DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2003/43

Field and laboratory reflectance spectra of kimberlitic rocks, 0.35 - 2.5 μm, West Greenland

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Introduction

Project background

Project Hypergreen 2002 of the Geological Survey of Denmark and Greenland (GEUS) conducted a hyperspectral (HS) airborne survey in West Greenland in 2002. The Bureau of Minerals and Petroleum (BMP), Government of Greenland financed the project. HyVista Corporation, Australia was selected as the contractor for the airborne survey using the company's HyMap hyperspectral scanner, manufactured by Integrated Spectronics Pty, Ltd, Australia.

The prime objective of the airborne HS survey is to assist the mapping of the kimberlitic rocks. The earlier investigations have demonstrated that some of the kimberlites in West Greenland are diamond-bearing, which has made the region an important target for diamond prospecting.

To establish the spectral characteristics of the kimberlitic rocks of West Greenland, a field programme was carried out to measure spectra from selected kimberlite occurrences. Accurate spectral ground truth from the known occurrences of kimberlitic rocks is of crucial importance for the development of image processing procedures for the mapping of kimberlitic rocks.

The field work was carried in the period 1st of July – 30th of July 2002. The activities were based on Kangerlussuaq International Science Support (KISS) facilities at Kangerlugssaq.

The most important means of transportation during the fieldwork was a helicopter - chartered on *ad hoc* basis from the company Grønlandsfly. Limited fieldwork could also be carried out by car in the surroundings of Kangerlussuaq airport.

The scope of this report is to provide (1) a technical description of the essentials of the data collection and (2) the spectral database with descriptive and geolocation information.

Personnel and responsibilities

Experts from Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Hannover, Germany and Geological Survey of Finland (GTK) were invited to carry out the field and laboratory measurements. The field staff comprised the following persons:

Uwe Schäffer	BGR	01 – 22/July 2002	Research scientist
Viljo Kuosmanen	GSF	04/July - 01/Aug 2002	Research scientst
Jukka Laitinen	GSF	04 – 16/July 2002	Research scientist
Johan Ditlev Krebs	GEUS	01- 30/July	Research assistent
Tapani Tukiainen	GEUS	03/July – 11/August 2002	Project leader

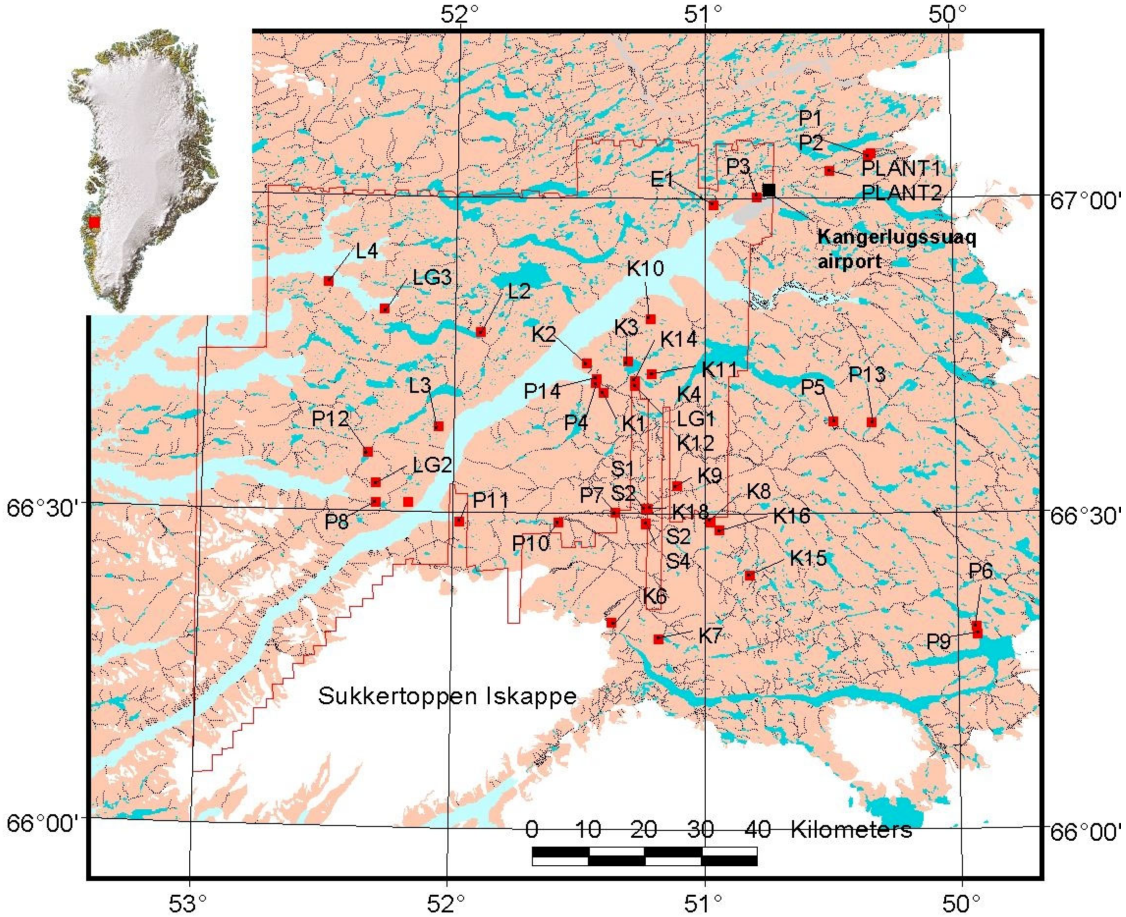


Figure 1. *Field localities where spectroradiometric measurements were carried out. The area covered by the airborne hyperspectral survey is indicated by the thin red line. Code for sites are: K = kimberlitic rocks, L = lamproitic rocks, LG= local geology, S=rocks of the Sarfartoq carbonatite complex, P=pseudo invariant fields, Plant=vegetation, E=environmental.*

Figure 2. *The biggest kimberlite exposure (K12) with abundant weathering material seen from the East. Insert: close up of the dike.*

Measurement localities

The 44 measurement localities (Fig. 1) fall into seven categories:

Kimberlite (K):

Field measurements were carried out in 18 localities. The visited occurrences vary from thin, some decimeter wide dykes or sheets to a major c 3 meter wide dyke (locality K12, Figure 1. andFigure 2.). Rock exposure is a rule poor, some of the localities are merely *in situ* block fields.

Lamproite (L):

Lamproitic rocks occur in the western part of the area. Size and rock exposure conditions are similar to the kimberlites.

