Mineralogical and textural characterisation of soils using thermal infrared spectroscopy

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Abstract

The ability of thermal infrared (TIR) spectroscopy to characterise mineral and textural content was evaluated for soil samples collected in the semi-arid environment of north-western Queensland, Australia. Grain size analysis and separation of clay, silt and sand sized soil fractions were undertaken to establish the relationship between quartz and clay emissivity signatures, and soil texture. Spectral band parameters, based on thermal infrared specular and volume scattering features, were found to discriminate fine clay mineral–rich soil from mostly coarser quartz-rich sandy soil, and to a lesser extent, from the silty quartz-rich soil. This study found that there was the potential for evaluating soil mineral and texture content using TIR spectroscopy.

Key Words

Soil composition, quartz, kaolinite, smectite, grain size, Tick Hill.

Introduction

Mapping soils for their composition and physical characteristics typically involves extensive field work and laboratory analysis of samples. Recent developments in proximal spectral sensing techniques offer the possibility of increasing the speed, and reducing the cost of interpreting soil samples. In particular, thermal infrared spectroscopy has been related to soil mineralogy and textural information (Salisbury and D'Aria 1992a). Spectral libraries, consisting of bidirectional TIR reflectance measurements, reveal diagnostic absorption features of many silicates (Salisbury and D'Aria 1992b). Proximal laboratory spectral measurements within the visible-near infrared and shortwave infrared wavelength region can identify clay, sulphates and carbonate minerals (Clark *et al.* 1992), common within soils. However discriminating the quartz or silicate content of soils requires spectroscopy within the mid- (*e.g.* 3-5 μm) and more commonly, the thermal- infrared wavelength regions (*e.g.* 7-14 μm) (Salisbury and D'Aria 1992b). This study was part of a much larger project to map surface minerals/chemistries using airborne hyperspectral and satellite ASTER imagery, applying visible, near infrared and shortwave infrared sensing (proximal and airborne) techniques (Cudahy *et al.* 2010). In particular this paper describes a study of thermal infrared emissivity measurements of soil samples from near Tick Hill (21°35'S, 139°55'E), to investigate quartz/clay content and texture.

Method

TIR spectra were measured from eight soil samples using the Designs and Prototypes microFTIR^{TM} 102 model (http://www.dpinstruments.com/). Soil samples were oven heated overnight at 60°C to obtain a consistent dryness. MicroFTIR^{TM} emission measurements were acquired from heated soil samples within ceramic crucibles, also at 60°C, from an approximate 20 mm field of view and using 16 scan integrations. Measurements were calibrated to radiance units ($W/m^2/sr/\mu m$) using hot and cold black body measurements set to 65°C and 30°C respectively. Background radiance (*e.g.* "downwelling") was removed by measuring the emission of a brass plate at room temperature (via a Pt thermocouple). Temperature-emissivity separation of the acquired radiance measurements was calculated using in-house software developed by CSIRO (Green, *pers. comm.*). Each soil sample was also analysed for mineralogy using XRD. The Tick Hill samples were analysed for grain size fractions, assuming traditional soil definitions: clay (< 2μm), silt (2-20 μm) and sand (20μm-2mm) by CSIRO Land and Water (http://www.clw.csiro.au/services/analytical/), using the traditional pipette method (McKenzie *et al.* 2002). These samples were firstly prepared by chemically removing salts, organic matter, and ferric iron (McKenzie *et al.* 2002). The resulting sand fraction was also separated between 20-60μm and 60μm-2mm. Each grain size fraction was measured twice for emission by the microFTIR^{TM}. The resulting emissivity signatures were imported into CSIRO software for processing proximal spectral data, “The Spectral Geologist^{TM} “ (TSG^{TM}, http://www.thespectralgeologist.com/). Interpretation of TIR spectroscopy was assisted by comparison with the Johns Hopkins University (JHU) TIR biconical reflectance spectral library (Salisbury and D’Aria 1992b), converted to approximate “emissivity” signatures, assuming Lambertian behaviour (*e.g.* emissivity=1- reflectance).

Results and discussion

XRD analysis of the Tick Hill soils revealed that their mineralogy consisted of quartz, smectite, kaolinite and minor amounts of illite. MicroFTIR^{TM} emissivity signatures of raw soil samples, MI122 and MI128, indicated the presence of quartz and clay minerals (*e.g.* kaolinite/smectite) (Figure 1). Although the quartz “reststrahlen” feature between 8 – 9.5µm is reduced in the raw soil samples compared to the JHU library spectra, the 8.62 µm feature remains distinctive. Likewise the 9.0 µm kaolinite feature is less distinctive in the raw soil mixture although the 9.5 µm feature remains.

