Multispectral VNIR Evidence of Alteration Processes on Solander Point, Endeavour Crater, Mars

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1) Introduction:

The Mars Exploration Rover Opportunity has been exploring Noachian-aged rocks on the rim of Endeavour crater. This exploration began on the Cape York rim segment [1, 2] and has, from Sol 3393 of Opportunity's mission to the present time, been over the rim segment known as Solander Point (**Fig. 1**). The visible and near infrared (VNIR) multispectral capability of the rover's Pancam has been an important tool for use in selecting targets for *in situ* investigation and in it's own right for characterizing the VNIR reflectance of rock surfaces [3, 4]. Among the rock targets encountered on the Murray Ridge portion of Solander Point were a set of outcrops that had the outward appearance of other occurrences of the Shoemaker formation impact breccia [1], but which had a distinct reflectance character. Also, the by chance overturning of the rocks Pinnacle and Stuart Island revealed light-toned subsurface materials which were likely formed by subsurface aqueous alteration.

2) Change in the Outcrop Reflectance:

At Murray Ridge, a change in the spectral and chemical character of that outcrop was observed. **Fig. 2** shows representative images of the outcrops and **Fig. 3** shows Pancam spectra of Shoemaker formation and Murray Ridge outcrops. Starting with the Trinity Island outcrop, imaged on sol 3522 and with a number of successive observations of Murray Ridge outcrops, spectra more closely resembled the brushed Green Island observation of sol 3571 in **Fig. 3** than the earlier Shoemaker unit spectra shown in that figure. The spectral differences include a deeper 535 nm band depth and a steeper 934 to 1009 nm slope in the Murray Ridge outcrops than in the earlier Shoemaker observations.

The spectral differences between the earlier Shoemaker observations and the Murray Ridge outcrops in the vicinity of Green Island include a deeper 535 nm band depth and higher 754 to 1009 nm and 934 to 1009 nm slopes. These differences are illustrated in the spectral parameter plot of **Fig. 4**. *Farrand et al*. [5, 6] observed a direct correlation between increases in 535 nm band depth and increases in Fe^{3+}/Fe_{Total} as measured by the Spirit rover's Mössbauer spectrometer. Increases in the 754 to 1009 nm and 934 to 1009 nm slopes are also consistent with increases in the fraction of red hematite in these materials. Thus, these factors are indicative of increased oxidation of the Murray Ridge outcrops.

