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The Simud–Tiu Valles hydrologic system: A multidisciplinary study of a possible site for future Mars on-site exploration

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ABSTRACT

When looking for traces of past life on Mars, we have to look primarily for places where water was present, possibly for long time intervals. The Simud and Tiu Valles are two large outflow channels connected to the north with the Chryse Basin, Oxia Palus quadrangle. The area, carved by water during the Noachian/Early Hesperian is characterized by a complex geological evolution. The geomorphological analysis shows the presence of fluvial and alluvial structures, interpreted as fluvial channels and terraces, debris flow fronts and short-lasting small water flows coexisting with maar-diatremes and mud volcanoes. Several morphological features indicate a change in water flux direction after the main erosive phase. During this period water originated from the Masursky crater and flown southwards into the Hydraotes Chaos. This phenomenon caused the studied area to become a depocenter where fine-grained material deposition took place, possibly in association with ponding water. This setting is potentially quite valuable as traces of life may have been preserved. The presence of water at various times over a period of about 1 Ga in the area is corroborated by mineralogical analyses of different areas that indicate the possible presence of hydrated minerals mixtures, such as sulfate-bearing deposits. Given the uniqueness of the evolution of this region, the long term interactions between fluvial, volcanic, and tectonic processes and its extremely favorable landing parameters (elevation, slope, roughness, rock distribution, thermal inertia, albedo, etc.), we decided to propose this location as a possible landing site for the ESA ExoMars 2018, the NASA Mars 2020 and future on-site missions.

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1. Introduction

One of the main questions regarding Mars is whether life ever existed on the planet. Liquid water is not synonymous with life but it is considered a first requirement for life to exist on a planet (Westall, 2005; Westall et al., 2015), together with organic carbon, nutrients and a source of energy (hydrothermal, chemical or solar) (Westall et al., 2011; Harris et al., 2015). Geomorphological features like valleys, lakes and deltas suggest that liquid water flowed on the surface of Mars during ancient times. In particular, on the basis of cratering rate and geomorphological evidence one can infer the presence of liquid water on Mars between 4.5 and 3.7 Ga ago (Carr, 1996; Fassett et al., 2010) and probably also later, though only episodically, till the Late Amazonian (e.g., Hauber et al., 2013).

Even if morphological evidence related to the presence of water runoff can be found all over Mars (e.g. Pieri, 1980; Baker et al., 1985; Mangold, 2004; Hynek et al., 2010), many aspects of the planet's hydrological evolution still remain unclear. Nevertheless, thanks to the increasing number of instruments observing Mars, providing higher and higher resolution data (e.g., few-meter scale DEM obtained from both Mars Express High Resolution Stereo

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Camera (HRSC) images and Mars Reconnaissance Orbiter Context Camera (MRO-CTX) stereo-pair images), multi-instrument and multi-disciplinary studies are being carried out that will provide important insights into the complex past history of the planet.

This paper focuses on the Chryse Planitia region, a plain area located in the northern equatorial region of Mars, between Lunae Palus and Oxia Palus quadrangles (Davies et al., 1992). Chryse Planitia, an old impact basin (Schultz et al., 1982), is the terminus for many outflow channels from the southern highlands as well as from Valles Marineris (Fig. 1). In this study, we devote specific attention to the Simud–Tiu Valles system, where many water-related features can be observed. The Simud and Tiu Valles are among the largest outflow channels that converge into Chryse Planitia. The origin of these channels has been controversial (e.g., Carr, 1974; Blasius and Cutt, 1979); however, the hypothesis that these areas were carved by water erosion is now accepted as the most plausible (e.g. Carr, 1996; Ori and Mosangini, 1998). Various sculpted landforms are found at the mouths of Simud and Tiu Valles. Remnants of the plateau through which the channels are incised have been molded into teardrop-shaped islands, elongated in the direction of the flow (Carr and Clow, 1981). Parts of the Chryse plain also appear etched, as a flow plucked part of the surface to form series of jagged, irregularly shaped depressions.

Elevation data from the Mars Orbiter Laser Altimeter (MOLA) and HRSC, as well as HRSC images and MRO-CTX images were used to reconstruct the geological and geomorphological evolution of the area. Particular attention was paid to the identification of the main phases of the Simud–Tiu Valles hydrological system, with a specific focus on water flow direction. In this perspective, the connection between these two valleys constitutes a critical point, to which we devoted closer attention.

2. Regional overview

2.1. Material and methods

In this section we present the results deriving from the investigation of the macro-scale processes that carved the Simud–Tiu complex and surrounding areas, integrated with data deriving from previous studies. In this analysis the Mars Global Surveyor-MOLA Digital Elevation Model (DEM) with a spatial resolution of 463 m (Smith et al., 2001) and the Mars Express-HRSC 12.5 m resolution images (Neukum et al., 2004) were used. HRSC DEMs covering the entire area under study, with a spatial resolution ranging between 50 and 75 m (Neukum et al., 2004) were also used. 2001 Mars Odyssey THEMIS visible images, characterized by a slightly lower resolution, 18 m (Christensen et al., 2004), but with different illumination conditions than the HRSC ones were also analyzed.

