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A large sedimentary basin in the Terra Sirenum region of the southern highlands of Mars

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ABSTRACT

Different lines of evidence point to hydrological cycling in the martian past. The extent, duration, and magnitude of this cycling remains unclear, as well as the magnitude of aqueous processes on the surface. Here, we provide geomorphic and mineralogic evidence of a large inter-crater sedimentary basin located in the Terra Sirenum region, which was once covered by a body of liquid water with an areal extent of at least 30,000 km^2 and a depth of approximately 200 m. The topographic basin, which is modified by a number of large impact craters, is partly controlled by ancient impact and tectonic structures. As a result of evaporation of the large body of water, salt flats formed in the lowest topographic reaches of the basin. Hydrated phyllosilicates occur in close proximity to the salt flats and in the ejecta and rim materials of small impact craters with stratigraphic relations that suggest that they underlie the evaporite deposits. Crater statistics place the maximum age of aqueous activity during the Late Noachian epoch. The relatively pristine mineral deposits in the basin have a high potential to yield information of the geochemistry and water activity during the ancient Noachian Period when conditions were seemingly more conducive to life.

1. Introduction

There is ample evidence of water flowing and ponding on the surface of Mars in the past, including widespread phyllosilicates (e.g., Poulet et al., 2005; Bibring et al., 2006; Mustard et al., 2008), salt deposits including sulfates and chlorides (Squyres et al., 2004; Gendrin et al., 2005; Osterloo et al., 2008, 2010), elevated elemental concentrations (Dohm et al., 2009), and geomorphic features such as valley networks, fluvial channels, layered sedimentary deposits, paleolakes, and deltas (e.g., Masursky et al., 1977; Carr and Clow, 1981; Scott et al., 1995; Carr, 1996; Cabrol and Grin, 1999; Malin and Edgett, 2001; Fairén et al., 2003; Di Achille and Hynek, 2010). Such lithologies, elemental concentrations, and geomorphic features point to hydrological cycling in the past. However, the extent, duration, and magnitude of this cycling remains unconstrained.

Recent studies have reported the presence of diverse hydrated minerals over large parts of the ancient cratered southern highlands (Mustard et al., 2008; Grant et al., 2008; Murchie et al., 2009; Wray et al., 2009). Many of these minerals occur in rock outcrops, which are associated with impact craters. Secondary minerals in impact craters on Mars can have three possible origins: impact excavation of buried deposits (e.g., Ehlmann et al., 2009; Fairén et al., 2010), local post-impact water activity, consistent with ancient crater lakes (e.g., Cabrol et al., 2001; Orofino et al., 2009; Marzo et al., 2010), or impact-induced hydrothermal activity (Marzo et al., 2010; Fairén et al., 2010). In the first case, information about the origin and formational conditions of the deposits is largely altered (if not destroyed) due to the impact and associated exhumation processes. Excavated aqueous deposits are not necessarily representative of aqueous processes on the surface, since the minerals could have formed below the surface with subsequent exposure through impact cratering. Rather, post-impact crater deposits are more indicative of water activity at the surface, though they may only relate to the local (intra-crater) environment in which they formed (Marzo et al., 2010; Fairén et al., 2010). In both cases, it is difficult to infer the duration and extent of the aqueous processes involved in the formation of the deposits.

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Extensive inter-crater sedimentary basins in ancient terrains, on the other hand, are windows into the ancient aqueous processes that took place on the surface of Mars. Sediments within these ancient basins contain information of the geochemistry of early martian waters and the environmental conditions at the time of formation, provided that these deposits have not been significantly altered by subsequent geologic processes. Irwin et al. (2002) described a 1,000,000 km^2 Noachian lake in the ancient cratered southern highlands, which drained northward, sculpting one of the larger martian valleys, Ma'adim Vallis. However, no mineralogic evidence was presented of aqueous deposits inside the basin (Irwin et al., 2002). Wray et al. (2009) recently identified Fe/Mg-phyllosilicates in the inter-crater plains on Sirenum and Noachis Terrae, associated with putative-chloride-bearing deposits. Both studies hint at the existence of large bodies of liquid water on the surface of the highlands in the past.

Based on geomorphic and mineralogic evidence, we describe a large inter-crater sedimentary basin in the Terra Sirenum region, which contains aqueous deposits including evaporites and phyllosilicates that formed early in the history of the planet. These sedimentary deposits could contain information of the geochemistry and aqueous activity from a period when conditions were seemingly more conducive to life. Though geologic processes such as impact cratering events, volcanism, erosion, and deposition have modified the basin, geomorphic and mineralogic features are still observable, pointing to a pervasive ancient aqueous martian environment.

