IDENTIFYING, QUANTIFYING, AND MAPPING CARBONATE AND SERPENTINE AT OUTCROP SCALE. E.K. Leask¹ and B.L. Ehlmann¹,². ¹California Institute of Technology, 1200 E California Blvd., Pasadena, California, 91125, ²Jet Propulsion Laboratory, 4800 Oak Grove Blvd., Pasadena, California, 91109.

Introduction: Visible-shortwave infrared (VSWIR) imaging reflectance spectroscopy is a technique to identify minerals, quantify their abundances, and assess textural relationships at multiple scales. Here, we apply the technique from cm- to sub-mm scale, without destructive or labour-intensive sample preparation. We image serpentinitized igneous rocks and carbonate-rich travertine deposits to 1) quantify the amount of carbonate present at outcrop scale and 2) demonstrate the ability to examine relationships between different compositional units, track the degree of serpentinization, target rare phases, and differentiate between spectrally similar minerals or organic pigments. The Samail Ophiolite (Oman) is chosen as an analogue for Martian carbonate and serpentine deposits in the Nili Fossae region [1], to demonstrate the ability to distinguish between spectrally similar minerals and quantify their abundances.

Methods: We use a Headwall Photonics imaging spectrometer with VNIR (400-950 nm) and SWIR (950-2600 nm) sensors. Each image takes ~ 3 min to acquire, and has a spectral resolution of ~1.5 nm in the VNIR range and ~5 nm in the SWIR. Data taken in the field are radiometrically and atmospherically corrected using Spectralon panels placed within the scene. Field data are cleaned up by MNF (minimum noise fraction) rotation [2]; noise-only components are removed and the remaining components reprojected into wavelength space. Spectra are identified based on characteristic absorptions (e.g. Fig. 1d, e; [3,4]). In-scene endmember spectra are used for linear spectral unmixing in small scale laboratory data [5, 6]. Otherwise, pixels are classified based on a combination of diagnostic absorptions (parameters), including the band depth and position at 2.3 and 2.5 μm (for carbonate [3]), and 2.1 μm (serpentine [4]); see Fig. 1 (d, e). Carbonate is quantified as a proportion of the pixels classified as carbonate.

Results: In-situ carbonate quantification. Carbonate and serpentine veins and their cross-cutting relationships can be identified at both hand sample and outcrop scales. At lab scale, we can reliably estimate the amount of carbonate present within a serpentinite sample [5], as at this scale, pixels are often composed of a single phase. The small scale quantification results provide a minimum bound for the amount of carbonate present in the whole outcrop (Fig. 1a-c is ~ 24% carbonate). Mixed pixels at outcrop scale are assumed to have the same proportion of small carbonate veins observed at hand sample scale. Large carbonate veins (10s of cm to m) observed at outcrop scale (Fig. 1f-g; ~15% of the total number of pixels) are then added to the amount calculated for the matrix (for a total of at least 35% carbonate in outcrop).

Rare phase identification. Spatially coherent rare phases can be readily

Fig. 1: Quantification of carbonate veining in a serpentine rock (Samail Ophiolite, Oman). A-D) Cut face and spectra of a hand sample, showing multiple generations of carbonate and serpentine veins (green vs. blue/white), progressive serpentinization and partially reacted pyroxene. E-H) Outcrop scale data for the same location.
identified both at hand sample and outcrop scales. In Fig. 1c, ~1% of the rock is composed of partially reacted pyroxene grains (shown in red). This can be scaled up to outcrop scale to estimate the total amount of pyroxene remaining in the serpentinite (in this case <1%). In Fig. 2, a single clast (~20 pixels) is composed of a unique phase with a sharp absorption at 1.6 μm (Fig. 2e).

Differentiation between similar phases (mineral and organic). The Caltech imaging spectrometer has sufficient spectral resolution to differentiate between spectrally similar phases, including different carbonate minerals where absorption minima shift by ~10 nm (see magnesite vs. calcite in Fig. 1e). Different organic phases (bacterial mats or algae, and grasses) are differentiated, based on the location of absorptions in the 500-900 nm range due to organic pigments (Fig. 2b,d).

Implications: This technique for estimating the quantity of carbonate within a rock unit can be used to provide bounds for the total amount of carbon it stores. We can use this to better understand natural carbon sequestration, both on Earth [e.g. 7] and on Mars. The completeness of serpentinization reactions can also be estimated, looking at the amount of pyroxene or olivine minerals still present within the rock. We can also use this method to access the actual ‘plumbing’ of the system, as zones of serpentinization follow the path of fluid flow through the rock unit (e.g. Fig. 1g).

The ability to differentiate between spectrally similar phases is useful, as changes in carbonate mineralogy follow changes in groundwater composition or timing of alteration. This technique could allow us to understand ancient groundwater systems if the minerals are preserved (e.g. on Mars); in modern systems, we could use this technique to target pools of different water chemistry, or to map the changes in chemistry.

The ability to readily identify rare phases that constrain physical and chemical environments makes small-scale VSWIR imaging spectroscopy ideal for scanning an area to target phases of interest and improve sampling [see also 8]. This is especially useful in situations (e.g. on a rover) where sampling ability is limited.


Fig. 2: Travertine spring complex, Samail Ophiolite, Oman. A) True colour image of site. B) VNIR stretch highlighting variability of organic pigments (spectra in D). C) SWIR band parameter stretch highlighting mineralogical diversity (spectra in E). In this stretch, serpentine minerals are orange to greenish, carbonates are purple and blue, and the mystery phase is bright green.