Local geology (LG):

Spectral characteristics of the country rocks; gneiss, amphibolite, mafic dykes, anorthosite, etc. were measured at some localities.

Sarfartoq carbonatite complex (S):

The major rock types of the Sarfartoq carbonatite complex: carbonatite (sövite, beforsite), fenite and pyrochlore enriched rocks were measured in four localities.

Pseudo invariant fields (P):

The airborne imaging spectrometry data is normally offered to the client by the operator as 'at sensor' radiance which has to be transformed into ground reflectance. Therefore spectral measurements on large 'standard reflectance panels'' on ground level are needed for downward calculation of radiance and to transform it into ground reflectance. In practise, large homogenous, flat fields, such as sand dunes, homogenous rock outcrops are chosen and prepared for these purposes. Wulder et al. (1996) call them 'Pseudo Invariant Fields' (PIF's). The PIF's are practically ideal if they fulfil the following requirements (Kuosmanen et al 2000):

- A PIF must be approximately a Lambertian surface
- Internal spectral reflectance should be smooth, no sharp absorption features
- Internal reflectance content of each PIF is as constant as possible. Sun illumination must be uniform on the PIF surface. These are checked by consecutive measurements from different locations on the PIF, before and after overflight.
- Minimum size of PIF is 3x3 pixel sizes
- Minimum number of PIF's is two, light (over all wavelengths) and dark (over all wavelengths)
- The PIF's are optimally located if they lie in the centre of the flight line.
- The PIF area must be distinguishable from its background. A clear spectral signal (e.g. a car) can be placed in the neighbourhood.
- Sun irradiance on each PIF is measured during the overflight
- A helicopter camera photo from each PIF is of great help, when a reference pixel is searched from HyMap data.

Fourteen PIF localities – mainly homogeneous, vegetation free exposures of alluvial material were selected from the HyperGreen survey area. Most of the above requirements were met in all chosen localities. However, due to complicated flight execution and actual instrument availability, irradiation measurements during the overflight were not possible.

Environmental (E):

Spectra from selected localities with an oil-contaminated surface layer were cursorily measured in the vicinity of the abandoned military radio antenna facility at Kellyville (E).

Instrumentation and methods

FieldSpecFR instrument specifications and set up

The specifications for the portable spectroradiometer FieldspecFR used for HyperGreen 2002 measurements are summarised in Table 1.

Table 1. *Specification for FieldSpecFR*

Parameter	Specifications
Spectral Range	350-2500 nm
Spectral Resolution	3.0 nm @ 700 nm 10 nm @ 1400 & 2100nm
Sampling Interval	1.4 nm @ 350-1050nm 2.0 nm @ 1000-2500nm
Scanning time	100 milliseconds
Detectors	One 512 element Si photodiode array 350-1000 nm Two separate, TE cooled, graded indexInGaAs photodiodes 1000-2500 nm
Input	1.4 m fiber optic (23° field of view) Optional foreoptics available
Calibration	Wavelength, reflectance, radiance*, irradiance*. All calibrations are NIST (NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY) traceable (*radiometric calibrations are optional)
Noise Equivalent Radiance (NeDL)	UV/VNIR 1.4 x 10^{-9} W/cm2/nm/sr @700nm NIR 2.4 x 10^{-9} W/cm2/nm/sr @400nm NIR 8.8 x 10^{-9} W/cm2/nm/sr @2100nm
Notebook Computer	Pentium processor, 800 MB hard disk, 16 MB Ram, 3.5" floppy disk drive, battery, AC power supply
Weight	7.2 kg

The fore optics (optical lenses in front of the scanner used to set the effective angle of incidence) for radiance measurements of the Spectralon reference panel (measured for irradiance determination) and target measurements under sunlight were as follows:

- GTK instrument: bare fibre (e.i. 23 degrees field of view (FOV))
- BGR instrument: fore optics resulting in 8 degrees of FOV

Makita contact probe and lamp was used for contact measurements of the targets. Type of fore optics is mentioned with all measurements in the HyperGreen spectral database.

Calibration and units

The following practise for the calibration of radiance, irradiance and reflectance measurements were used:

Radiance and irradiance calibration is in-built in the instrument but it was cross-checked between the GTK and BGR instruments. (Radiance Unit: W/sr•m^{2,} Irradiance Unit: W/m^2).

Reflectance Standard: A Lambertian diffuse 'Spectralon Reference panel' was used as a reflectance standard. This panel is mainly composed of PTFE and it provides 100% light reflectance over wavelengths 400-2500 nm. (Spectralon® is a registered trademark of Labsphere, Inc.).

Reflectance: Reflectance of a surface is the ratio of the radiant energy reflected from a surface to the radiant energy incident on the surface. (Reflectance unit: % or fraction).

Reflection: The process by which incident illumination reacts with the sample and is converted to radiant energy that subsequently travels back away from the sample surface (also see Absorbed Energy). All real reflection involves varying degrees of specular reflection and diffuse reflection.

For more definitions and details see http://www.asdi.com/asdi_t2_sc_glo.html

Illumination conditions

Sun illumination conditions were highly variable during the fieldwork in July 2002 due to unpredictably changing weather. This may affect the HyMap data quality. However, because it was possible to choose and measure several ground truth localities (PIF's) by Makita light, it is expected that satisfactory homogenisation of the HyMap data can be achieved.

Field measurements

Two persons are normally needed to carry out field measurements with one FieldSpecFR instrument. The technical performance of field reflectance measurements is carried out through a repeated sequence of steps after arriving to the target, explained in the following instructions:

1. Open FieldSpec and mount the accessories, turn the instrument on and then the computer on.
2. Choose fore optics according to target distance and size, and illumination needed depending e.g. on sunlight availability.
3. Run 3-sensor calibration & black current determination
4. Choose the savefile number and mode (Radiance Irradiance or Reflectance) of measurements to be stored
5. Run White Reference (WR) if reflectance was chosen in 4
6. Direct the fiber with foreoptics to the target
7. Record the reflectance to the ASD savefile.
8. Transfer the savefile into Excel or ascii for further input into HyperGreen spectral database

Laboratory measurements

Perkin Elmer Lambda 19 laboratory spectrometry

Seventy six selected samples of rocks, debris and soils from different target areas have been chosen for laboratory spectrometry at the BGR Perkin Elmer Lambda 19 laboratory instrument in Hanover. Multiple measurements of kimberlitic and other rock samples with respect to different surfaces underlined the fact that the general reflection signal of dark kimberlites is very weak. Fresh samples of kimberlites (cutted or broken surfaces) reveal a very poor and non-distinctive data set in the reflective range of 400 to 2500 nm.

