Super-resolution of Martian Chloride Sites and the Associated Mineral Assemblages

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Introduction: Super-resolution is the process of improving spatial resolution from that of the original data source (or native) resolution. A first-order approach is the fusion of original data with an additional source, which has the desired resolution. There are a variety of techniques that can be used to fuse these data sets; however, a trade-off has been noted between techniques that are the most visually appealing and those that are most radiometrically accurate [1]. The technique for super-resolution presented here is a modification of an algorithm [2] that was originally tested successfully using multi-resolution data from the Earth orbiting Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument [4]. The spatial and spectral resolution of ASTER is broadly similar to the Mars orbiting Thermal Emission Imaging System (THEMIS) instrument [5]. The current study investigates the applicability of the technique to enhance the THEMIS thermal infrared (IR) data of a putative chloride deposit in Terra Sirenum using the instrument's visible (VIS) data. The result is a radiometrically-accurate IR dataset at an improved spatial resolution of 36 m/pixel. It provides an independent approach to traditional sub-pixel deconvolution techniques, and it can be used in the search for small-scale thermal and compositional variations within the deposit and at its contact with the surrounding surficial deposits.

Chlorides: Data from the THEMIS instrument led to the discovery of unique spectral IR signatures that were postulated to be chloride deposits [6]. These are light-toned and located in topographic lows at a variety of altitudes. The spectral signatures are generally featureless, and exhibit a negative slope in the IR. One way negative slopes can arise is from a material that has a low non-unit emissivity across the entire spectral range coupled with an incorrect assumption of the maximum emissivity [6,7]. Due to the unique shape of the spectrum and the desire to better understand the stratigraphic relationship of the deposit, these data become a good candidate for super-resolution. As the spectra are dissimilar from their surroundings, those pixels containing the spectrum would be easily isolated and emphasized within data clustering approach used in the super-resolution algorithm [2].

Preliminary Results: The modified super-resolution algorithm has been used on several THEMIS images [2,10]. Figure 1 shows a THEMIS IR image of a region near 180°E, 28°S acquired in mid-December, 2009 at an Ls of 22.475 and a local time of 15.08. This region contains a surface with a chloride spectral signature, shown as the large blue irregular shape in the upper right side of the image. It is co-located with darker-toned deposits in the VIS data that lie within a local topographic low. Figure 2 is an enlargement of this region and its immediate surroundings. The chloride region is composed mainly of a single cluster type, shown as blue in Figure 2B. At least two other units (shown as purple and green in Figure 2B) are also chloride-bearing units, while the sea-green cluster is typical of the surrounding plains. Figure 3 shows HiRISE data over the chloride deposit. In this image, the deposit is shown to have a lower albedo, but is similar in a geomorphic sense to the surrounding area. The separation of the deposit into different VIS clusters may indicate sub-pixel mixing even at the super-resolved scale.

Future Work: Data from a number of other instruments, such as HiRISE and CTX, have been acquired over the region of interest (Fig. 1) as well as over other putative chloride sites. These data need to be integrated with the super-resolved THEMIS data. Furthermore, the spectra of the super-resolved data surrounding the chloride bearing units need to be examined for composition, using techniques such as spectral deconvolution [11]. Super-resolution will be applied to contemporaneous multi-band THEMIS IR and VIS data from multiple chloride sites, as well as to other contemporaneous image pairs over this site to be acquired in the future. In some locations, there are abundant multi-band IR data sets, but fewer multi-band VIS data. In these areas, non-contemporaneous image pairs can be used, and the results compared to super-resolved data from the contemporaneous pairs. If practical, this may allow for the examination of temporal changes at the sub-pixel scale in these and other areas of interest. Once validated, this technique can be extended to the high-resolution source originating from other instruments, such as CRISM or HRSC. Because these instruments examine the surface at different look angles and local times, differing parts of the scene may be emphasized. The super-resolved data will also be compared to Earth analogue sites using data from ASTER and field-based validation.

