AQUEOUS MINERAL DEPOSITS IN AN ANCIENT, CHANNELED, EQUATORIAL TERRAIN. P. R. Christensen[1], Mikki Osterloo[2], Victoria Hamilton[3], Christopher Edwards[1], James Wray[4], F. Scott Anderson[3] [1]Arizona State University, Tempe, AZ, 85287, phil.christensen@asu.edu, [2]University of Hawaii, Honolulu, HI, 96822 [3]Southwest Research Institute, Boulder, CO, 80302, [4]Cornell University, Ithaca, NY, 14853

Introduction: This site contains spectral evidence for chloride salts and phyllosilicates in an in-place stratigraphic sequence in ancient terrain in eastern Margaritifer Terra. These deposits occur in an ~19 km diameter basin that lies ~50 m below the surrounding plain. The sequence of units exposed by erosion in this basin have an unaltered, basaltic unit at the top of the sequence that overlies a phyllosilicate-bearing unit, which in turn overlies a chloride-bearing unit at the base. The exposures of salt occur in three primary locations within this basin, each 2-5 km in diameter and ~10 m thick. The largest and best defined of these is in contact with a phyllosilicate-bearing unit that is exposed over an area ~4 km in diameter. A major channel extending over 350 km in length wraps around this site at a distance of 13 km to the north and 22 km to the east. In this region the channel is 2-4 km wide and 150-250 m deep, and provides evidence for significant fluvial processes in this region. The regional setting of this chloride/phyllosilicate site is shown in Figure 1 with the study area outlined. Figure 2 shows medium resolution day and night THEMIS IR views of the basin of interest (arrow) and a proposed landing ellipse immediately to the west. This landing ellipse is on flat, smooth terrain with many similarities to the Opportunity site plains, allowing a rapid drive to the basin of interest. Additional study may allow this landing ellipse to be placed significantly closer to the mineral deposits of primary interest.

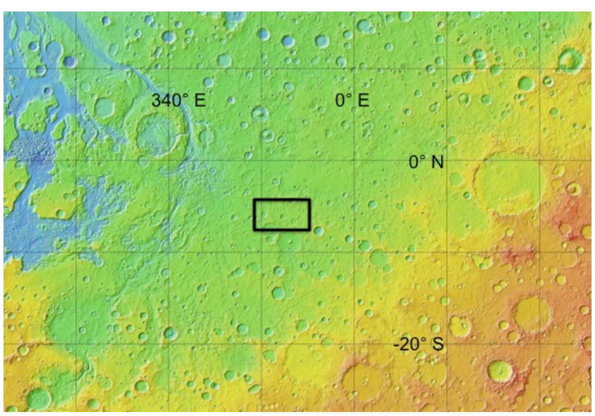

Figure 1. Regional setting of the Eastern Margaritifer chloride/phyllosilicate site. The approximate region of Figure 2 is highlighted by box.

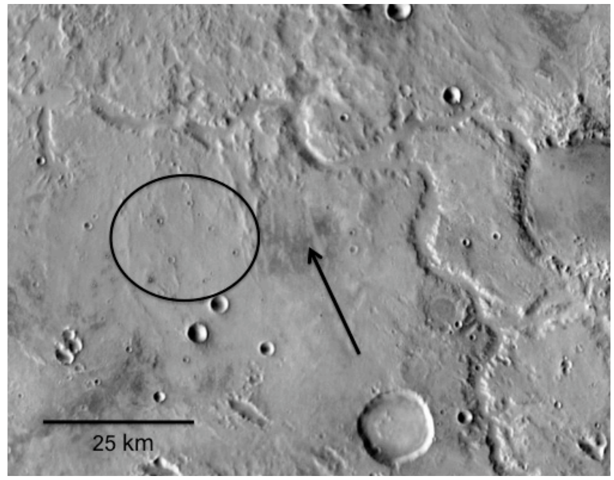

Figure 2a: Example 25 km by 20 km ellipse on THEMIS day IR. The ellipse is centered at 5.59°S, 353.52°E at an elevation of -1.25 km with respect to the MOLA planetocentric geoid. The prime science targets are chlorides and phyllosilicates within a shallow basin immediately east of the ellipse (arrow).