Distinctive features can be expected from brighter weathered surfaces, which reflect the natural field conditions. For that reason some samples have been measured several times under different conditions.

For simplification, the results and the assessment of signal quality have been differentiated into:

- strong signal,
- distinct signal,
- existing signal,
- weak signal,
- no, or weak signal.

The important specifications of the UV/VIS/NIR Perkin Elmer Lambda 19 instrument are:

- double beam ultraviolet / visible / near-infrared spectrometer,
- PC-controlled,
- Spectral range: 185 – 3200 nm,
- Spectral resolution: +/- 0.15 nm (UV / VIS), +/- 0.6 nm (NIR),
- Sampling slit: 0.05 – 5.0 nm (UV / VIS), 0.2 – 20 nm (NIR),
- Sampling interval: 0.01 nm (UV / VIS).

All measurements have been carried out in the range of 400 to 2500 nm, with a sampling slit of 2.0 nm and samling interval of 1.0 nm.

FieldSpecFR laboratory spectrometry

A set of kimberlite hard rock and powdered samples were also measured by FieldSpecFR in GTK's Remote Sensing Laboratory. These measurements do not significantly differ from those done in the field. Fore-optics for hardrock samples was Bare Fiber with 50 W tungsten-halogen light source and for the powders, the Makita mounting was used.

Spectral database

Overview

To make the data readily available for interested parties, the results of the fieldwork is stored in a Microsoft Excel-file on CD-ROM:

HyperGreen2002_Spectral_library.xls

The spectral database contains references to digital photographs (jpeg - format): these are stored on a directory HyperGreen2002_photos on the CD-ROM.

Table 2. *The structure and attributes of the database:*

Sheet Name	Field name	Values	Comments & descripton
Descriptions	Spectra_Id	BGRnnn GTKnnn	*Unique spectra id*
Descriptions	Date		
Descriptions	GEUS_Sample_#		
Descriptions	Locality	*Locality types:*	*K=kimberlite,* *L=lamproite* *LG=local geology* *P=pseudo invariant feature* *S=rocks types within Sarfartoq Carbonatite complex.* *E=environmental (from Kelly Ville)* *Plant = vegetation*
Descriptions	Measuring method		
		Sun 8 deg	*FieldSpec optic fibre with lens sunlight*
		Sun 23 deg	*FieldSpec raw optic fibre sunlight*
		Lab/Perkin Elmer	
		Lamp & Lab/lamp	*FieldSpec raw optic fibre Tungsten halogen lamp*
		Cos receptor	FieldSpec cosine alpha receptor
Descriptions	Data type		
		Ref	*Reflectance*
		Rad	*radiance*
		Irad	*irradiance*
Descriptions	Distance	metres	*Distance between sensor and target*

Descriptions	Photo	file name	*Digital photo of target*
Descriptions	Latitude	decimal degrees	*Geographical co-ordinate*
Descriptions	Longitude	decimal degrees	*Geographical co-ordinate*
Descriptions	Altitude	metres	*Altitude above sea level*
Descriptions	Collector	initials	*Collectors' initials*
		UW = *Uwe Schäffer*	
		JDK = *Johan Ditlev Krebs*	
		TT = *Tapani Tukiainen*	
		JL = *Jukka Laitinen*	
		VK = *Viljo Kuosmanen*	
Descriptions	Loc_photos	file name	*Overview digital photo of locality*

Sheet	***Column 1***	***Column_2 – Column_n***	
BGR_LAB	Wavelength	Spectra	
GTK_LAB	Wavelength	Spectra	
			Row # 1: Spectra_ID Row # 2: GEUS sample # Row # 3 – 2500 data
BGR_FIELD_1	Wavelength	Spectra	Row # 1 Spectra_ID
BGR_FIELD_2	Wavelength	Spectra	Row # 2 – 2500 data (BGR)
GTK_FIELD_1	Wavelength	Spectra	
GTK_FIELD_2	Wavelength	Spectra	

In addition to the Excel-files a collection of digital photographs are included in the spectral database.

Spectral targets

Pseudo invariant features

Numerous PIF localities – mainly homogeneous, vegetation free exposures of alluvial material were selected for detailed, measurements. Reflectance measurements and the interpreted outliers for one PIF locality are shown in Figure 3. However, due to instrument availabilities the irradiation measurements during the overflight are not available. However, some mid day clear-weather irradiance measurements were done and documented into the spectral database. Spectral variability of the PIF reflectances (Figure 4) is not high, but maybe sufficient for finding 'dark' and 'light' pixels. The reflectance spectra in Figure 4 are averages of measurements for each PIF (outliers excluded).

In a few PIF localities, reflectance was measured both under sunlight and by Makita.
In the locality P3 (Figure 5) reflectance curves from sunlight and Makita measurements fit well in short wave infrared (SWIR) area, which is most important for mineral detection purposes. Differences in visible (VIS) and NIR area are due to the fact that the measurement localities were not exactly the same.