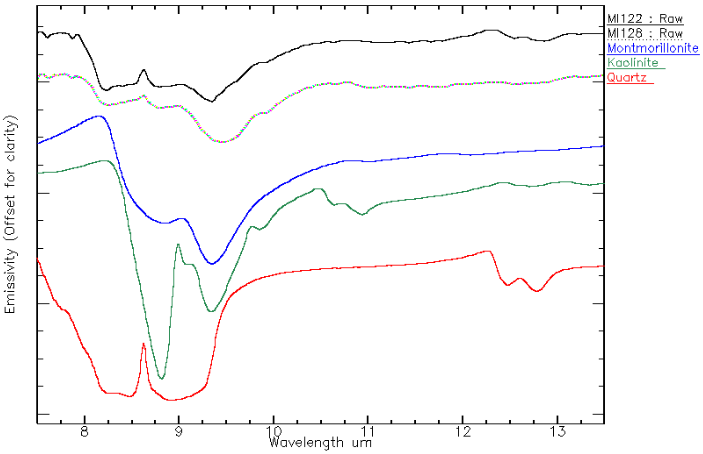

Figure 1. Example MicroFTIR^{TM} emissivity spectra of Tick Hill soil samples and JHU spectral library (Salisbury and D’Aria 1992b) highlighting the presence of mixtures of clays and quartz minerals within the samples.

The corresponding emissivity signatures for the various grain size fractions of samples MI122 and MI128, show a trend of increasing quartz reststrahlen 8.62 µm and decreasing clay 9.5 µm features, with increasing grain size (Figure 2). Also within the 10.5 – 12 µm wavelength region, “volume” scattering quartz features are associated with the 2-20 µm and 20-60 µm soil fractions (Salisbury and Eastes 1985) (Figure 2).

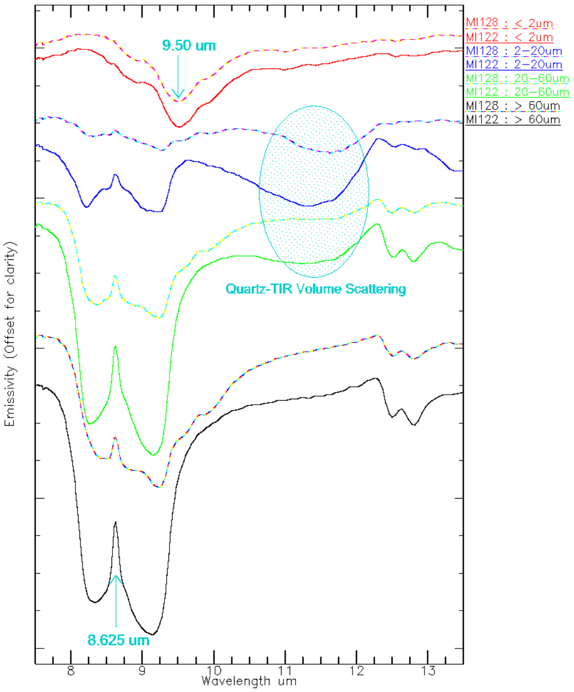

Figure 2. Example MicroFTIR^{TM} emissivity spectra of grain size separated Tick Hill soil samples showing diagnostic mineral and textural related spectral features.

By comparison, the reststrahlen quartz feature is associated with specular scattering from coarser quartz grains (Salisbury and Eastes 1985). Several samples, including the displayed MI128, also indicate small amounts of kaolinite within the 2-20 µm and 20-60 µm grain size fractions, as shown by their 9.0 and 9.8 µm spectral features (Figure 2).

The TSG^{TM} software was customised to target those emissivity features associated with kaolinite/smectite, quartz, and its volume scattering fine grained variation. In particular, band ratio parameters were devised to estimate the coarser quartz content (Emiss8632 / Av8383,8897) where Emiss8632 is the mean microFTIR^{TM} emissivity (±30 nanometres, nm) and Av8383,8897 is the average of the associated emissivity values at 8383 and 8897 nm. Similarly a band ratio parameter was devised for clay content (EmissAv9178,9852 / 9500) and the effects of fine quartz volume scattering, Qtz_scat._index (*e.g.* EmissAv10318,12279)/ (Emiss(1132+11664)). The results of these band parameters for each Tick Hill soil fraction, processed using TSG^{TM}, are shown in Figures 3, 4 and 5. Figure 3 shows that there is an approximate increasing trend in the quartz spectral parameter with increasing grain size. A higher quartz volume scattering behaviour for the mid-sized fractions (*e.g.* 2-60µm) is shown by the auxiliary colour coding (green to red, Figure 3). Figure 4 shows an inverse trend between the clay and quartz spectral parameters however a high clay value can still appear present within silty fractions (*e.*g. cyan coding, Log ~ 1.0 or ~ 10 µm) and some coarser fractions (*e.g.* red) exhibit a high clay spectral parameter. Developing predictive clay % algorithms is complicated by such residual clay content within separated soil fractions. However Figure 5 suggests predicting clay mineral content within fractions less than 10 µm with low quartz content (*e.g.* blue) is possible although finer soil fractions are required. Applying these spectral parameters to the eight raw soil samples did not reveal clear trends with grain texture although the number of samples limited this interpretation.

