LATE STAGE FORMATION OF MARTIAN CHLORIDE SALTS THROUGH PONDING AND EVAPORATION. B.M. Hynek[1-2], M.K. Osterloo[1] and K.S. Kierein-Young[1], [1]Laboratory for Atmospheric and Space Physics & [2]Dept. of Geological Sciences, University of Colorado-Boulder, 3665 Discover Drive, Boulder, CO 80303, hynek@lasp.colorado.edu

Introduction: Small deposits of chloride salts have been documented at hundreds of locations on Mars through the use of multispectral orbital data [1]. Yet given their small spatial extent, the formation mechanisms, timing, and relation to other aqueous processes in Mars' history are presently poorly constrained. Here we detail one of the chloride deposits near Meridiani Planum; the location of the Opportunity rover. This chloride deposit unequivocally formed from fluviolacustrine processes associated with late stage hydrologic activity. This hydrological episode occurred after the regional widespread fluvial incision and also post-dates formation of the sulfate bedrock being investigated by Opportunity. We conclude that this chloride deposit represents some of the last vestiges of inhabitable surface water on Mars as recorded in the mineralogical record.

Physiography of the Meridiani Chlorides: Roughly 200 km southwest of the Opportunity landing site exists three chloride deposits identified by [1] (Fig. 1). Two of these are small and heavily degraded, obscuring the geologic context. However the largest deposit (~30 km^2) with the strongest chloride spectral signatures resides in a local basin superposed on highland terrain. Between Opportunity and the chlorides exist sinuous ridges and phyllosilicate detections within Miyamoto crater [2-3]. These workers infer that the sinuous ridges are inverted fluvial channels that formed prior to the emplacement of the Meridiani sedimentary package. Their formation was likely coincident with the main fluvial episode that was responsible for regional highland dissection [3]. Low-lying extensive plains lie to the west of the chloride locales (Fig. 1). This unit is characterized by long, linear to sinuous, mare-type (wrinkle) ridges, lobate margins, low albedo, and other features suggestive of low-viscosity lava flows [4].

Datasets and Methods: Chloride salts, including those presented here, were first proposed as a surface compositional unit of Mars by [5] based on the thermal infrared (IR) spectral characteristics observed in data from Mars Odyssey's Thermal Emission Imaging Spectrometer (THEMIS) and Mars Global Surveyor's Thermal Emission Spectrometer (TES). A characteristic featureless slope in emissivity across these wavelengths is best matched by laboratory spectra of halite mixed with basalt [6]. Over 600 small (~< 25 km^2) discrete chloride deposits have been noted across the surface of Mars and are characteristically light toned and often have fine scale polygonal fractures [1]. We used decorrelation stretched THEMIS images and a full-resolution CRISM scene, combined with geomorphic indicators, to map the Meridiani chloride deposits.

The recent geologic map of [4] was used for context to place the chloride deposits in a regional and well-understood geologic history. To detail the chloride deposits for this study, we created a higher resolution mosaic of Context Camera (CTX) visible images at ~6 m/pix with near-complete coverage in our region of interest. Also available were eight visible images from the High Resolution Imaging Science Experiment (HiRISE) that provide complete coverage over two of the three Meridiani chloride deposits at ~25 cm/pix resolution.

The main chloride deposit had both HiRISE and CTX stereo image pairs suitable for construction of digital terrain models (DTMs). The EDR products were processed with ISIS and ingested into BAE's SOCET Set. A 16 m/pix CTX DTM was created covering most of the chloride basin and a 1 m/pix HiRISE DTM was generated for the chloride deposit.

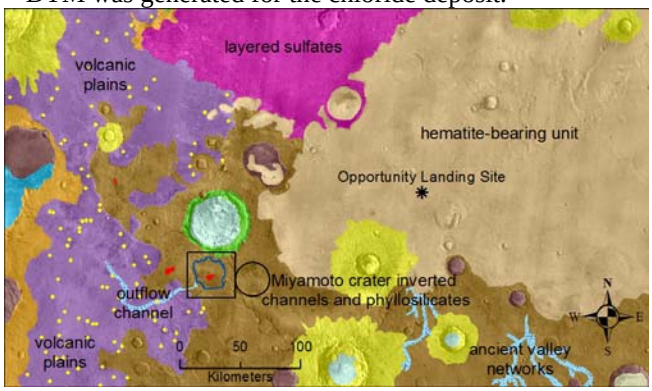

Fig. 1. Context of Meridiani chloride deposits on geological map of [4]. Chloride detections are in red and the boxed area is the region of interest in Fig. 2. The blue line within the box represents the -1530 m elevation contour and inferred lake extent. Yellow dots represent superposed impact craters > 1 km diameter used for age determination of outflow.

Observations: Fig. 2 shows a CTX DTM over the main Meridiani chloride deposit. It is nested in a local 35-km-wide basin in cratered highlands terrain. The basin's rim is heavily dissected by fluvial valleys on the north and east sides that flow into the topographic low with their heads near the drainage divides (Fig. 2).

The phyllosilicate nontronite is found in a few small (~1-2 km^2) eroded knobs ~4 km south of the chloride deposit around -1620 m elevation. The chloride deposit is entirely enclosed within the lowest area near the center of the basin. The basin's rim contains a ~2.1 km-wide breach on the low point along the southwest side. A ~50-m-deep valley system emanates from this breach and continues beyond the basin for 100 km, moving downslope across the highlands and cross-cutting low-lying plains.