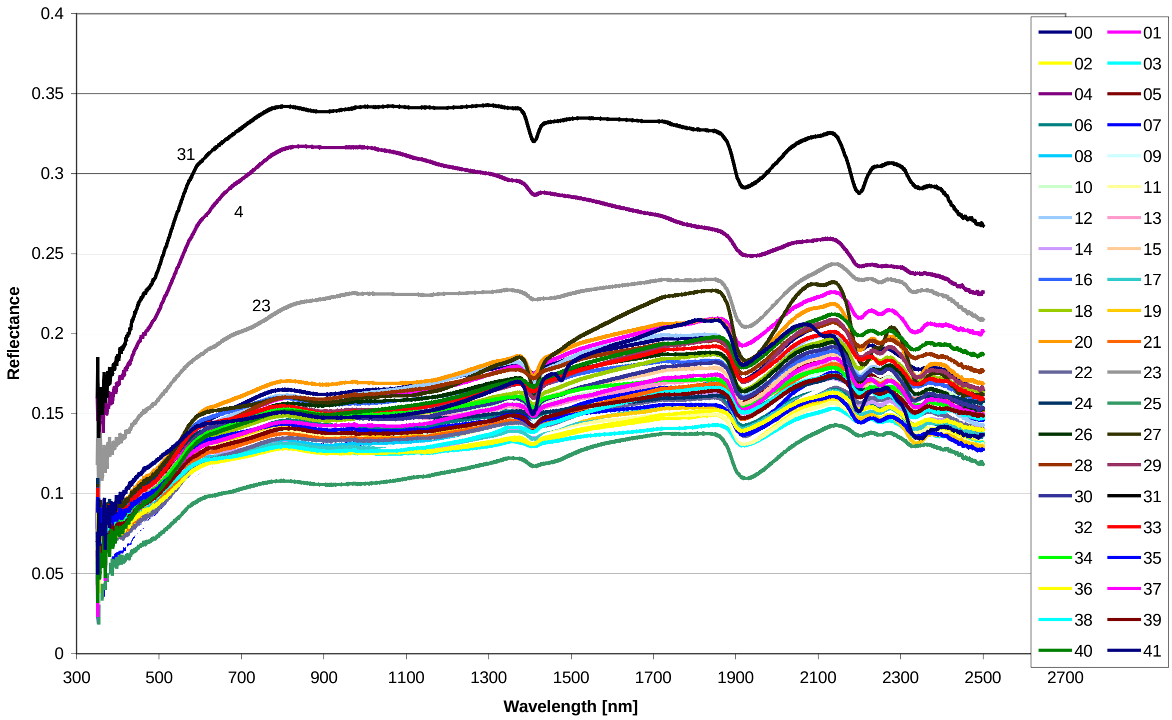


Figure 3. *Individual measurements from the PIF locality P10. The sample numbers 4, 23 and 31 indicates the excluded outliers.*

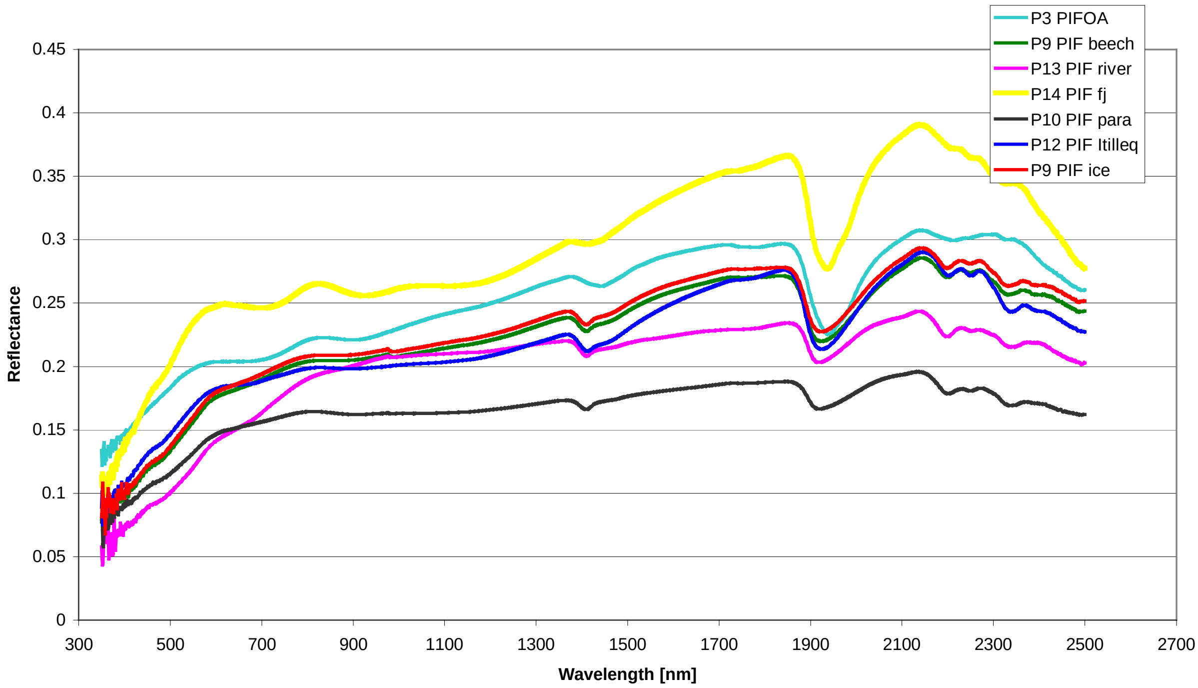


Figure 4. *Average spectral reflectances of seven PIF localities*.

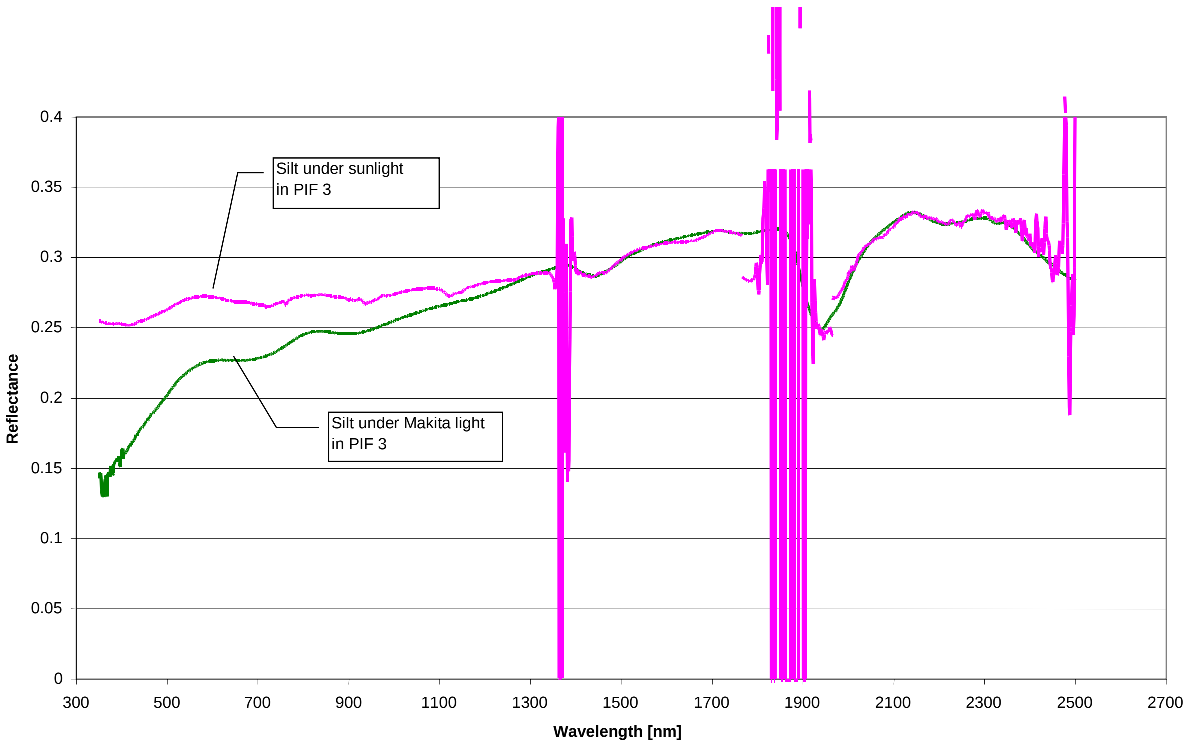


Figure 5. *Reflectance of the silt surface at PIF P3. Differences in the VIS &NIR area are due to slightly different measurement locations.*

Kimberlite targets

The kimberlite targets in the area are frequently covered by a weathering surface. Both the weathered 'soil' cover, the exposed hard rock weathered surface and the unaltered hard broken kimberlite surface were frequently measured (Figure 6).