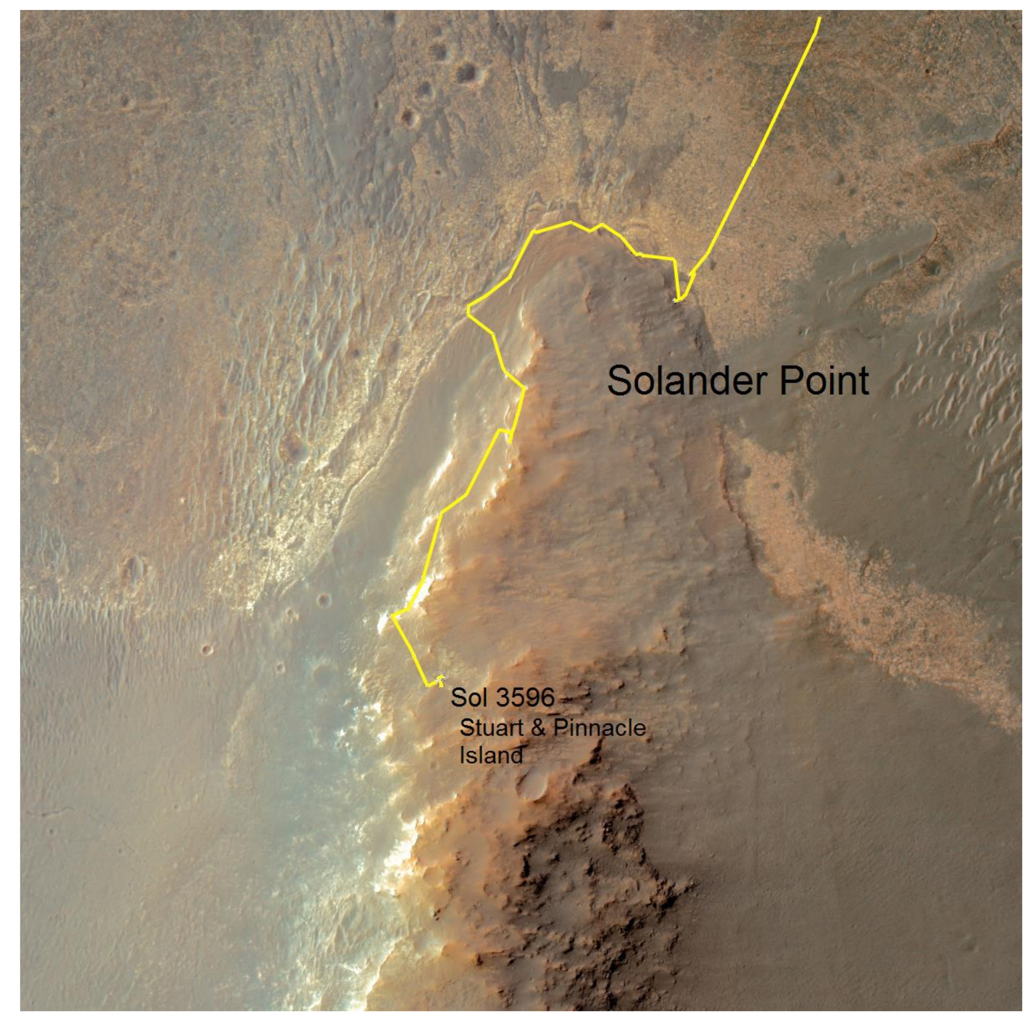

Fig. 1. Opportunity's traverse path on Solander Point up to sol 3596 overlaid on HiRISE color (traverse map courtesy of Tim Parker, JPL).

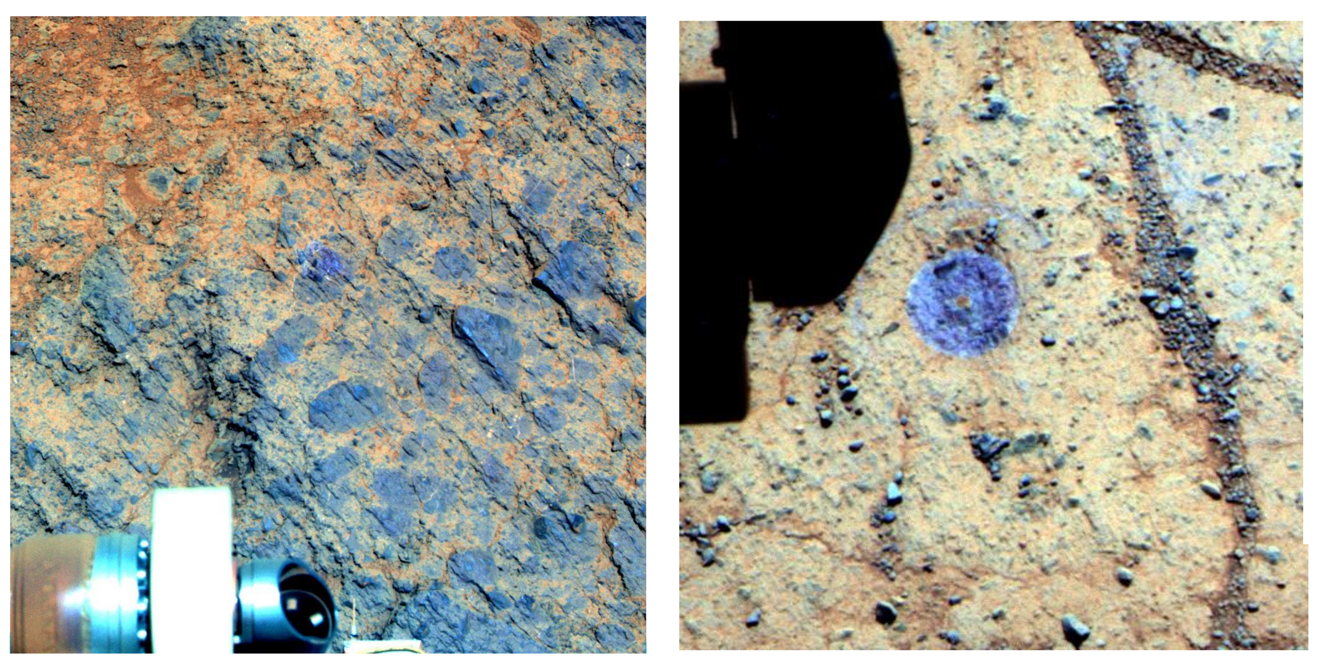

Fig. 2. (**A**) Sol 3466 P2579 L357 (673, 535, 432 nm) view of Kangaroo Paw outcrop. (**B**) Sol 3571 P2537 L357 of Green Island RAT brush.

