erosion since emplacement (Colchester 1980). Smaller diatremes and dykes of similar age are known in the district and recent interpretation of regional airborne magnetic data suggest the presence of three significant zones of kimberlite dyke swarms trending northwest-southeast and centered on the townships of Eurelia, Peterborough and Jamestown (Figure 2) (Flinders Diamonds Ltd. 2004). Similar dyke swarms in South Africa host commercial grades of diamonds, although dykes from the same swarm can vary widely in diamond grade and include dykes barren of diamonds (Flinders Diamonds Ltd, 2004). The exploration objective is therefore to locate as many dykes as possible and to test each for diamond grade initially using micro-diamond content in 20 kg loam samples with follow-up bulk sampling on positive results. The use of airborne hyperspectral surveys as a regional exploration tool is being considered, in addition to detailed gravity, magnetic and electrical geophysics, as a technique to improve success in defining targets for sampling, especially in areas already identified as high priority on the basis of positive returns for diamond indicator minerals from regional stream sampling.



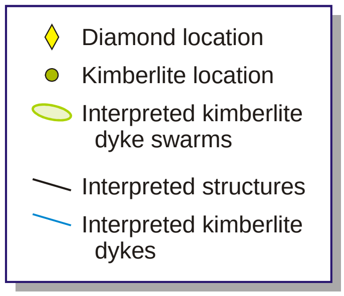


Figure 2: Interpreted kimberlite dyke swarms in the Terowie district from airborne magnetic data with location of known kimberlite and diamond occurrences (reproduced with permission of Flinders Diamonds Ltd.).

SPECTRAL DATA ACQUISITION AND PROCESSING

HyMap hyperspectral data were acquired on 13 March 2002 as four adjacent image strips each of 26 km length and 2.45 km swath width. Flying height was a nominal 2000 m on headings of 113/293 degrees with 5 m pixel resolution. Unfortunately, incorrect terrain data resulted in a lower flight altitude being selected, giving a higher pixel resolution of ca. 4.5 m and incomplete overlap for portions of the flight lines.

HyMap delivers high accuracy, calibrated radiance data over 126 channels covering the wavelength range 400 to 2,500 nm with approximately 15-20 nm spectral resolution. adiance data were processed to apparent reflectance using ATREM software (CSES 1999). ENVI image analysis software was used for analysis of the spectra. Processing techniques included correction for variation in cross-track illumination, spectral unmixing and end-member selection using Pixel Purity Index™ (PPI), with identification of end-members from their reflectance spectra, supported by field sampling. End-members assigned to kimberlite were confirmed to be predominantly a mixture of Mg-clay and carbonate. With this information, an approach to defining regions of interest was adopted based on the absorption feature at around 2,300 nm wavelength and using colour RGB composites for bands 115:118:109 with density slicing on band 115 (2,313 nm) (Figure 3).

FIELD SAMPLING

The airborne spectral data were acquired prior to a detailed investigation of secondary dispersion of kimberlitic indicator minerals at the Pine Creek site by a consultant (Howard 2003a). That study required backhoe excavation of a series of trenches in kimberlite and alluvial sediments. The opportunity was taken to collect surface and subsurface samples in order to track mineralogical changes down the profile at trench site PTC I (Howard 2003b) excavated in weathered kimberlite. Spectra of bulk samples were recorded using a portable near-infrared spectrometer (PIMA II - wavelength range 1,400-2,500 nm) and samples were selected for analysis by X-Ray Diffraction (XRD) and Scanning Electron Microscope (SEM). In addition, the clay (0.2-2 µm) and fine clay (< 0.2 µm) fractions were separated by repeated dispersion and centrifugation for clay mineral characterisation by XRD and near-infrared techniques.

RESULTS AND DISCUSSION

From the airborne spectral data, a strong 2,300 nm wavelength absorption feature over kimberlite is characteristic but not unique. In areas where the stratigraphy is dominated by quartzose sedimentary rocks of mainly quartz, illite and kaolin mineralogy, a strong 2,300 nm absorption feature in the spectral data is anomalous and worthy of investigation, especially when the shape is compatible with that of a basic dyke or diatreme. Where carbonate was more abundant, spectral anomalies were common and it was difficult to differentiate those due to primary and surficial carbonate from those due to basic rocks or their weathering products. This is the case for Pine Creek kimberlite where marble of the Ucocola Inlier (Figure 3) gives rise to thin soil with Mg-carbonate and associated Mg-clay that have a strong 2,300 nm absorption feature. A further complication at Pine Creek is the possibility of additional diatreme intrusions within and marginal to the Ucocola Inlier as inferred from ground spectral surveys, airborne magnetics and indicator minerals but as yet not confirmed (Hussey 1998, Howard 2003a, b).