An average reflectance curve of six PIFs can be regarded as the reflectance of 'bulk bed-rock' in Figure 7. Comparison between the average PIF reflection and the surface expressions of kimberlite in locality K12 gives a rough idea about their spectral separability (Figure 7 and Figure 8).

Kimberlite targets are mafic rocks with flat reflectance curves. The weathering surfaces, however, show tendency to have more vivid spectral appearance than the fresh broken surfaces. The spectral contrast between the weathered kimberlite and the surrounding rocks, as exemplified by the rocks in locality K12, is not great but clearly recognisable (Figure 8).

Comparison of the 'soil' covering the kimberlite and hard kimberlite rock suggests that the 'soil' on the kimberlite bodies seem to be a result of physical weathering rather than arise from chemical change (Figure 9 & 10).

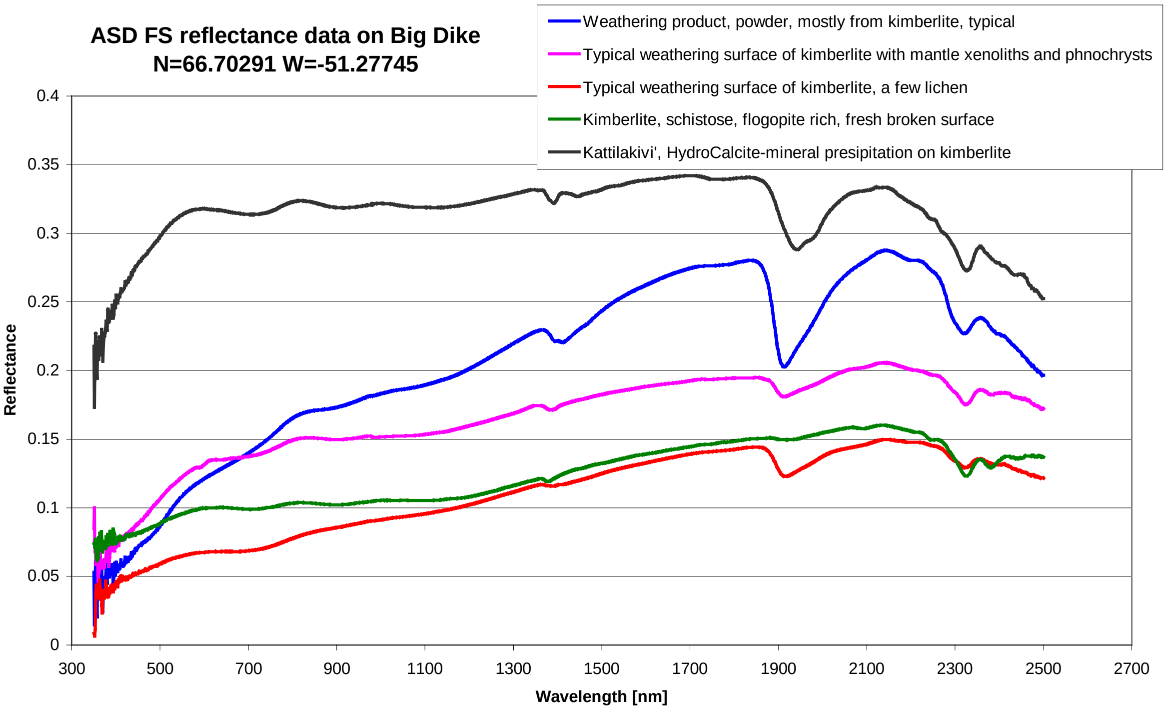


Figure 6. *Typical surface expressions of kimberlites.*

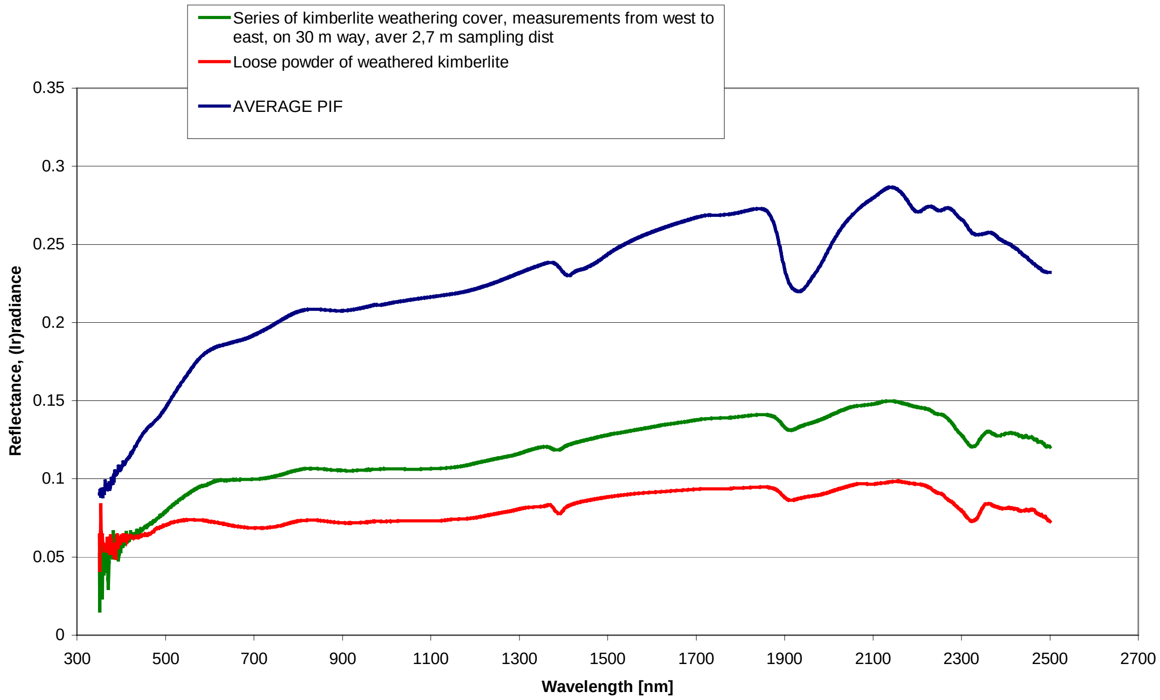


Figure 7. *Surface expressions of kimberlite (two lowest curves) in the kimberlite location K12 and average reflectance of six PIFs.*