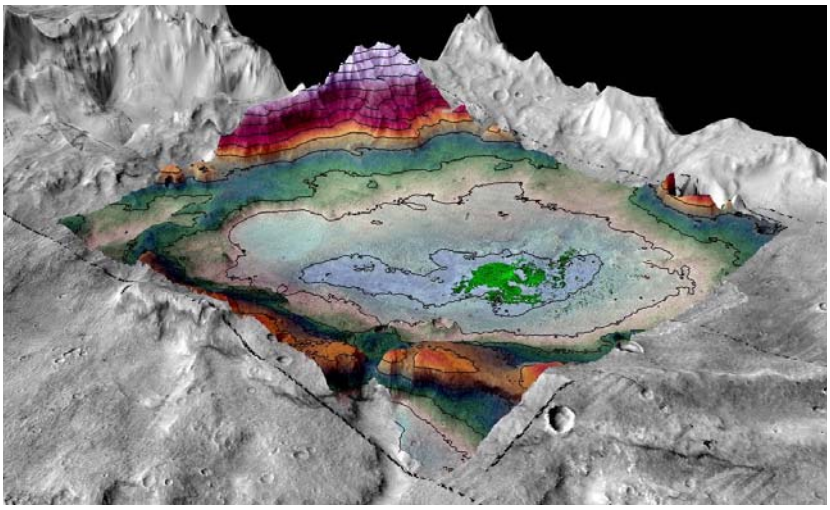

Fig. 2. 6 m/pix CTX mosaic and DTM rendered into perspective view looking northeast. The chloride deposit is shown in green and mapped from CRISM data. Valleys are seen incising the surrounding highlands and extend to the drainage divides. The basin rim breach and outflow channel is shown in the foreground. Contour interval is 50 m and DTM width is 26 km.

Interpretation: Precipitation and surface runoff under inferred clement climate conditions incised the highland terrains, leading to ponding in the local basin. The basin filled to form a lake that eventually rose to the point where it overtopped the lowest point of the rim in the southwest. This led to downcutting the rim and outflow that formed the large channel beyond the basin. The remaining water remained ponded in the lake. Eventually, the final evaporating water led to concentration of solutes and precipitation of a chloride salt pan in the lowest areas. The outflow channel from the lake breach cross-cuts volcanic plains that have an age of 3.60 Ga [4], representing the maximum age of the lake and chloride deposits.

The HiRISE 1 m/pix DTM was used to map the extent and thickness of the salt flat. In places, intact blocks of the fractured salt deposit are thrust upward, exposing the interior structure and thickness. These up-thrust blocks were used to constrain the minimum thickness of the salt layer. Elevation profile measurements were taken throughout the salt flat and averaged ~1.5 m. The total area of the chloride deposit was determined from the VNIR and mid-IR spectroscopic measurements and the clear morphologic and albedo boundaries of the unit and encloses an area of 29.83 km^2. The estimate of 1.5 m thickness applied to the area of the salt flat, results in a volume of salt of 44.75 km^3. Porosity measurements in terrestrial salt flats such as Lake Bonneville average 45% [7] and that value was used for calculation of mass. Density of the salt was assumed to be that of halite (2.16 g/cm^3), giving a total mass of ~55×10^9 kg.

The CTX DTM was used to determine the lake extent by extracting the portion contained within the -1530 m contour line, which is approximately at the elevation of the breached rim (Fig. 2). The volume between the actual surface of the DTM and the -1530 level was calculated on a pixel-by-pixel basis within the GIS with a result of 35.87 km^3, with a corresponding mass of 35.87×10^{12} kg. This is a minimum estimate of the lake characteristics, since the CTX DTM does not cover the southern ~10% of the region. Salinity is commonly reported in grams of solute per kilogram of solvent. Accordingly, the Meridiani chloride lake had a salinity of ~1.53 g/kg, which is 4% the salinity of Earth's ocean. Thus, by this standard, the Martian lake was a habitable environment.

Conclusions: The Meridiani region of Mars underwent numerous episodes of hydrologic activity, beginning with fluvial incision in the highlands and alteration of the crust to Mg/Fe smectites. This was followed by regional emplacement of the layered sedimentary package and subsequent diagenesis under acid-sulfate conditions. The final signs of surface water in the region are manifest by the Meridiani chlorides. The main Meridiani chloride deposit is located at the bottom of a local topographic basin in highlands terrain near the Opportunity rover. The incised valleys draining from the surrounding highlands into the basin imply a fluviolacustrine environment. This is the first clear demonstration of Mars chlorides forming in a lake and first definitive age estimation for a Martian chloride deposit. The youthful age represents some of the youngest mineralogical signs of water on the surface of Mars as identified with orbital data.

References: [1] Osterloo M.K. et al. (2010) *JGR, 115*, E10012. [2] Wiseman S.M. (2008) *GRL, 35*, L19204. [3] Newsom H.E. et al (2010) *Icarus, 205*, 64-72. [4] Hynek B.M. & G. di Achille (2014) *USGS Meridiani Map* (in press). [5] Osterloo M.K. et al. (2008) *Science, 319*, 1651–1654. [6] Jensen H.B. & T.D. Glotch (2011) *JGR, 116*, E12. [7] Turk L.J. et al. (1973) *Economic Geol., 68*, 65-78.