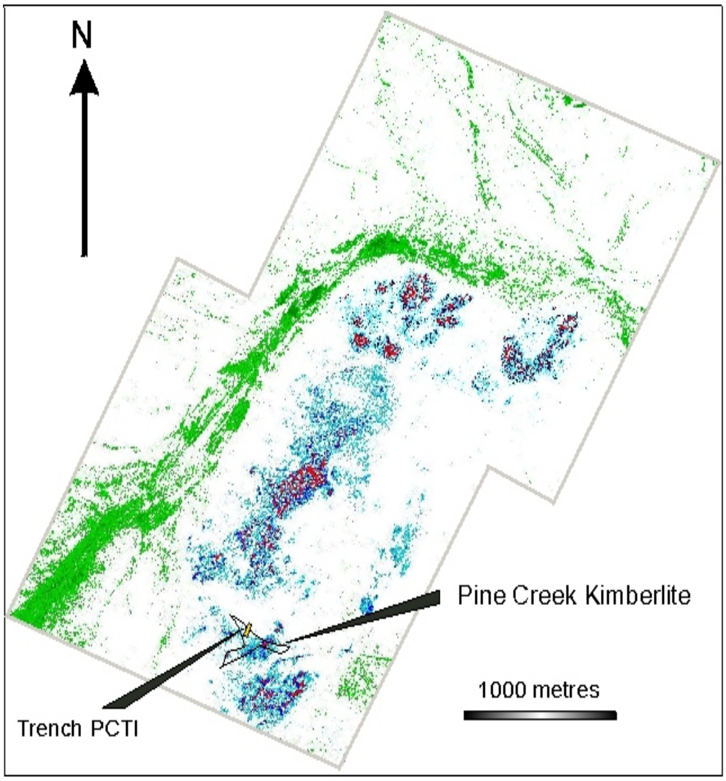


Figure 3: RGB image for band ratios 115:118:109, showing anomalous 2,300 nm wavelength absorption features (red) in the Ucocola inlier.

Trench PCT I was excavated shortly after the HyMap survey on near-surface kimberlite which did not show a surface spectral anomaly (Figures 3 & 4). The lack of an anomaly is apparent from the mineralogy (Table 1, Figure 5a), where the top 0.5 m contains significant transported alluvium exotic to the underlying kimberlite bedrock. In particular, high quartz content, calcite, illite and dominantly Al-rich smectite produce absorption at around 2,200 nm and only a small inflection at 2,310 nm (Figure 5a). This is substantially different from weathered kimberlite composed of calcite with co-dominant dolomite, smectite as ferruginous saponite, and vermiculite. These combine to contribute a strong Mg-OH absorption feature at around 2,300 nm (Figure 5a). Composition of the smectite as ferruginous saponite was confirmed by XRD and near-infrared on < 0.2 µm size fractions (Figure 5b), and by SEM/EDX analysis. The fine-grained Mg-Fe smectite is ubiquitous as a coating on larger mineral grains and dominates the observed reflectance spectra. The combination of vermiculite with ferruginous saponite gives a distinctive absorption spectrum (Figure 5a) that may be useful in identifying weathered micaceous kimberlite in shallow subsurface samples.

Figure 4: Trench PCTI excavated in Pine Creek kimberlite showing 0.5 m of transported alluvium over weathered micaceous kimberlite.

Table 1: Mineralogy (XRD) of a profile through weathered kimberlite in trench PCTI.

Depth	Bulk mineralogy	<0.2µm fraction
0.0-0.5m	*Dominant* quartz, sub-dominant calcite, *minor* dolomite, vermiculite, smectite, albite and kaolin, *trace* mica, hematite, orthoclase and talc.	*Dominant* smectite, *minor* illite and calcite, *trace* kaolin.
0.5-0.8m	*Co-dominant* calcite and dolomite, *minor* smectite, vermiculite and quartz, *trace* mica, hematite, orthoclase, kaolin and talc.	*Dominant* nontronite/saponite, *trace* calcite
0.8-1.3m	*Co-dominant* calcite and dolomite, *subdominant* smectite, *minor* vermiculite, *trace* quartz, mica.	*Dominant* nontronite/saponite, *minor* sepiolite? *trace* calcite.
1.3-2.2m	*Co-dominant* calcite and ankerite, *subdominant* smectite, *minor* vermiculite, *trace* quartz, mica, hematite and anatase.	*Dominant* nontronite/saponite.