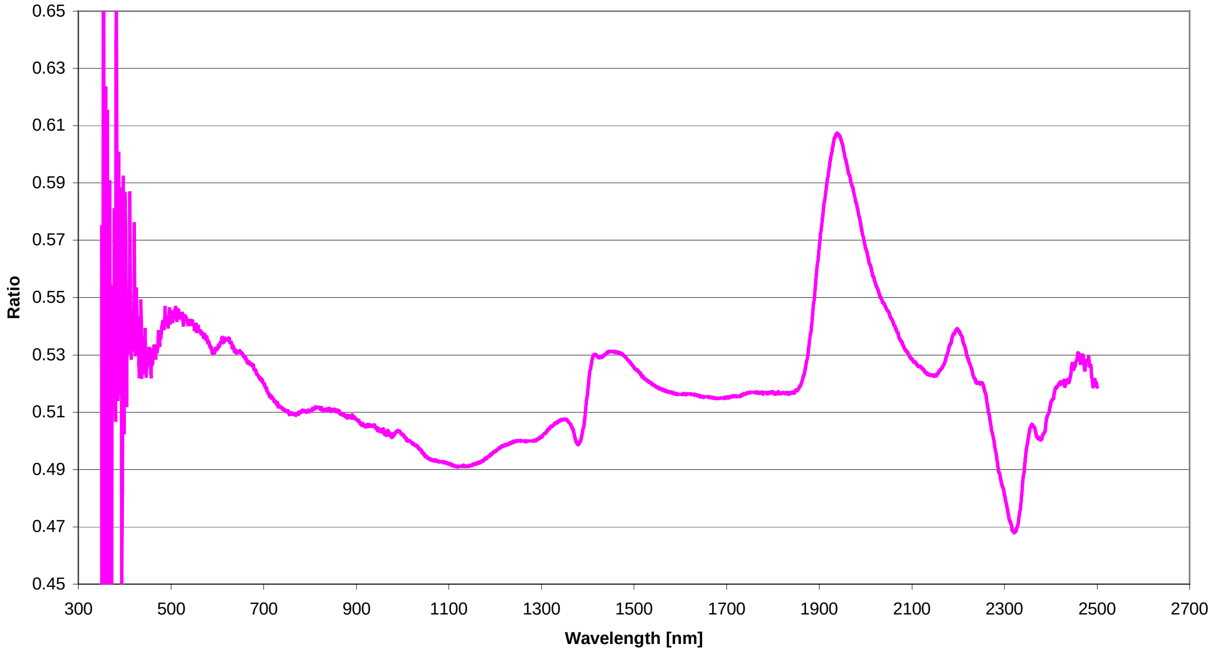


Figure 8. *Ratio between kimberlite suface expression and average PIF reflectance.*

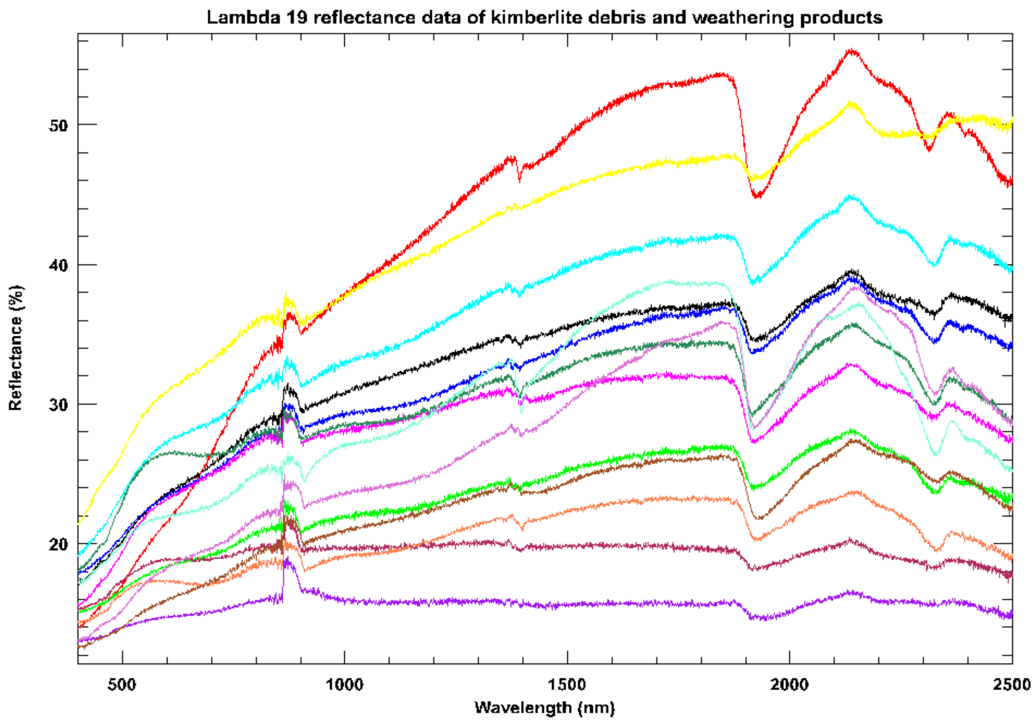


Figure 9. *Reflectance spectra of kimberlite debris, weathered kimberlite and overlying soil.*

