

THE SOURCES OF MARTIAN OUTFLOW CHANNELS: WATER RESERVOIRS OR ACCUMULATION OF ICE BEARING DEPOSITS? A CASE STUDY OF HELLAS BASIN VALLES. V.-P. Kostama¹, M.A. Ivanov^{1,2}, J. Raitala¹, T. Törmänen¹ and J. Korteniemi¹, ¹University of Oulu, P.O. Box 3000, 90014 University of Oulu, Finland, <petri.kostama@oulu.fi>, ²Vernadsky Institute, RAS, Kosygin Str. 19, 119991 Moscow, Russia.

Introduction: The NE rim of the Hellas basin is the major concentration of large fluvial structures in the southern hemisphere of Mars. They occur within a large topographic depression (Hesperia-Hellas trough, HHT [1,2]; also called the SW trough [3]) that connects Hesperia Planum and Hellas basin. The surface within the trough is smooth and different from the rough surfaces of the Noachian terrains, which indicate that the trough was filled by a variety of materials. According to the studies, the time span of accumulation of volcanic and sedimentary materials within HHT continued from Late Noachian to Early Amazonian [4,5].

The major channel features (Dao, Niger, and Harmakhis Valles) form deep canyons that cut the suites of sedimentary and volcanic deposits and, largely post-date emplacement of these materials [4-6].

Characteristics of the valles: Following the previous interpretations [e.g. 7-10], we consider the canyons as structures formed due to release of ground water. They demonstrate several important characteristics that must be accounted for in the models of the history of accumulation of water in their source areas.

(1) The canyons and head areas clearly postdate majority of the surrounding terrains and are among the youngest features within HHT [4,5].

(2) They cut through a layered suite of materials that likely represents a thick stack of sub-horizontal volcanic and perhaps sedimentary layers [4,5].

(3) The floors of the head depressions, canyons, and channels occur at distinctly different levels [1].

(4) The canyons begin in distinct closed and flat-floored depressions. There are no fluvial features on the surface which could have contributed to formation of the depressions. The alternative is formation due to release of water from the subsurface sources that may include subsurface ice deposits [e.g. 4,5,10,11]. Niger Vallis provides evidence for subsurface flows that probably was related to subsurface sources of water: subsidence of the original surface due to removal of material by subsurface flows [12]. The change from the moats to the distinct canyons suggest that, the underground flow burst to the surface and carved the canyon. Similar situation is observed in the uppermost portion of Reull Vallis [13].

(5) The depth of visible layering varies between canyons. The layers in the head depressions of Harmakhis and Dao Valles are seen deeper than the floor of Niger Vallis. Within Niger the layering continues

almost to its floor. There is also evidence for extension of the layering below the floor of Ausonia Cavus. These observations suggest that the source of Niger was completely within the layers that fill HHT [1].

Discussion: These characteristics of the fluvial systems are consistent with two models explaining the origin of the systems. Both models consider formation of the fluvial systems due to release of ground water, but the mode of accumulation and storage of water is different.

Reservoirs of water: In the first model, water is accumulated around the source regions from a large underground watershed area. This model faces some serious difficulties. The topographic configuration of the surface within HHT either around or upslope of the beginning of the canyons/channels does not show any evidence for the presence of topographic barriers and/or closed depressions in the subsurface. The layers exposed on the walls of the canyons are always parallel to the surface and no evidence for the perturbations in the sub-horizontal bedding is seen. Thus, neither topographic nor morphologic features suggest the presence of reservoirs where ground water could have accumulated before being released to the surface.

The model of formation of the fluvial systems due to the release (either catastrophic or gradual) of water from an aquifer confined under the thick cryosphere [7,8] probably can explain the canyons/depressions of Dao and Harmakhis Valles. This model, however, is hardly applicable to the shallower Niger Vallis, which formed inside the layered suite.

Also problematic to the first model is the distinctly different topography of the head areas (Niger Vallis) that indicates the existence of several different levels along which water could flow toward the depressions. This requires the presence of a series of confining layers within the layered suite corresponding to the levels of the floors of the canyons. The confining layers on Earth consist of incompetent, very fine-grained, and, most importantly, clay-bearing rocks or layers of clays. The surface exposures of phyllosilicates on Mars are rare, small, and all occur in the Noachian terrains [14-16]. The formation of extensive water-confining layers during the Late Hesperian–Early Amazonian by deposition of clay-bearing dust is unlikely.