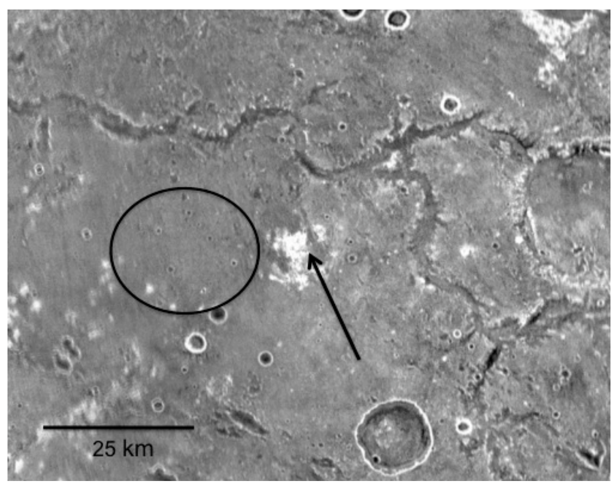

Fig. 2b. THEMIS night IR. The primary science targets are in the high inertia (rocky) outcrop surfaces to the east of the ellipse that are warm (bright) at night.

Scientific Rationale: A wide range of aqueous minerals, including phyllosilicates, chlorides, sulfates, carbonates, and hematite, have been found throughout the ancient cratered highlands of Mars [e.g. 1-7]. These minerals provide strong evidence for aqueous processes early in martian history, and have focused the future exploration of Mars on understanding the detailed properties – chemistry, pH, temperature, duration, etc – of the potentially habitable environments in which these minerals formed. Of particular interest are regions in which a wide variety of these minerals occur in in-place sedimentary sequences.

Phyllosilicates have been identified in numerous areas, primarily in ancient terrains [e.g. 1, 2, 3]. Many of these sites lie directly below unweathered olivine-bearing units, suggesting that they may have formed by an early, relatively short lived period of deposition in an aqueous environment, by aqueous alteration of a volcanic materials, or by impact-related alteration [2, 8]. One of the key questions regarding phyllosilicate formation is the duration and abundance in which water was present. For example, phyllosilicates in some sites could have formed during or immediately after an impact into ice-rich materials, with the aqueous processes ending quickly after the ejecta materials cooled and the water refroze [8]. Another key question concerns the composition and fate of 'missing salts' that are critical to understanding the oxidation state and weathering on early Mars [7]. In the Eastern Margaritifer site we have identified additional mineral evidence in the form of extensive chloride deposits that can provide further insight into the extent and role of water in this region. This identification, based on their thermal- and near-infrared spectral properties, indicates high water/mineral ratios that result in the formation of meters-thick deposits of chloride evaporites, and may provide clues to the formation of materials associated with the aqueous alteration of basalt.

The putative chlorides have been identified at over 200 locations throughout the ancient highlands [4]. Many of these deposits are in closed basins with extensive channel systems that drained into these basins. Many occur in 5-20 km diameter, closely-associated basins that are at similar elevations, suggesting more extensive units that are being exhumed in isolated windows. These deposits are up to 10-m thick, and typically have unique, polygonal fractures on their surface suggestive of desiccation fractures found on terrestrial salt deposits.

In analyzing the Eastern Margaritifer site we have mapped the occurrence and distribution of phyllosilicates, chlorides, and igneous minerals using the CRISM and THEMIS spectral data. We have used the CRISM multispectral summary products [9] to identify phyllosilicates, and have examined the CRISM spectra of key terrains to estimate the composition these materials. We have also used the THEMIS decorrelation stretch (DCS) products to identify regions with an unusual IR spectral character that has been proposed to correspond to chloride salts [4]. Salt minerals provide the best match to the observed low, featureless emissivity of these materials [10].

Science Merit Related to MSL Objectives: Figures 3 and 4 show the overview of the site on a CTX mosaic. Both CRISM and THEMIS spectral data have been converted to color indices indicating the relative abundances of phyllosilicates and chlorides respectively, and these indices are shown superimposed on a CTX mosaic of the basin.