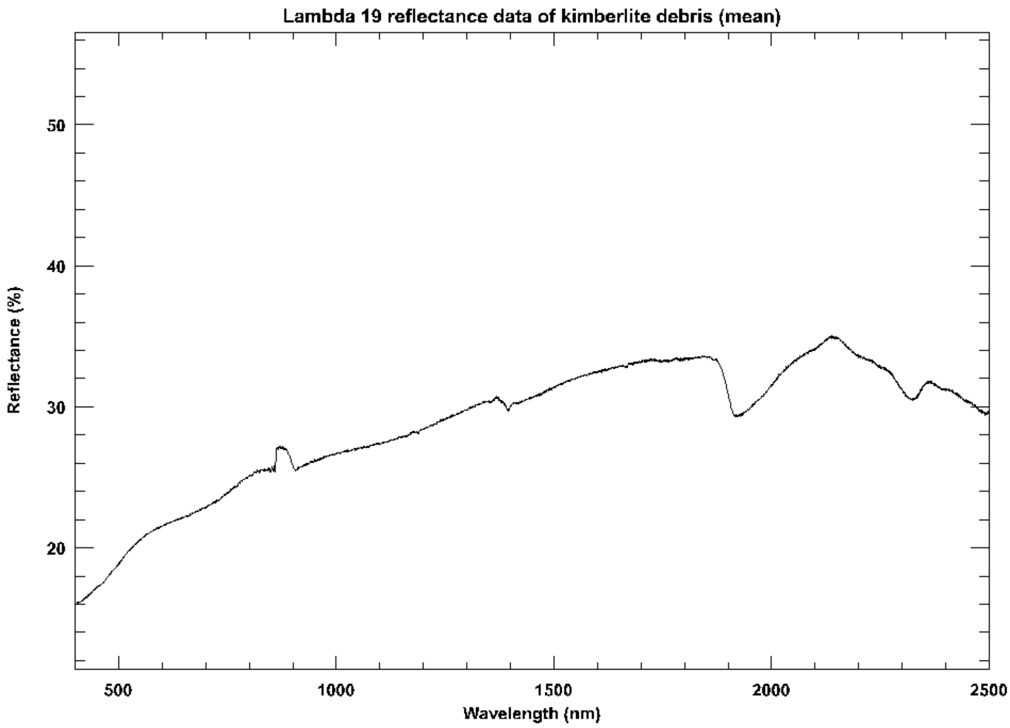


Figure 10. *Reflectance spectrum of calculated mean of crushed and weathered kimberlites.*

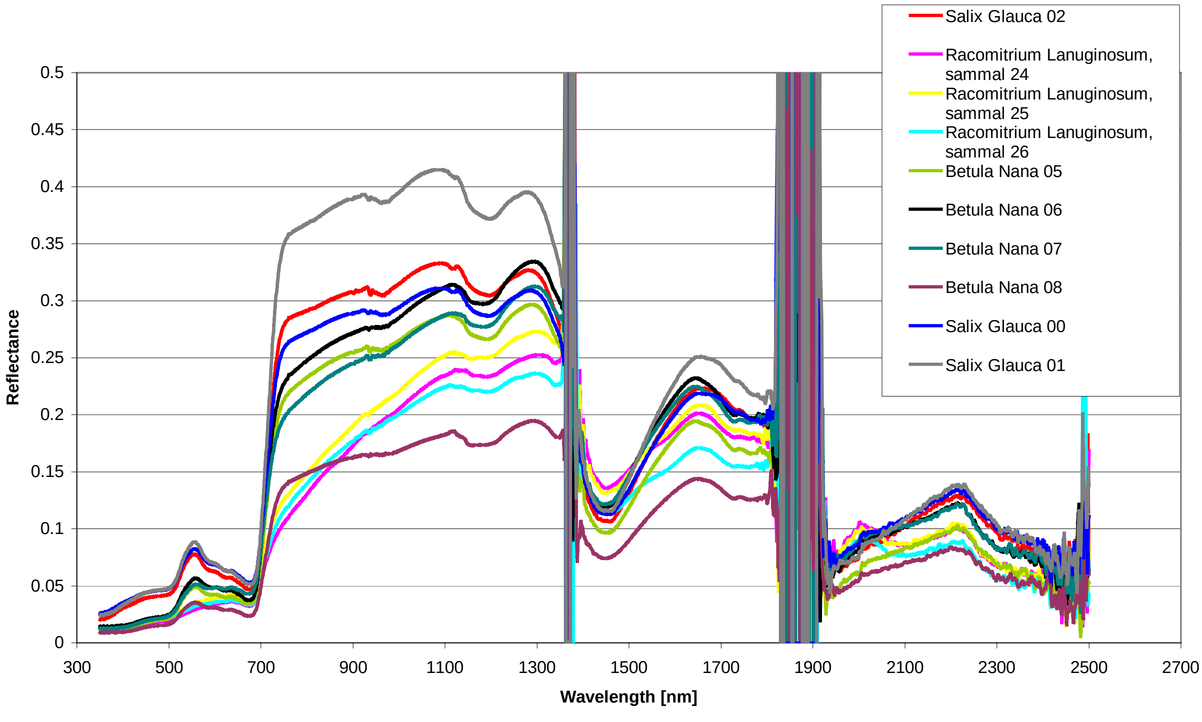
Vegetation targets

Twenty four typical vegetation targets were selected for reflectance measurements under sunlight. The GTK instrument used bare fiber for 'canopy' measurements from a distance of 0.3-1.0 meters.

The following plants were measured (Figure 11):

- Salix Glauca (willow)
- Betula Nana (birch)
- Kobresia Myosuroides (yellow hay)
- Calamagrostis Langsdorfii (green long flourishing hay)
- Racomitrium Lanuginosum (moss)
- Mixed pixel with hay, birch and moss

An orange lichen (Species not identified) seemed to be a typical cover for mafic/dark rocks such as gabbros, amfibolites, peridotites and kimberlites. This lichen occurred seldom on felsic rocks. A set of rock-lichen targets were measured (Figure 11). A typical exposed kimberlite surface is included in the diagram for comparison. Some kimberlite targets seem to



be covered by more flourishing vegetation than the country rock gneises.

