EVIDENCE FOR EFFUSIVE MUD VOLCANISM IN UTOPIA PLANITIA ON MARS,

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Introduction: Utopia Planitia is one of the largest impact basins on Mars [1,2] that is ~2000 km in diameter but only 1.5-2 km deep. The larger portion of the basin floor is covered by the Hesperian-age Vastitas Borealis Formation (VBF), materials of which may indicate existence of an ocean in the geological past of Mars. SW edge of Utopia Planitia hosts occurrences of the thumbprint terrain (TPT) [3,4], the largest exposure of which is in Isidis Planitia that we recently mapped in detail [5]. One of the goals of our study is the comparison of the geological settings of TPT in both regions that can help to constrain the origin of this terrain. The area of our study is between 20-45°N and 100-120°E and we mapped this region using all available imagery data sets. Here we describe the most important units and structures that form the regional geological context for TPT in Utopia Planitia.

Major units and structures in SW Utopia: Extensive material units: Vastitas Borealis interior unit [6] occupies the largest portion of our study area (Fig. 1). Vast plains that appear morphologically smooth at the resolution of the CTX images make up the surface of the unit. Its southern margin consists of numerous lobes that extend southward and overlap the surrounding terrains. The daytime THEMIS IR data show that the peripheral portions of the unit have uniform and higher brightness temperature but large darker spots are seen closer to the center of Utopia. Materials derived from the Elysium rise are concentrated in the center of the Utopia basin, superpose the surface of the interior unit, and have been formed by volcanic and fluvial activity [6]. The stratigraphically higher deposits in this region are related to flows from Tinjar Vallis and have bright surface with numerous short ridges and very sinuous/digitate boundary. The size-frequency distribution (SFD) of impact craters on the surface of these materials corresponds to the absolute model age of ~1.4 Ga.

Impact craters: Impact craters in Utopia Planitia show a variety of morphologies likely related to the target properties and degree of degradation. The most degraded craters [7] appear as very shallow depressions surrounded by concentric graben [8-10]. In our study area there are 90 of these structures in the diameter range from ~20 to ~35 km that are distributed apparently randomly in the area of the interior unit (Fig. 1).

Morphology of ejecta from prominent craters in Utopia is changed as a function of the distance from the basin center. In the peripheral zone of the basin (Fig. 1) the ejecta of craters in all visible range of diameters have usual morphology but in places show broad lobes suggesting some degree of fluidization during impact [11-13]. Closer to the center of Utopia (at angular distance <~20 degree from the center, Fig. 1), most of the impact structures > ~1 km in diameter are pedestal-like craters, the formation of which seems to require the presence of ice in the target [14-18].

Giant polygons: The polygonal terrain in Utopia Planitia [8,19,6] is formed by intersecting of broad and shallow troughs that cut the surface of the interior unit. Areas of polygonal terrains in Utopia occur circumferentially around the flat central portion of the basin [8]. In our study area the onset of the polygons approximately coincides with the transition from the common to the pedestal craters (Fig. 1).