Ice-bearing deposits: This model relies on the presence of the ice-bearing deposits below and around the head depression of the fluvial features and explains

formation of the systems by release of water in their source areas due to melting of ice. In this model, the depth of the head depressions indicates the levels at which the ice or ice-bearing materials accumulated. Two processes may have caused the accumulation: (1) Seepage of liquid water toward the region of accumulation. This mechanism faces the same difficulties as the first model. (2) Deposition of ice from the atmosphere. This mechanism is supported by the interpretations of formation of the younger features such as viscous lobate flows and lineated valley fill [e.g. 17]. If atmospheric ice was the principal source of the icy materials in the head areas then the topographic levels at which their floors occur should correlate with the age of ice deposition. We assume that the layered materials within the topographic depression of HHT have been (on the average) deposited evenly over the entire width of the trough. Further, we discuss possible consequences of this model. Dao and Harmakhis Valles demonstrate the deepest source depressions. It is unclear whether they cut through the entire thickness of the layered materials and reach the Early to Middle Noachian rocks that are exposed on both sides of HHT or they only continue to the lower, older horizons of the layered suite. Their formation is consistent with both the release of water from the deep aquifer and melting of ice in the source areas. In the latter case, the ice deposits should be the oldest, formed either before or near the beginning of accumulation of layered sequence in HHT. The layering on the walls of Dao and Harmakhis is exposed to deeper levels than the floor of Niger Vallis. This suggests that a significant portion of the layered fill within HHT was already emplaced by the time of formation of the later ice-bearing deposits in the source region of Niger. Other indications of the process of later accumulation of ice in the past are a chaos related channel system, LDAs, lineated valley fill and viscous flows (see [1] and references therein).

Emplacement of the ice-bearing materials occurred alternately with the emplacement of the volcanic and perhaps sedimentary materials within HHT during a long period of time, at least since before the Late Noachian if formation of Dao and Harmakhis Valles is related to the ice deposits. There is no evidence, however, that may suggest either a specific pattern of rate of ice deposition or its amount as a function of time. The deposition of ice could have represented a discrete process consisting of periods of enhanced accumulation of ice during periods of increased obliquity [18]. On the other hand, the rate of deposition of ice could have been fairly uniform through time compared to the rate of emplacement of volcanic and other materials. This could cause accumulation of greater amounts of icy materials during periods of volcanic quiescence at

different topographic levels of the growing layered suite. Theoretical studies [11,19] show that superposition of lava flows onto a surface of ice caused little effect and may not be recognized even at the high-resolution images. However, when a sill or other intrusion comes closer to a glacier from below, this type of interaction leads to melting and removal of a portion (if not all) of the ice above the intrusion [e.g. 20]. If formation of the systems was related to the initial accumulations of ice, heating of the ice-bearing deposits from beneath lead to melting and re-mobilization of water, undermining rocks above the source and caused their collapse and formation of the head areas and the canyons/channels. The heating events may have been due to the late and localized intrusions [2] within the area, which affected the ice deposited at specific levels.

Conclusions: The valleys of Hellas basin region formed due to release of subsurface water and apparently have their sources at different topographic levels below or within the layered suite of volcanic deposits in HHT [1]. Two scenarios can explain the subsurface nature of their sources: (1) flow of liquid ground water from extensive watershed toward the source areas and accumulation of water there and (2) deposition of ice-bearing materials in and around the sources. The first scenario requires the existence of extensive confining layers at different topographic levels corresponding to the levels of the floors of the canyons/channels. Because the presence of such confining layers on Mars is problematic, second scenario is more likely. The deposition of ice-bearing materials at different levels during the growth of the lava plateau in HHT can explain the key features of the fluvial systems: the subsurface nature of the sources and the relatively young age. In this scenario, the higher topographic position of the ice-bearing deposits corresponds to the younger age of deposition. The possible accumulations of ice were buried by successive lava flows in HHT and later were heated from below by magmatic intrusions that caused melting of the icy deposits, release of water, and formation of the structures.

References: [1] Kostama et al. (2009) *EPSL*; [2] Korteniemi et al. (2009) *EPSL*; [3] Ivanov et al. (2005) *JGR*; [4] Price (1998) *USGS I-2557*; [5] Crown & Greeley (2007) *USGS I-2936*; [6] Greeley & Guest (1987) *USGS I-1802-B*; [7] Carr (1979) *JGR*; [8] Carr (1996) *in: Water on Mars*; [9] Baker et al. (1992) *in: Mars*; [10] Crown et al. (1992) *Icarus*; [11] Squyres et al. (1987) *Icarus*; [12] Crown & Mest (1997) *LPS XXVIII*; [13] Kostama et al. (2007) *JGR*; [14] Bibring et al. (2005) *Science*; [15] Poulet et al. (2005) *Nature*; [16] Mustard et al. (2008) *Nature*; [17] Morgan et al. (2009) *Icarus*; [18] Laskar et al. (2004) *Icarus*; [19] Ogawa et al. (2003) *JGR*; [20] Wilson & Head (2002) *in: Volcano-ice interaction on Earth and Mars*.