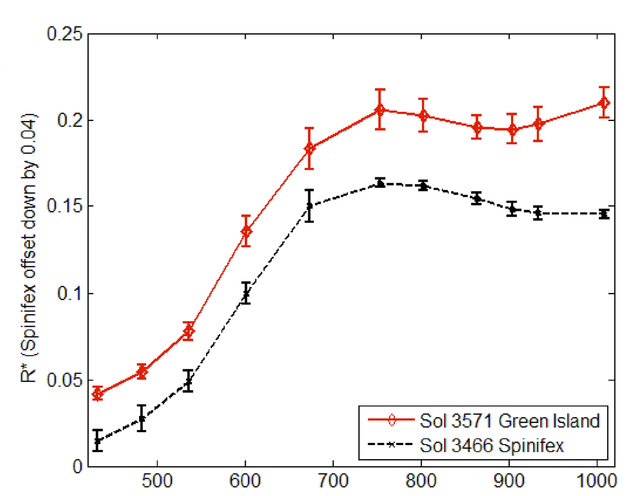

Fig. 3. Pancam spectra of sol 3466 Spinifex target on Kangaroo Paw and of Green Island RAT brush.

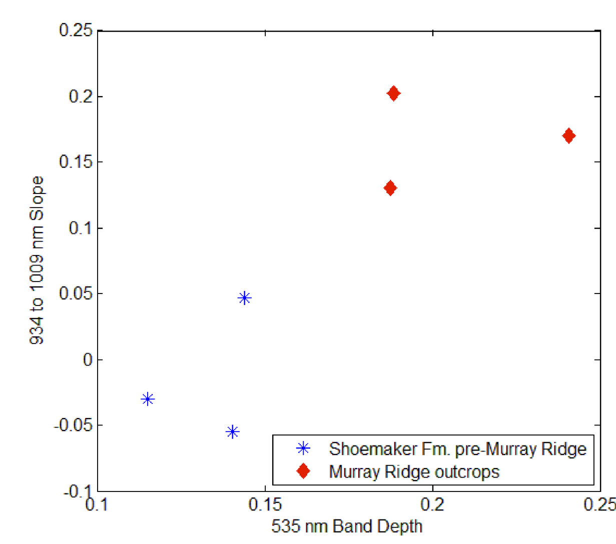

Fig. 4. Plot of 934 to 1009 nm slope vs. 535 nm band depth for several pre-Murray Ridge Shoemaker formation outcrops and those on Murray Ridge near Green Island.

3) Overturned Rocks:

The overturned rocks Pinnacle Island and Stuart Island allowed for an examination of materials from the near sub-surface. These rocks were spectrally diverse with several spectrally distinct color units (**Fig. 5** and **6**):

1. A light-toned material with a downturn in reflectance from 934 to 1009 nm, potentially due to a water-overtone absorption band
2. A material with a red spectral slope, generally lacking in absorption features
3. The fresh rock material like that of the brushed Green Island target (**Fig. 3**)