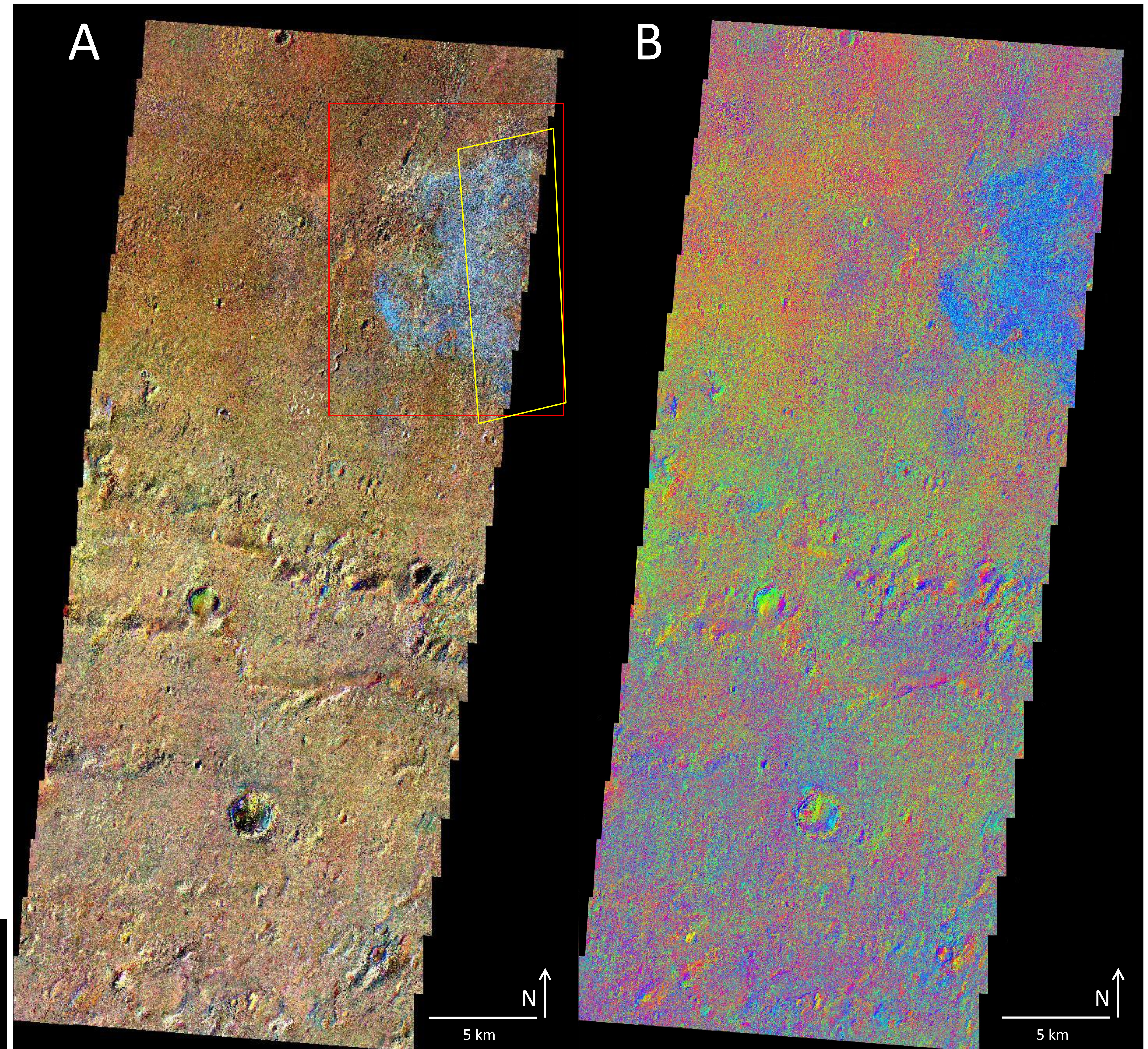

Figure 1. Super-resolved data of THEMIS IR data I35462005, using cotemporaneous VIS data V35462006 for the super-resolution. The entire area of overlap between the two data sets was used, as shown, including the masked-out area where no visible data was available. **(1A)** Super-resolved THEMIS IR image, with bands 8 (11.79 µm), 7 (11.04 µm), and 5 (9.35 µm) in R, G, and B. The red rectangle denotes the extent of Figure 2 while the yellow rectangle denotes the extent of Figure 3. This region contains the chloride deposit. Details of smaller features, such as numerous craters. Areas with extensive shadowing in the VIS, such as the large crater in the southeast of the image, show some salt-and-pepper noise as a result of poor data for the VIS clusters, as shadowed regions are clustered rather than with the appropriate cluster if fully illuminated. As a result, too few pixels are available to each colocated IR cluster. **(1B)** Decorrelation Stretch (DCS) image of Fig. 1A. The putative chloride deposit is shown as an irregular blue polygon near the northeastern corner of the scene.