Figure 11. *Vegetation spectra measured under sunlight.*

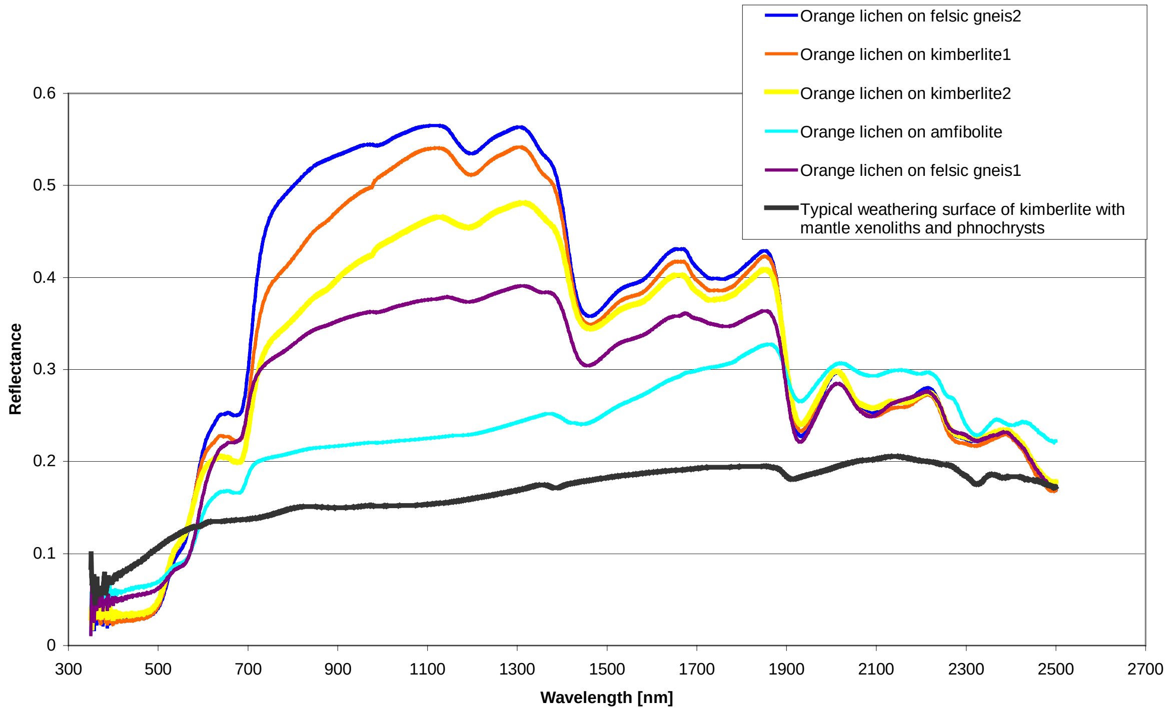


Figure 12. *Reflectances of mafic and felsic rock targets covered by orange lichen near locality K12. The lowermost curve characterises a lichen free, exposed and weathered (hard) kimberlite surface.*

Environmental targets

Reflectance measurements of environmental targets were cursorily measured in the vicinity of the abandoned US Antenna facility in Kellyville. The yard surrounding the facility is contaminated with hydrocarbons used for the antenna power supply station. Figure 13 shows reflectances of the contaminated black soil from the yard. The arrows indicate the typical hydrocarbon absorption features

In the greater area surrounding the yard, remnants of very dark oil spill were detected. Field spectroscopy and laboratory measurements (Lambda 19 at BGR) did not indicate the diagnostic hydrocarbon feature at the wavelength 1730 nm and 2310 nm within the radiance spectra. The reason for that is the very dark surface where nearly total absorption of the measurable reflective spectrum from 400 nm to 2500 nm exists. The “hydrocarbon feature” here is camouflaged due to this physical properties.

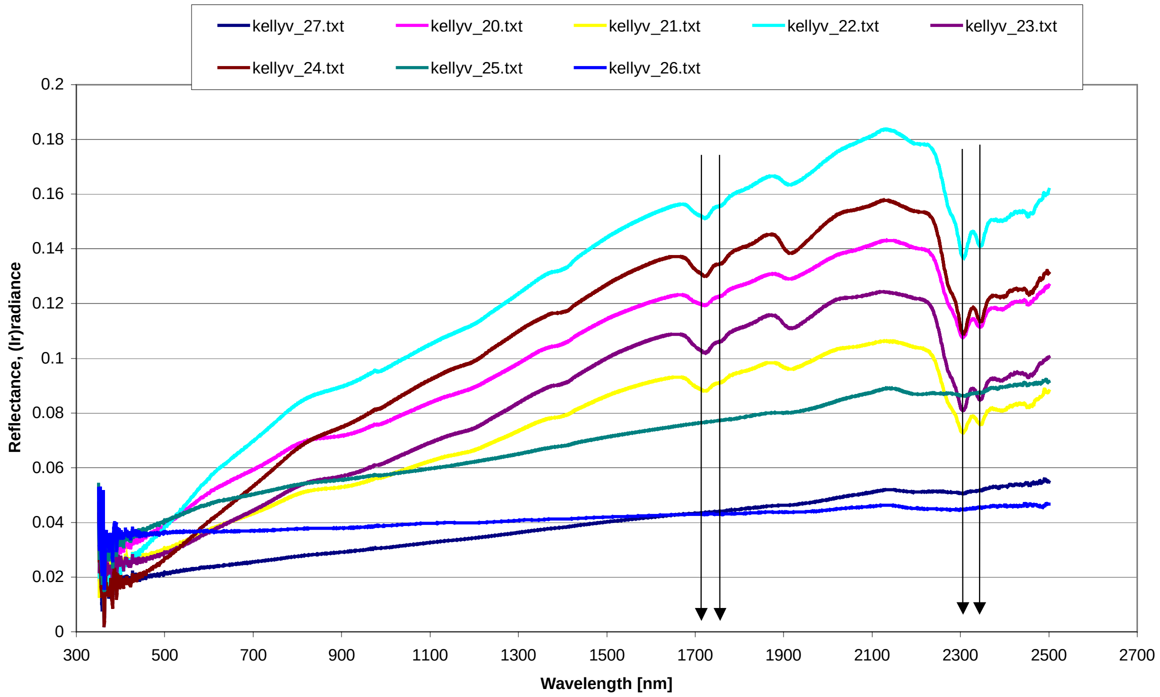


Figure 13. *Reflectances of black contaminated soil around the Kellyville abandoned antenna facility. The arrows indicate diagnostic features for hydrocarbons. –The "hydrocarbon feature" is lacking for the black oil contaminated soil samples (three lowermost flat curves, see text above).*

Evaluation of results

Kimberlite targets, by virtue of their mineralogy, are dark mafic rocks with generally low reflectances with a few absorption features. These features are, however, enhanced on the weathered rock surfaces contributing to a satisfactory spectral contrast between kimberlite and the country rock.

The spectra of the covering soil and hard kimberlite rock suggests that the 'soil' covering the kimberlite bodies seem to be a result from physical weathering rather than from chemical change.

The study area included several excellent sand or gravel Pseudo Invariant Features (PIF's) and a sufficient amount of their spectral characterisation could be recorded for their further use as ground truth for atmospheric corrections of HyMap data.

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