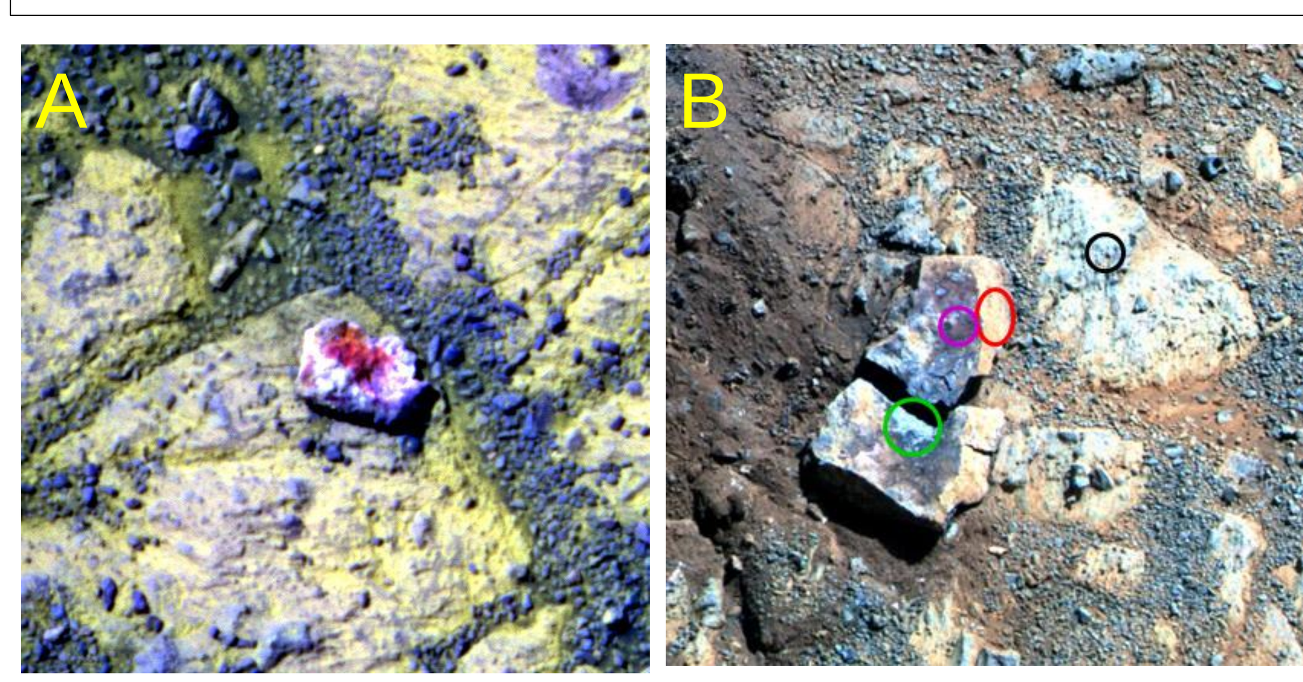

Fig. 5. (**A**) Sol 3555 P2531 R731 (1009, 803, 436 nm) view of Pinnacle Island. (**B**) Sol 3589 P2545 R731 view of broken Stuart Island.

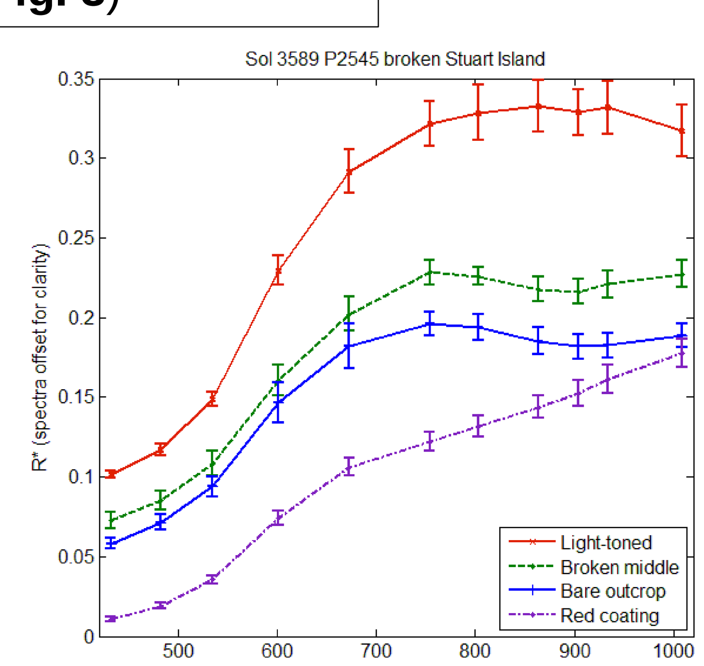

Fig. 6. Stuart Island color unit spectra.

4) Sulfates and oxide minerals in the sub-surface?

Given the multispectral character of spectra collected by Pancam, a unique identification of mineral phases is generally impractical. The drop in reflectance from 934 to 1009 nm in the light-toned materials on Pinnacle and Stuart Island (which can be caused by a H_2O overtone absorption [7]) could have been caused by any one of several phases. Calcium sulfate veins observed by Opportunity show this downturn and the high $CaSO_4$ content of the veins indicate that they are composed of gypsum [1, 3]. However, the 934-1009 nm drop in reflectance in the light-toned material on Pinnacle and Stuart Island is more likely caused by another phase. An intriguing possibility is kieserite which also can show this downturn (**Fig. 7**) and correlates well with APXS results indicating high Mg and S over light-toned areas on these rocks.

The material with "red" spectrum, lacking in absorption features has a spectrum similar to Mn-oxide rich desert varnishes (**Fig. 8**). Again, this correlates with APXS results indicating high Mn over the central "red" area of Pinnacle Island (**Fig. 9**).