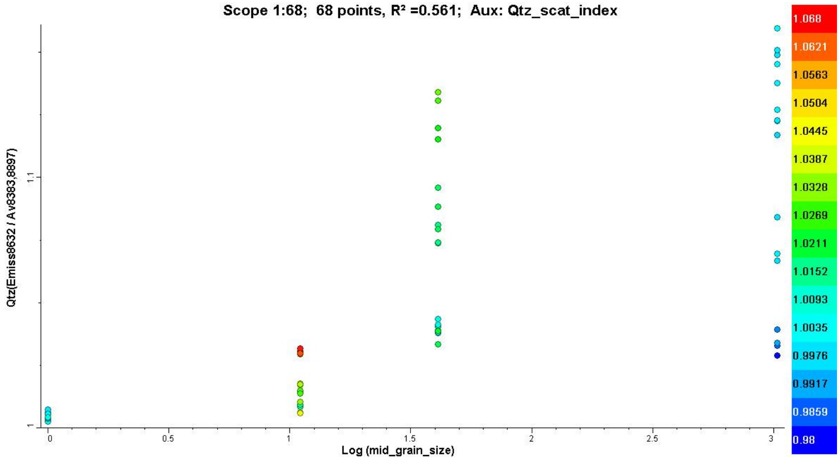

Figure 3. Quartz content spectral parameter versus Log of the grain size fraction, colour coded by the estimated effect of fine quartz volume scattering (*e.g.* red = high scattering associated with fine quartz), showing an approximate decrease in quartz content with decreased grain size.

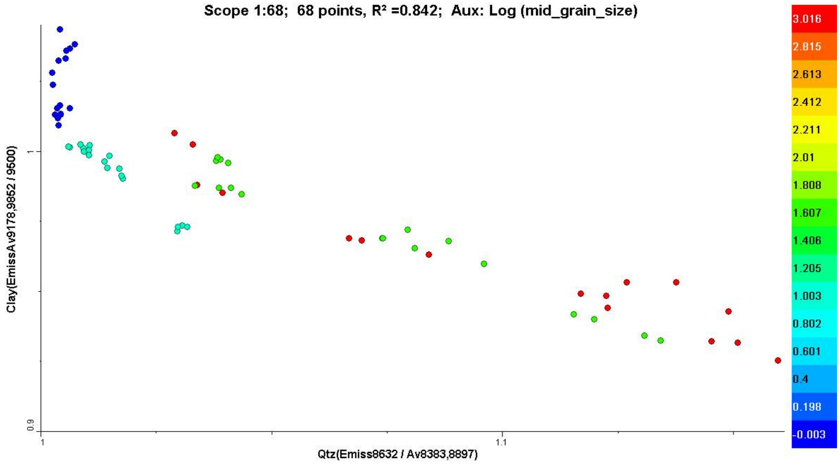

Figure 4. Relationship between quartz and clay content spectral parameters, colour coded by the Log of the grain size fraction (*e.g.* red : 60 µm-2 mm; blue : < 2µm), showing the inverse relationship between TIR interpreted quartz and clay mineral contents.

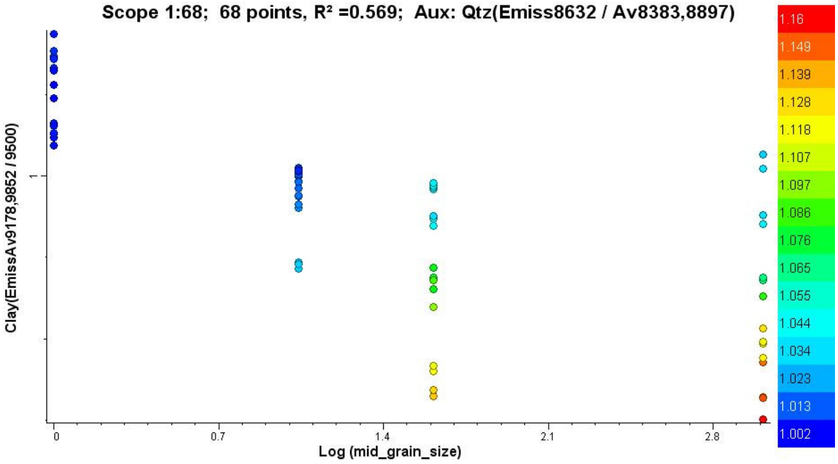

Figure 5. Relationship between the clay content spectral parameter and the Log of the grain size fraction, colour coded by the quartz content spectral parameter (*e.g.* low quartz content : blue, high quartz : red).

Conclusions

These initial results show the intimate connection between mineralogy and texture when using thermal infrared spectroscopy to investigate soils. In particular, coarse and fine grained quartz components have distinct TIR spectral features. The spectral results also indicate that residual clay mineral content may still be present, even with fractions obtained from thorough grain size separation techniques, and potentially bias the interpretation of "clay" content if based on textural analysis alone (*e.g.* < 2μm). Proximal spectral measurements indicate the potential to analyse for clay mineral content, as distinct from clay sized soil content. This study indicated the potential for evaluating soil mineral and textural characteristics using TIR spectroscopy. Further investigations using a larger number of soil samples are recommended to establish the best approach to extract TIR spectral parameters related to mineralogy and textural characterisation. Such studies would also be assisted by loss on ignition heating and shortwave infrared spectral techniques for estimating clay content (Cudahy *et al.* 2005).

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