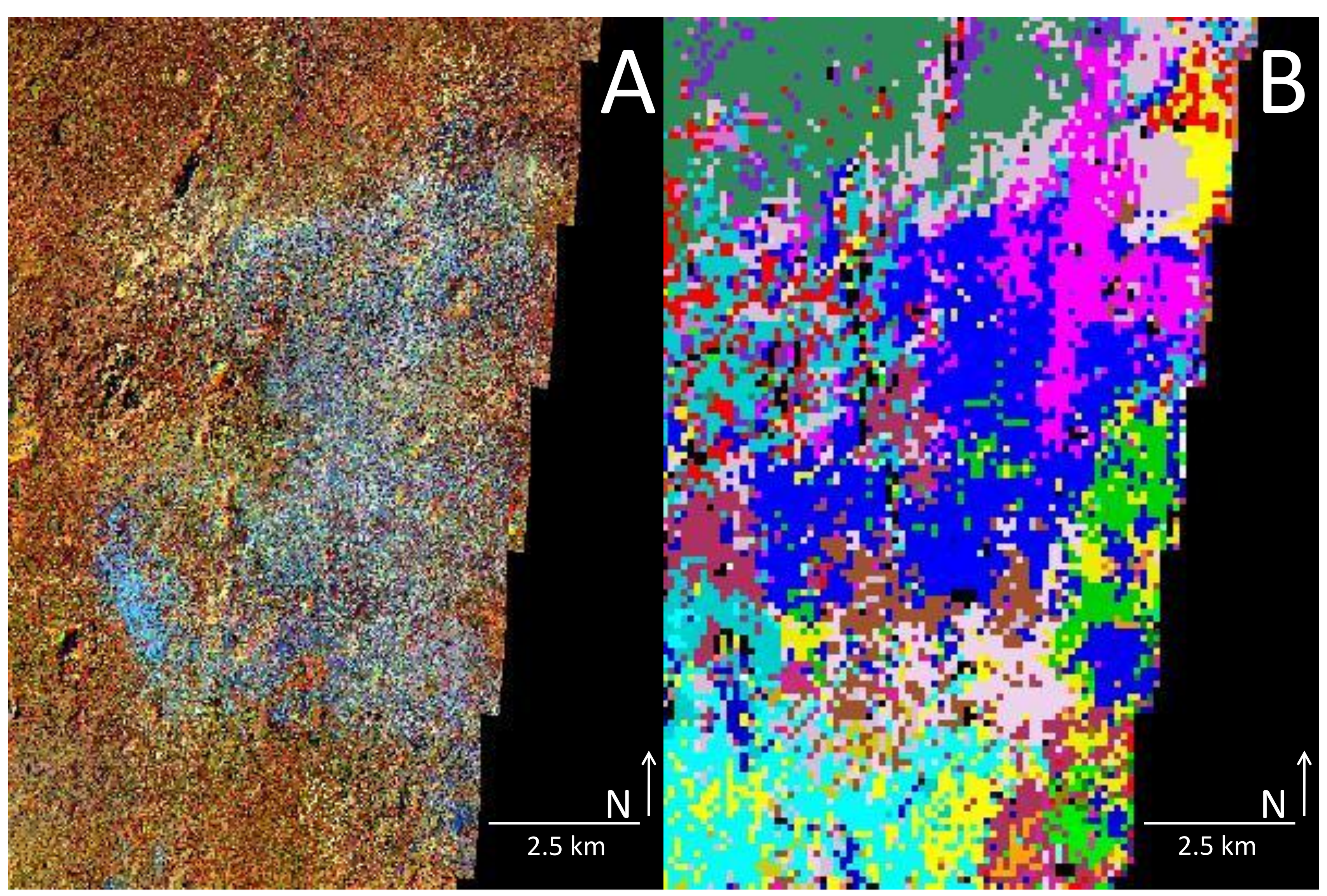

Figure 2. Immediate area surrounding the putative chloride deposit. **(2A)** Super-resolved THEMIS IR image, with bands 8, 7, and 5 in R, G, and B. **(2B)** Cluster map from the super-resolution process. The blue unit is colocated with the majority of the chloride deposit, with the green and purple units covering the most of