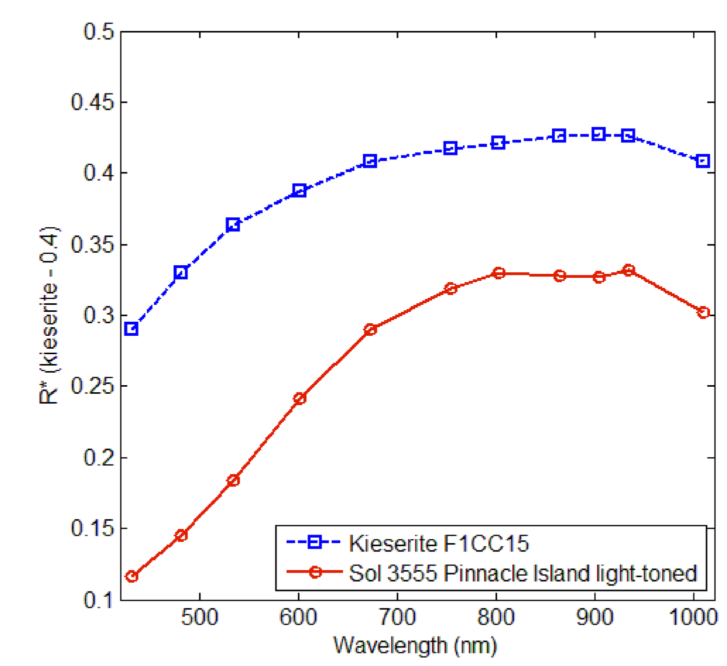

Fig. 7. Library kieserite spectrum F1CC15 convolved to Pancam bandpasses compared to Pinnacle Island light-toned material.

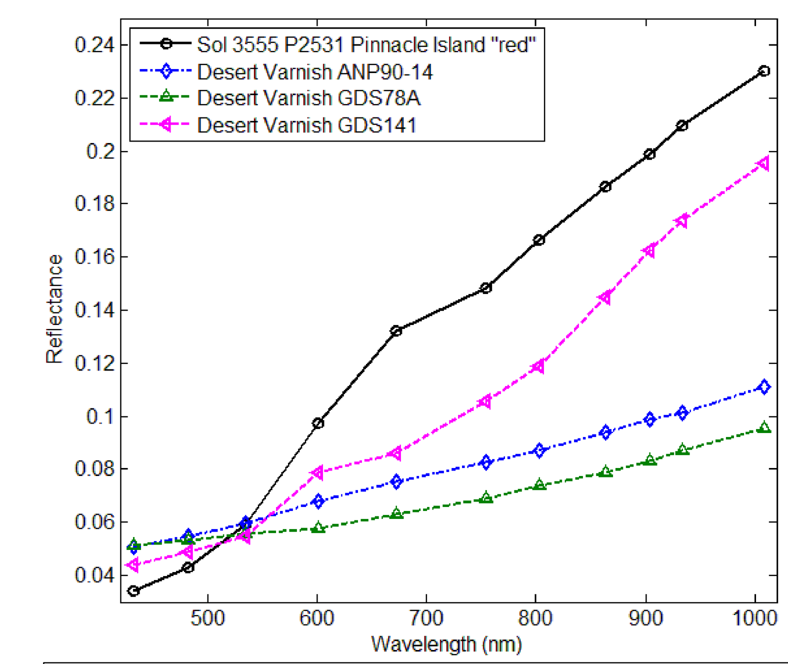

Fig. 8. Pinnacle Island "red" compared with USGS spectral library [8] desert varnish spectra.

Fig. 9. Merged Pancam color and MI mosaic data over Pinnacle Island. Circles represent approximate APXS sampling areas for different APXS measurements (MI/Pancam merger courtesy of Tim Parker, JPL).

5) Conclusions:

- A portion of Murray Ridge hosted outcrop with spectral features indicative of alteration processes
- Overturned rocks in this region had a light-toned material with a drop in reflectance from 934 to 1009 nm consistent with a hydrated phase- potentially kieserite (consistent with APXS-determined chemistry)
- The overturned rocks also had a spectrally red material that could consist of a Mn-rich phase, a Mn oxide or Mn sulfate, with the former potentially being analogous to terrestrial desert varnish.

References: [1] Squyres, S.W. et al. (2012) *Science*, **336**, 570-576. [2] Arvidson, R.E. et al. (2014) *Science*, **343**, doi:10.1126/science.1248097. [3] Farrand, W.H. et al. (2013) *Icarus*., **225**, 709-725. [4] Farrand, W.H. et al. (2014) in revision, JGR-Planets. [5] Farrand, W.H. et al. (2006) *JGR*, **111**, 10.1029/2005JE002495. [6] Farrand, W.H. et al. (2008) *JGR*, **113**, 10.1029/2008JE003237. [7] Rice, M.S. et al. (2010) *Icarus,* **205**, 375-395. [8] Clark, R.N. et al. (2007) *USGS Digital Data Series 231*.

Acknowledgements: The first author was funded as a MER Participating Scientist.