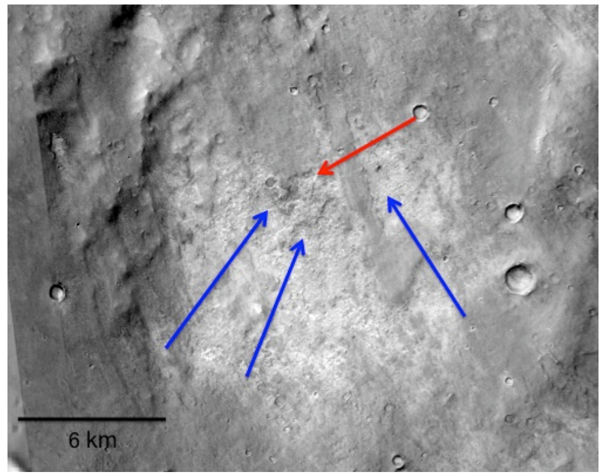

Figure 3a. CTX mosaic of the primary science target. This ~20 km diameter basin is ~50 m below the surrounding plains, exposing in-place sedimentary rock units. Main phyllosilicate-bearing units are indicated by red arrow; chloride salt locations by blue arrows.

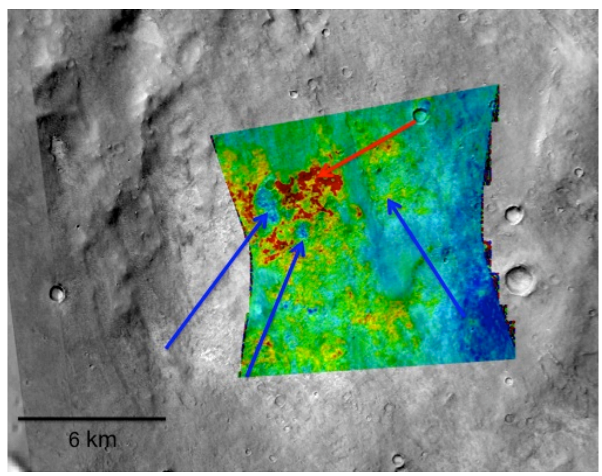

Figure 3b. CRISM FRT (00009ACE_07) image overlain on CTX image of the primary science target. The CRISM index D2300 [9] is shown with colors representing varying amounts of Fe-smectites with high abundances (deepest band depth) shown in red.

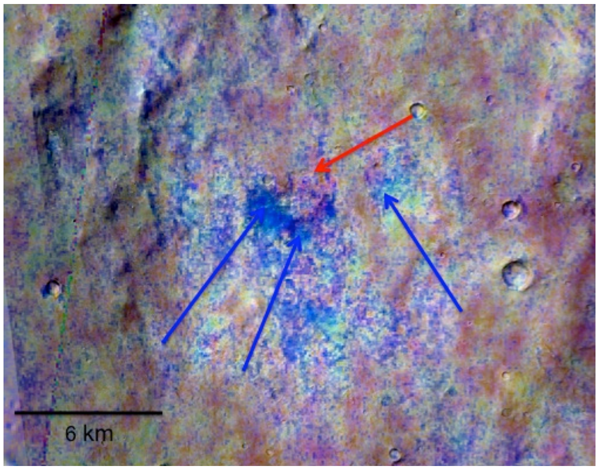

Figure 3c. THEMIS multi-spectral IR DCS overlain on CTX. The colors represent varying amounts of chlorides, with high abundances shown in blue.

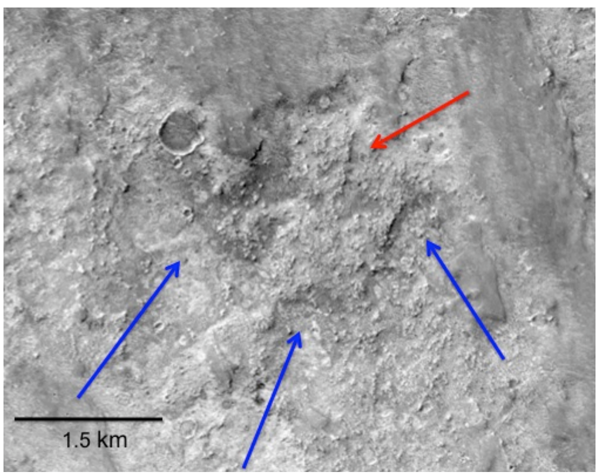

Figure 4a. CTX mosaic of the target basin.