the remaining deposit. The sea-green unit to the northwest is typical of the immediate surroundings.

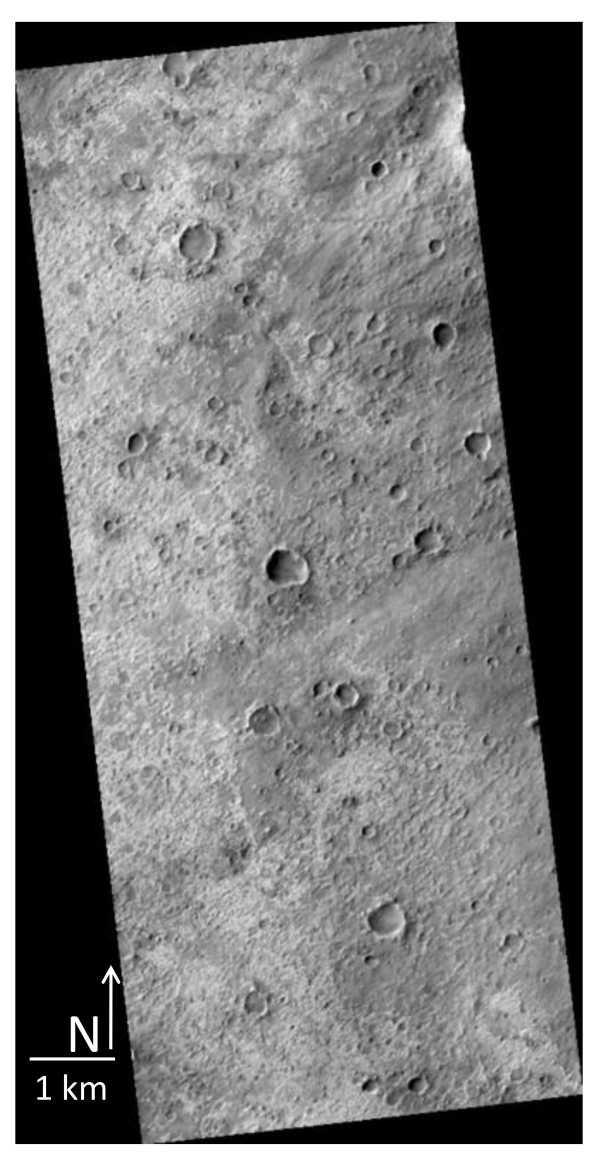

Figure 3. HiRISE image PSP_005680_1525_RED is located along the chloride deposit, as shown in Figure 1A, and shows the geomorphic similarity between the chloride unit and the nearby area. The chloride unit has a lower albedo.