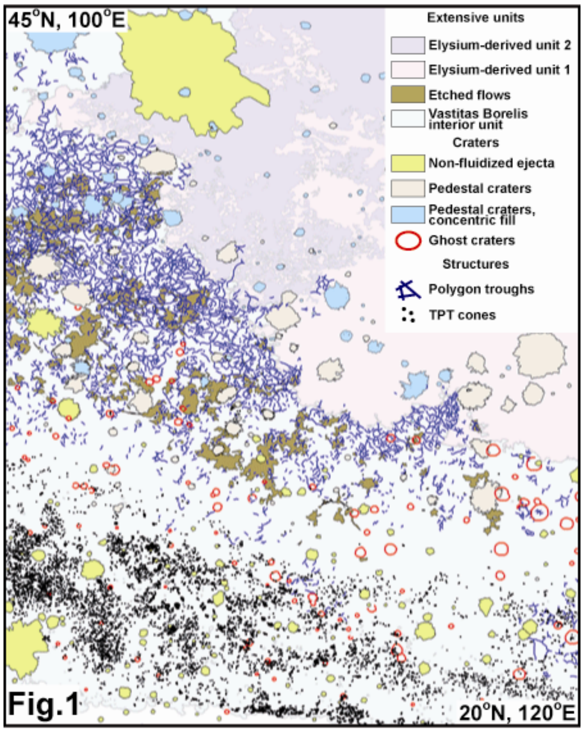
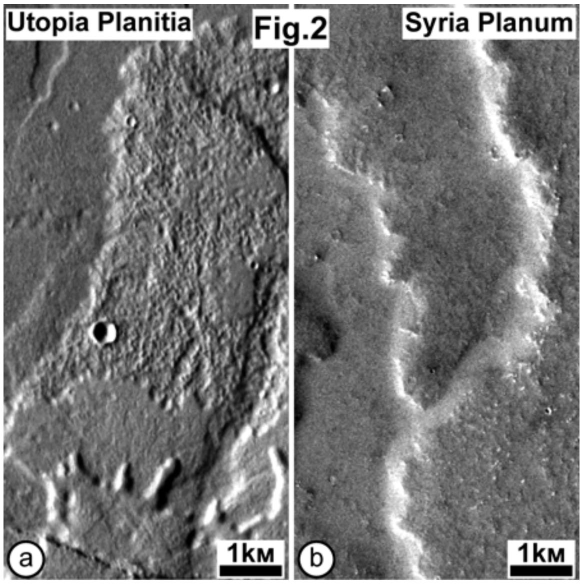


Fig.1

Structures of TPT: Numerous small cone-like structures with a summit pit characterize TPT in Isidis and Utopia Planitiae [20,21]. The main difference of TPT in Utopia is that the cones in this region usually form broad clusters and are not arranged in long, curvilinear, and nested chains as it often occurs in Isidis Planitia. The absolute majority of the cones in Utopia are concentrated within a broad (200-300 km) zone near the periphery of the basin and almost do not occur in the zone of polygons (Fig. 1).

Flows: Lobe- and flow-like features (tens of km wide, many tens of km long) are seen in the high-resolution images (e.g., CTX, THEMIS-VIS, Fig. 2a) within the zone of polygons. In many cases they correspond to the darker spots seen in the daytime THEMIS IR data. The flows usually emanate from long and narrow fractures and produce the classical pattern of fissure eruptions. In many places they consist of several stacked layers and superpose most of the polygon troughs.

The most important characteristic of the flows is that they are significantly more eroded than the underlying plains (Fig. 2a). The marginal portions of the flows are etched and scalloped and the smoother surface in their central portions displays collapse pits (Fig. 2a). The uppermost layers of the stacked flows sometimes consists of isolated, flat-topped, and pitted mesas with very sinuous boundaries. Such morphologic characteristics of the etched flows in Utopia Planitia strongly distinguish them from the usual lava flows (Fig. 2b).



Discussion: The oldest features detected in the area of our study are the ghost craters. In contrast to all younger features that form broad concentric zones around the center of Utopia Planitia, the ghost craters are apparently randomly distributed within the interior unit (Fig. 1). This suggests that 1) the craters likely represent remnants of the background population that existed before emplacement of the interior unit (VBF) and 2) formation of the unit was not able to erase completely the older craters with diameters ~20 km and larger. The size-frequency distribution of the ghost craters corresponds to the absolute model age of ~3.6 Ga, which likely represents the lower time limit for VBF. The population of larger impact craters (1-20 km) superposed on the surface of the interior unit corresponds to the absolute model age of ~3.5 Ga. Crater counts on the etched flows that superpose the surface of VBF indicate the age of emplacement of the flows to be ~3.2 Ga. This age likely represents the upper time limit for VBF.

The etched flows play an important role in understanding of the nature and mode of emplacement of VBF. The source areas of the flows and their pattern of emplacement strongly indicate that the flows formed due to effusive eruptions. Morphology of the flows, however, is strongly different from that of typical lava flows (Fig. 2). Three important features characterize the flows: (1) selective erosion of the flow materials without evidence of erosion of the adjacent plains, (2) abundant rimless pits that most likely are collapse structures, (3) mesas that are bordered by very sinuous cliffs and probably represent isolated remnants of previous contiguous layer(s).