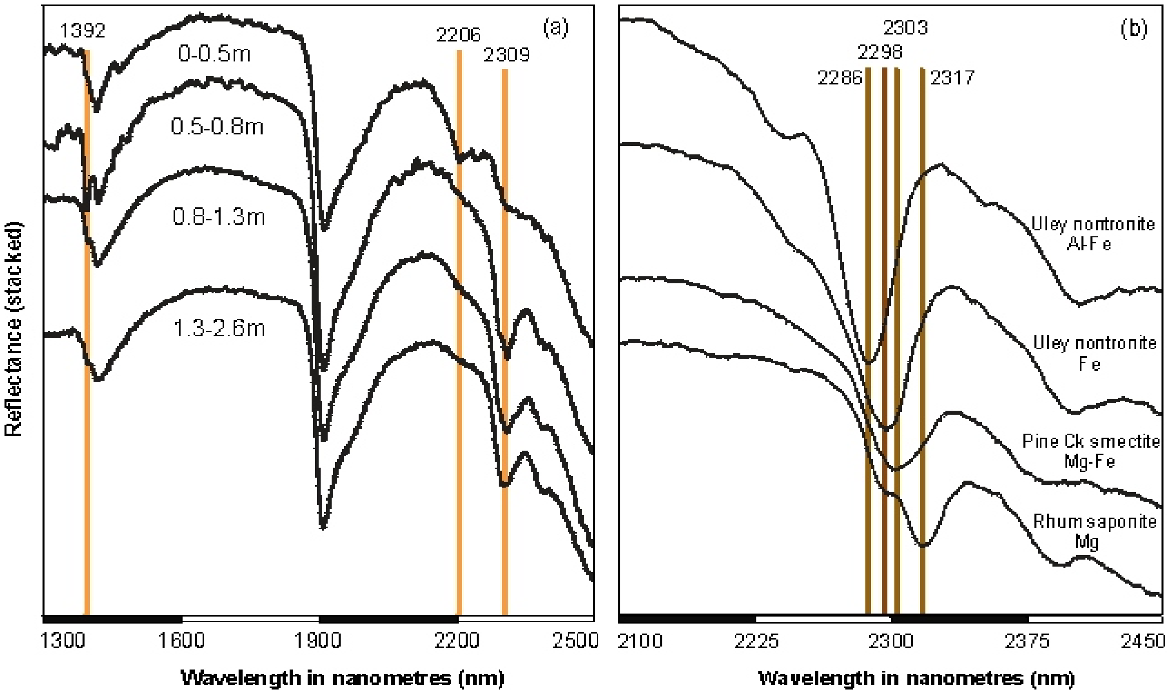


Figure 5a (left): PIMA spectra for pulp samples down the profile in trench PCTI recording 0.5 m transported alluvium over weathered kimberlite that shows strong absorption near 2,300 nm wavelength and distinctive absorption at 1,392 nm, probably due to vermiculite. **(b) (right):** PIMA spectra of separated < 0.2 µm sample fractions of Pine Creek clay and selected standard Fe-Mg smectite showing regular shift of the absorption feature to higher wavelengths as Mg content increases relative to Fe.

In erosional bedrock landforms in the Pine Creek area, where thin soils reflect the weathered products of underlying bedrock, a strong absorption in the 2,300 nm region due to Mg-clay and Mg-carbonate is consistent with the presence of either basic intrusive rocks or high carbonate concentration. This spectral feature clearly identified the Ucocola Inlier as broadly anomalous with particular anomalies showing reasonable coincidence with known kimberlite (Figure 4). Also highlighted were two smaller diatremes in the Calcutteroo area, 9 km northwest of the Pine Creek diatreme. In all cases, surface disturbance by previous exploration activity had increased the area of bare soil and redistributed subsoil at the surface that enhanced the 2,300 nm spectral feature. Field checking of a number of additional spectral "targets" showed these to be mostly recrystallised Mg-carbonate veins or soil carbonate/clay, although some remain ambiguous. To date, no new kimberlite has been identified from the spectral data. While surface soil exposure in this semi-arid region is typically between 30 and 50%, in some areas vegetation cover is an impediment to airborne spectral mineral mapping and for areas of subdued topography, aeolian, alluvial and fluvial sediment effectively mask any bedrock signature.

Results were not sufficiently encouraging to recommend expenditure on regional hyperspectral coverage, especially given that narrow dykes, commonly < 1 m wide, are the focus of current exploration in the area.

Ground spectral surveys in conjunction with loam sampling could assist with identifying weathered kimberlite near-surface. Company exploration techniques proposed for the district include detailed airborne magnetic surveys at 100 m line spacing, stream and loam sampling for the indicator minerals picroilmenite, pyrope, chromite and chrome diopside and micro-diamonds, and targeted soil geochemistry for elevated Nb, Cr and Ni. Detailed structural mapping has also been promoted as a means of locating further kimberlite vent sites by identifying strike-slip macro-faults regarded as a significant structural control on kimberlite dyke emplacement in the region (Curtis 2003).

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