2.2. Simud–Tiu Valles

The Simud and Tiu Valles are two of the many outflow channels that are believed to have carried water flowing into the putative ocean of Chryse Planitia (Tanaka et al., 2003). The carving of these valleys has been attributed to catastrophic flows (e.g., Carr and Head, 2010) formed by water (Baker and Milton, 1974), debris flows (e.g., Tanaka, 1997, 1999) or a mixture of them (MacKinnon and Tanaka, 1989). More recently, Rodriguez et al. (2006) studied the area of Simud and Tiu Valles and divided the evolutionary history of these channels into two main phases. During the older phase, the incision of the higher outflow channels located on top of the topographically highest Middle-Noachian terrains (Tanaka et al., 2014) took place. This event was probably biphasic with an initial stage characterized by catastrophic floods followed by a non-catastrophic surface flow (Rodriguez et al., 2006). During the second main evolutionary phase of the Simud–Tiu area, the lower outflow channels were carved and the so-called ''Hesperian transition flow unit'' deposited (Tanaka et al., 2014; blue unit in Fig. 4a). These incisions are more broadly distributed than the older ones, and reach up to 300 km in width near the Simud Vallis/Chryse Planitia boundary. According to Rodriguez et al. (2006), multistage debris flows originating from the Hydraotes Chaos (Figs. 2 and 4 for location) and draining into the Chryse Planitia carved these channels and deposited the sedimentary units located at their bottom. This hypothesis was also proposed by previous studies (e.g., Ivanov and Head, 2001), with the Simud/Tiu Vallis system draining into an existing body of water in the Chryse Planitia, during the Hesperian–Early Amazonian age. Following this main paroxysmal stage, a later multi-stage phase, characterized by intermittent filling of the Hydraotes Chaos by multi-directional and alternating water fluxes (Ori and Mosangini, 1998), took place.

Due to a lack of clear flow indicators, it is generally difficult to identify the very last flow directions in the majority of the channels exiting the Hydraotes Chaos (Ori and Mosangini, 1998). As can be seen in Fig. 4d, we identified a very peculiar morphological feature located at the southern extremity of the westernmost channel, that connects the Hydraotes Chaos with the Simud Vallis. This morphology that consists of a triangular-shaped region that presents a clearly different texture than the nearby main chaotic terrains, and can give us an insight on paleofluxes. Streamlines, lobate fronts, and asymmetrical profile of the deposit are present whenever a collision with an obstacle takes place (e.g., the mesas of the chaotic terrain) are present. These indicators point to a southwards flow direction, entering the Hydraotes Chaos from the Simud Vallis itself. The freshness of this landform suggests that this depositional phase followed the debris flow events that, according to Rodriguez et al. (2006), shaped the lower channels of the Simud and Tiu Valles, flowing from the Hydraotes Chaos to the Chryse Planitia.

The Simud Vallis can be separated into two different regions: a northern one, which leads to the Chryse Planitia lowlands, and a southern one, extending from the Simud Chaos down to the Hydraotes Chaos (Rodriguez et al., 2008). A morphological threshold located at about 15°N separates these two large areas marked by a clear break in the slope (Fig. 3a, Rodriguez et al., 2005, 2008), thus suggesting that different evolution paths were followed by the two regions. The northern part still preserves traces of liquid fluxes, such as erosional terraces and streamlined islands, whereas the southern region is more uneven, with no evident major flow features and widespread chaotic terrains. These chaotic terrains can be interpreted as the result of the disruption of the paleochannel floor, along with possible preexisting shorelines, not associated with catastrophic floods, due to the lack of any recognizable flow features (Rodriguez et al., 2008). The authors, moreover, suggest that the Simud Chaos is indicative of a complex and long-lived history of volatile terrain deflation, possibly still ongoing, which also resulted in a relative subsidence of the whole area.

2.3. Ares Vallis

The Simud–Tiu complex is located next to the Ares Vallis (Fig. 2), an outflow channel that was deeply studied in connection with the landing site selection for the NASA Pathfinder mission (Golombek et al., 2003), which ultimately landed near its mouth. Pacifici et al. (2009) suggest for the Ares Vallis an Early-to-Late Hesperian multi-stage origin, connected with at least six catastrophic floods and glacial/periglacial processes. These flooding events present many similarities with those depicted by Rodriguez et al. (2006) for the Simud–Tiu Valles, e.g., their cyclic nature and their provenance, in both cases related to Chaotic

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