All these features are consistent with and indicative of the presence of volatiles whose escape upon emplacement of the flows would cause their partial collapse and formation of the observed unusual morphologies. In no case, however, features related to explosive activity were met in association with the etched flows in Utopia Planitia and emplacement of gas-saturated lava flows under very low atmospheric pressure on Mars is extremely unlikely [22]. Thus, we interpret the etched flows as evidence for widespread (Fig. 1) effusive mud volcanism in Utopia Planitia.

The etched flows similar to those in Utopia were not detected on the floor of Isidis Planitia [5] where the characteristic features of TPT (cones) are very abundant [20]. In Utopia Planitia, the TPT cones are concentrated away from the zone where the etched flows occur (Fig. 1). Thus, the possible explanation of formation of the cones by the processes related to mud volcanism [23,24] is poorly consistent with the observations.

The occurrences of the mud flows in SW Utopia probably mark approximate extension of a subsurface reservoir of water/ice-rich materials that may represent remnants of the former and more extensive body of water/ice in the northern lowlands of Mars [25-27]. Eruption of the mud flows require the presence in the reservoir of either liquid materials, or their liquefaction under thermal influence of the Elysium magmatic center, or squeezing of the solid-state ice-rich material under the load of the late Amazonian materials derived from the Elysium rise. The last hypothesis is not consistent with the modal absolute age of emplacement of the mud flows (~3.2 Ga). Although the time of onset of magmatic activity in Elysium is unknown, the areal distribution of the mud flows follows the pattern of concentric distribution typical of other units/structures in the Utopia basin unrelated to volcanism in Elysium. This does not favor the hypothesis of triggering of the mud volcanism in Utopia by the thermal pulses from the Elysium center. Thus, we prefer to link emplacement of the mud flows with the final episodes of evolution of a standing body of water that was responsible to formation of VBF. In this scenario, which is consistent with the age estimates and the general pattern of the spatial distribution of features in Utopia Planitia, the flows may represent the last portions of still liquid material [28] squeezed to the surface from the residual reservoir under the pressure of growing bodies of ice.

References: 1) McGill, G.E., JGR, 94, 2753, 1989; 2) Smith, D.E. et al., Science, 284, 1495, 1999; 3) Grizzaffi, P. and P.H. Schultz, Icarus, 77, 358, 1989; 4) Lockwood, J.F., et al, LPSC-23,795, 1992; 5) Ivanov M.A. et al., Icarus, 2012; 6) Tanaka, K.L. et al., USGS Map 2888, 2005; 7) McGill, G.E., GRL, 13, 705, 1986; 8) McGill, G.E. and L.S. Hills, JGR, 97, 2633, 1992; 9) Buczkowski, D.L. and G.E. McGill, GRL, 29, 2002; 10) Buczkowski, D.L. and M.L. Cooke, JGR, 109, 2004; 11) Head, J. W. and R. Roth, LSI, 50, 1976; 12) Carr, M.H. et al., JGR, 82, 4055, 1977; 13) Mouginis-Mark, P. JGR, 84, 8011, 1979; 14) Mouginis-Mark, P.J., Icarus, 71, 268, 1987; 15) Schultz, P.H., and A.B Lutz, Icarus, 73, 41, 1988; 16) Wrobell, K.,P.et al., MPS 41, 1539, 2006; 17) Kadish, S.J. et al., GRL, 35, 2008; 18) Kadish, S.J. et al., JGR, 114, 2009; 19) Hiesinger, H. and J.W. Head, JGR, 105, 11999, 2000; 20) Hielscher, F.J. et al., LPSC-41 #2394, 2010; 21) Ghent, R.R., et al., Icarus, 217, 169, 2012; 22) Wilson, L. and J. W. Head, Rev. Geoph., 32, 221, 1994; 23) Tanaka, K.L., JGR, 102, 4131, 1997; 24) Skinner, J.A. and A. Mazzini, MPAG 26, 1866, 2009; 25) Parker, T.J. et al., Icarus, 82, 111, 1989; 26) Parker, T.J. et al., JGR, 98, 11061, 1993; 27) Carr, M. H., and J. W. Head, JGR, 108, 2003; 28) Kreslavsky, M.A. and J.W. Head, JGR, 107, 2002