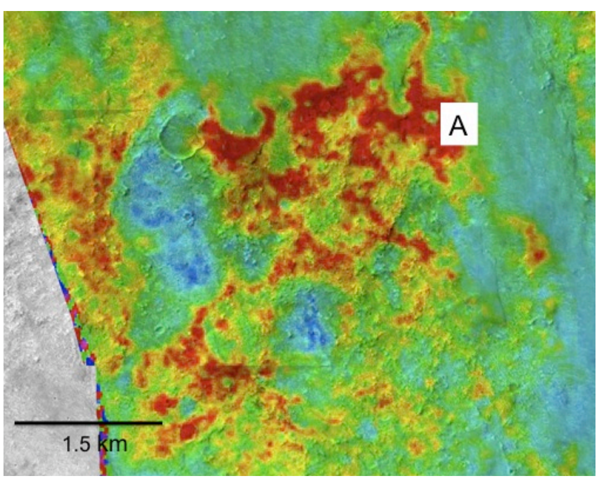

Figure 4b. CRISM FRT00009ACE_07 image over the target basin. The phyllosilicate-rich units are seen in red; the chloride-rich units correspond to blue areas with low phyllosilicate abundance.

As seen in these figures there is a well defined series of compositionally-distinct units exposed in this ~20 km diameter basin, whose floor lies ~50 m below the surrounding plains. The phyllosilicate units lie beneath a basaltic layer and above the chloride-rich rocks at the base. The CRISM data show very strong phyllosilicate absorptions (Figure 5) over a large area, indicating significant abundances of these minerals. The phyllosilicate composition is best fit by Fe-bearing smectites (Figure 5).

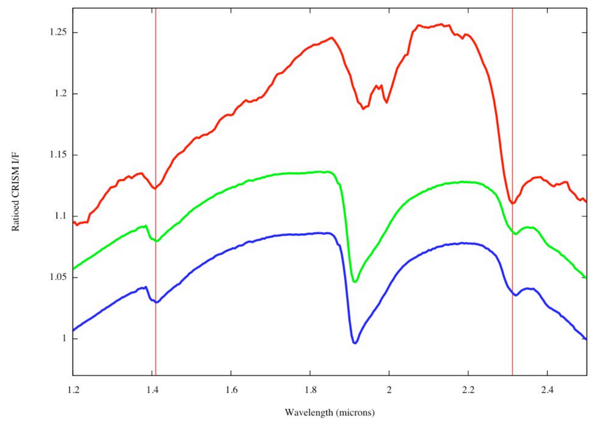

Figure 5. Sample CRISM spectra of the phyllosilicate unit at location A in Figure 4b. Red spectrum is the CRISM data; green is saponite lab spectrum; blue is vermiculite.

One of the key attributes of this site is the presence, within a stratigraphic sequence, of multiple rock units of diverse mineralogy. These units occur in an in-place set of layers with exposed, high-inertia outcrop. These layers will result in the development of a time history for their formation through aqueous alteration and deposition. These units are ancient, occurring as layers being exposed with the ancient cratered highlands, and will provide insights into the aqueous processes during the early history of Mars when aqueous interactions appear to have been more common [1]. Because the units of interest occur within an eroding basin on the intercrater, channeled plains, these deposits can be directly related to the stratigraphic development of these major, ancient plains units of Mars.

Another key characteristic of this site is the presence of both phyllosilicate minerals indicative of aqueous alteration and chlorides that have excellent biopreservation potential, as well as being indicators of high water/rock ratios. While the salt content of fluids capable of precipitating chlorides is too high to support known biology, it is possible (likely?) that the salinity of these fluids may have been lower prior to the onset of precipitation. This is certainly the case for many terrestrial salt deposits, in which organisms that existed at low salinity levels have been preserved in salts deposited as the water evaporated.