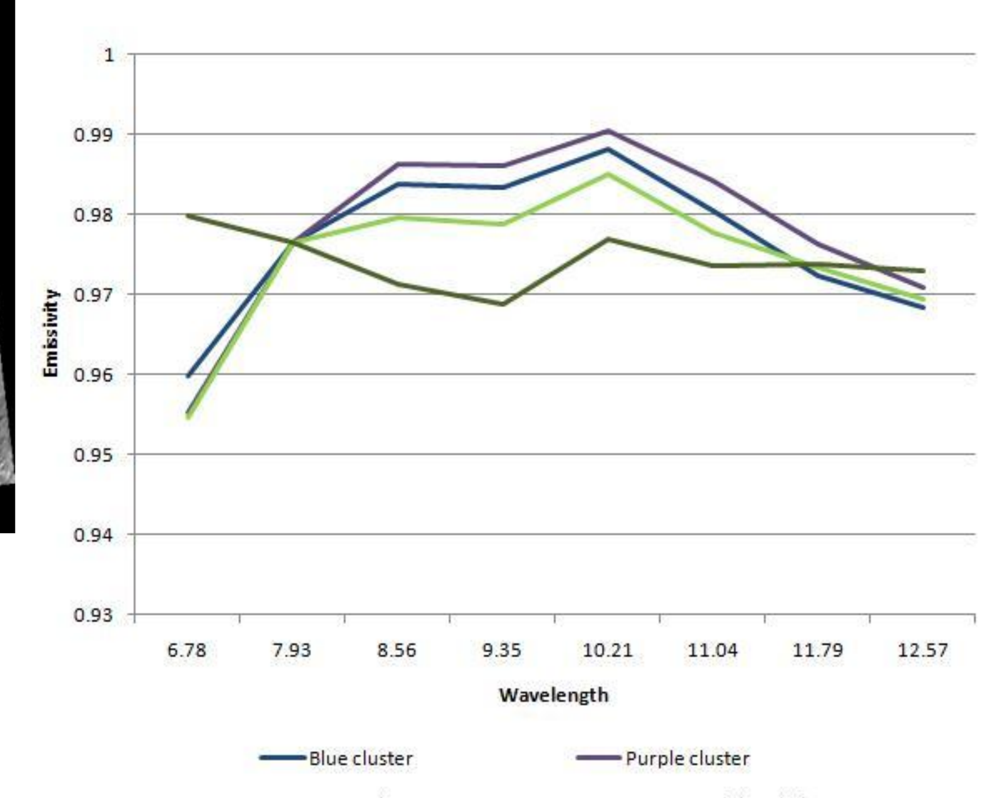

Figure 3. Spectra of selected clusters. Each spectra in this figure is created by averaging a large number (between 200 and 700) of pixels from each cluster. The purple cluster represents the purest of the chloride end-members in this area. The blue and green spectra are formed by spectral mixing between the purple spectrum, the sea-green plains unit, and a blackbody. The blackbody end member may be due to surface darkening from weathering. While the spectra are shown out to 6.78 µm (band 1 and 2), this band is generally considered noisy as a result of insufficient surface temperature for that band to overcome background noise.

References: [1] B. Zhukov et al. (1999), *IEEE Trans. Geol. and RS, 37, 1212-1226. [2] C. Hughes et al. (2009), LPS XL, abs. #2359 [3] H. Tonooka (2005), Proc. SPIE, 5657, 9-19. [4] Y. Yamaguchi et al. (1998), IEEE Trans. Geol. And RS, 36, 1062-1071. [5] P. Christensen et al. (2004), Space Science Reviews, 110, 85-130 [6] M. Osterloo et al. (2008), Science, 319, 1651-1654 [7] J. Bandfield (2009), Icarus, 202, 414-428 [8] N. Tosca et al. (2008), Science, 320, 1204 – 1207 [9] D. Schulze-Makuch et al. (2008), Int. J. Astrobiology, 7, 117-141 [10] C. Hughes and M. Ramsey (2008), LPS XXXIX, abs. #2530 [11] M. Ramsey and P. Christensen (1998), JGR, 103, 577-596*