2. Physiographic and geologic setting

The inter-crater basin is located approximately 300–400 km northeast of Newton impact crater in the Terra Sirenum region (Fig. 1). The basin occurs in an ancient geologic province marked by distinct magnetic signatures (Connerney et al., 1999; Acuña et al., 1999, 2001), relatively high density of large degraded impact craters, and faults and ridges (Scott and Tanaka, 1986; Zuber, 2001). The basin floor is characterized by mostly dark-albedo surfaces through daytime THEMIS images, and which are the center of this investigation. The basin contains previously reported chloride-bearing deposits, likely formed in an evaporitic environment within the ancient geologic province of Terra Sirenum (Osterloo et al., 2008, 2010). Similar chloride-bearing deposits appear to be common in the southern highlands between 25° and 40° of latitude (Osterloo et al., 2008, 2010; Murchie et al., 2009; Wray et al., 2009).

3. Methods

3.1. Satellite images and spectral data

Diverse orbiting spacecraft information was used in this study to investigate the area of interest in the Terra Sirenum region. The information included: (1) images from the High Resolution Imaging Science Experiment (HiRISE) (up to 25 cm/pixel; McEwen et al., 2007) and Context (CTX; 6 m/pixel; Malin et al., 2007) cameras on the Mars Reconnaissance Orbiter (MRO); (2) topographic data from the Mars Global Surveyor (MGS) Mars Orbiter Laser Altimeter (MOLA) (altitude resolution of 13 m, Zuber et al., 1992); (3) multi-band images through the Mars Odyssey (ODY) Thermal Emission Imaging System (THEMIS) (100 m/pixel near-infrared (IR) day and nighttime images and 18 m/pixel visible multi-band images; Christensen et al., 2003); and (4) the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) (hyperspectral observations with a spatial resolution approximating ~18 m/pixel; Murchie et al., 2007). CRISM, in particular, measures reflected radiation in the visible and near infrared (VNIR) from the surface of Mars, providing the ability to recognize both primary (e.g., pyroxenes) and secondary minerals (e.g., clays). CRISM spectral data was converted to apparent I/F (the ratio of reflected to incident sunlight), then divided by the cosine of the incidence angle to correct for the illumination geometry (Murchie et al., 2007, 2009); the atmospheric contribution was removed using a volcano-scan correction (McGuire et al., 2009).

THEMIS IR data was used to identify chloride-bearing deposits within the basin, previously reported by Osterloo et al. (2008, 2010). The chloride-bearing deposits appear blue in THEMIS IR decorrelation stretched images using bands 8, 7, and 5 (Osterloo et al., 2008) (Fig. 2). Context (CTX) and high-resolution (HiRISE) images were used to map and characterize evaporites (morphology, size, surface texture, patterned ground, etc.), as well as other

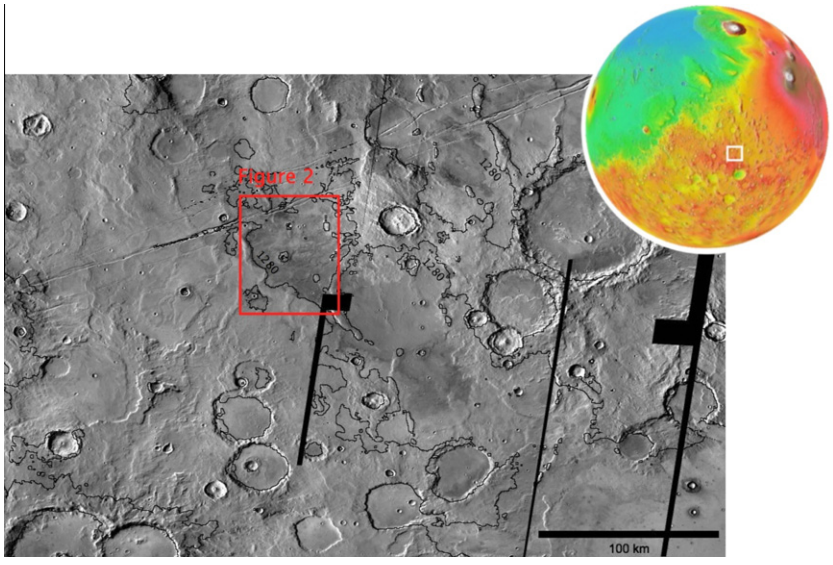

Fig. 1. THEMIS daytime IR with topographic contours (black solid lines) at 1200 m intervals based on MOLA altimetry showing the region of study in Terra Sirenum. The proposed paleobasin is limited by the 1280 m contour. The basin floor can be distinguished by its darker albedo. North is at top. The inset at the upper right shows the location of the basin with respect to the Tharsis volcanic province which is to the northeast.