Engineering Constraints and Landing Ellipse: The site is equatorial (-5.6°) and at low elevation (-1250 m), with an average albedo of 0.12 and a thermal inertia of 200-260 J m^{-2} K^{-1} $s^{-1/2}$, which places it within the engineering constraints for these parameters. As with most sites with exposed stratigraphy and outcrop, the basin of interest may prove to be unlandable based on further analysis of the existing and future HiRISE imaging. Therefore, at this point in time we are classifying this site as a "go to" site, but suggest that this classification be assessed by the MSL engineering team. There is an excellent candidate landing ellipse immediately west of the scientific target basin (Figure 2) that is located on smooth, flat-lying, uneroded terrain that is covered at CTX resolution by small, oriented wind ripples (Figure 6). This ellipse has been located such that its eastern end is at the boundary between the flat-lying terrain and edge of basin of interest, minimizing the drive distance to outcrops on primary interest.

Summary: Table 1 summaries the site characteristics and drive distances at this site. The site has excellent exposures of a diverse suite of aqueous minerals in sedimentary rocks, with associated channels, and highly favorable engineering properties.

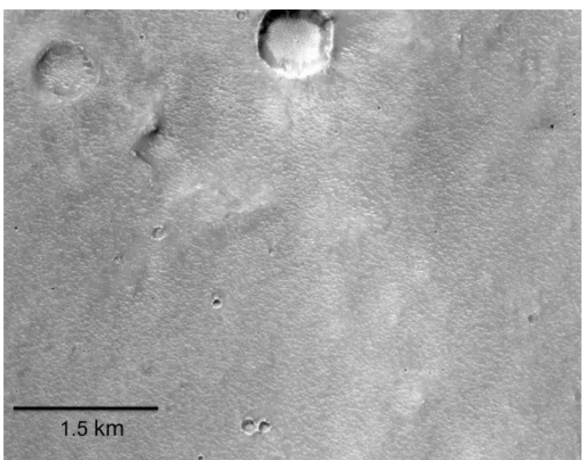

Figure 6. Example CTX image of the candidate landing ellipse surface.

Table 1: Landing site characteristics.

Site Name	Eastern Margaritifer Terra
Science Target Center Coordinates; Landing Ellipse Center Coordinates	5.59°S, 353.83°E 5.59°S, 353.52°E
Elevation	-1.25 km
Prime Science Targets	Chlorides and phyllosilicates in layered materials; Channel system; Ancient basalt plains
Distance of Science Targets from Ellipse Center	Chloride layers: 13.5 km to E Phyllosilicate layers: 16.5 km to E Channels: 19 km to N Basalt plains: In ellipse

References: [1]. Bibring, J.-P., et al., *Global mineralogical and aqueous Mars history derived from OMEGA/Mars Express data.* Science, 2006. **312**: p. 400-404, doi:10.1126/science.1122659. [2]. Mustard, J.F., et al., *Hydrated silicate minerals on Mars observed by the Mars Reconnaissance Orbiter CRISM instrument.* Nature, 2008. **454**(7202): p. 305-309. [3]. Murchie, S.L., et al., *A synthesis of Martian aqueous mineralogy after 1 Mars year of observations from the Mars Reconnaissance Orbiter.* J. Geophys. Res, 2009. **114**(null). [4]. Osterloo, M.M., et al., *Chloride-bearing materials in the southern highlands of Mars.* Science, 2008. **319**: p. DOI: 10.1126/science.1150690. [5]. Bandfield, J.L., T.D. Glotch, and P.R. Christensen, *Spectroscopic identification of carbonates in the Martian dust.* Science, 2003. **301**: p. 1084:1987. [6]. Ehlmann, B.L., et al., *Orbital identification of carbonate-bearing rocks on Mars.* Science, 2008. **322**(5909): p. 1828. [7]. Milliken, R.E., W.W. Fischer, and J.A. Hurowitz, *Missing salts on early Mars.* Geophys. Res. Lett., 2009. **36**(11): p. L11202. [8]. Tornabene, L.L., G.R. Osinski, and A.S. McEwen, *Parautochthonous megabreccias and possible evidence of Iimpact-induced hydrothermal alteration in Holden Crater, Mars.* Lunar and Planet. Sci., 2009. **40**. [9]. Pelkey, S.M., et al., *CRISM multispectral summary products: Parameterizing mineral diversity on Mars from reflectance.* J. Geophys. Res, 2007. **112**: p. 1ñ18. [10]. Baldridge, A.M., *Thermal Emission Studies of Sulfates and Chlorides: Implications for Salts on the Martian Surface*. 2008, Arizona State University: Tempe. p. 189.