Valleys, Fan-shaped Deposits and Associated Phyllosilicates of a Paleolake Site at Libya Montes, Mars: Evidence of Complex Hydrologic Activity G. Erkeling[1], M. A. Ivanov[2], D. Reiss[1], H. Hiesinger[1], J. L. Bishop[3,4], D. Tirsch[4], R. Jaumann[4], L.L Tornabene[5], O. Ruesch[1] [1]Institut für Planetologie (IfP), WWU Münster, Wilhelm-Klemm-Straße 10, 48149 Münster, Germany (gino.erkeling@uni-muenster.de/ +49-251-8336376). [2]Vernadsky Inst. RAS, Moscow, Russia. [3]Carl Sagan Center, The SETI Institute, Mountain View, California, USA. [4]Institute of Planetary Research, German Aerospace Center (DLR), Berlin, Germany. [5]University of Western Ontario, London, ON, Canada.

Introduction:
The last decades of Mars research have revealed numerous observations of past flowing and ponding of water on the surface of Mars, including channels, valleys, paleolakes, seas and oceans. A region on Mars with the highest density of fluvial and lacustrine landforms is the Noachian-aged Libya Montes highlands at the southern rim of Isidis Planitia [e.g., 1-5]. In particular, a 60-km diameter crater paleolake site located at 85.8°E/2.7°N reveals a diverse and complex setting of fluvial and lacustrine landforms [4]. The dense appearance of valleys, fan-shaped deposits and associated mineral assemblages record the repeated occurrence of liquid, flowing and standing water and provide significant insights into the aqueous geologic record of Libya Montes. The complex hydrologic activity proposed for this crater lake site indicates a great potential for discovery of past environmental conditions that may have been favorable for life [4].
The complex geologic and geochemical nature of this site encouraged multiple proposals for candidate landing sites for future rover missions to Mars [4,6,7]. Although this site has not yet been selected as a final landing site due to difficulties meeting the engineering requirements of near-future missions to Mars, it has been monitored with high priority by recent Mars orbiter missions. New HiRISE images provide, together with the HRSC DEM for the geologic context (Fig. 1), a terrific view into the paleolake site and, in particular, of the fan-shaped deposits. Here we present the morphologic maps of the deposits at HiRISE scale (Fig. 2-4) and added hyperspectral data from CRISM to investigate the mineralogy in greater detail.

Proposed formation history:
The stratigraphically oldest units in the 60-km crater are heavily degraded valleys that are partly dendritic and are present only on some sections of the eastern and southeastern walls. They are comparable to the dendritic valley networks observed elsewhere in Libya Montes and represent earliest phases of fluvial activity characterized by precipitation-induced surface runoff [e.g., 1-4]. At that time (~3.8 Ga, [4]), water was possibly also initially ponding in the 60-km crater. As the terrain declines toward the north, water may have spilled over the northern rim of the crater and resulted in an initial breach in the wall. The crater rim should have been initially intact to an elevation above -2500 meters. This is supported by the elevation of fluvial and lacustrine landforms in the 60-km crater, which suggest later and repeated ponding events.
We proposed that a second lake-size standing body of water is associated with cliffs near -2500 and -2800 meters elevation along which the majority of valleys terminate. A terrace between the cliffs may also be

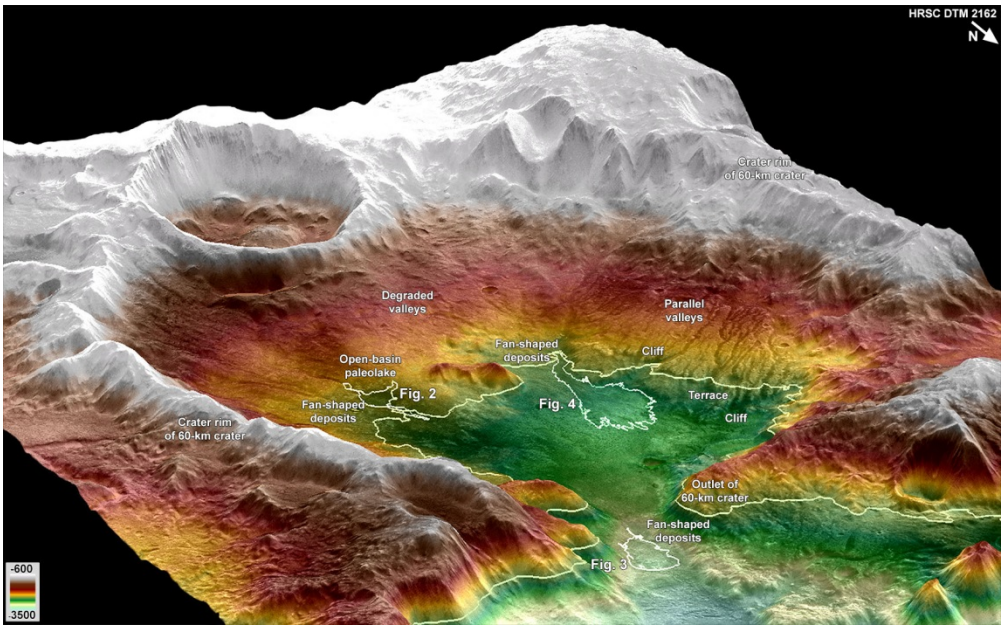

Fig. 1: Perspective view of the 60-km diameter crater at the boundary between the Libya Montes and Isidis Planitia. The crater-lake site hosts a complex diversity of fluvial, lacustrine and possible fluvio-glacial landforms, in particular degraded valleys, parallel (tunnel) valleys, two cliffs and a terrace, an outlet cut into the northern rim of the 60-km crater, a delta with associated Al-rich phyllosilicates, a small-scale open-basin paleolake with another delta, widespread bright, polygonally-fractured Fe/Mg phyllosilicates, and an alluvial fan. Color-coded HRSC h_2162 DTM on CTX mosaic.

related to a lake-size standing body of water and suggests, together with the cliffs, variations of the lake-level and distinct still-stands. Further evidence for fluvio-lacustrine processes that occurred later and were different from those that formed the degraded valleys and the initial breach are the parallel valleys and a few individual valleys that appear stratigraphically higher than the degraded valleys. One of the individual valleys drains as the inlet channel into a small open-basin paleolake (Fig. 2). Our HiRISE based morphologic map shows the fan-shaped deposits, including typical morphologies such as a topset lobe with numerous exhumed distributary channels, a heavily degraded foreset and the degraded and buried remnants of the bottomset. The latest fluvio-lacustrine activity at this site appeared likely along a distributary channel along the western edge of the fan-shaped deposits. The distributary channel follows the channel through the outlet breach. The topographic setting in an open-basin crater-lake site, the lobe morphologies and strong evidence for hydrous alteration supports the interpretation of this feature as a delta.

Overspill events of the second lacustrine phase had eroded the breach in the northern rim of the 60-km crater to its present state at -3100 meters elevation. In a depression immediately north of the outlet, another fan-shaped deposit indicates a third phase of lake formation (Fig. 3). The deposits consist of three individual topset lobes with decreasing extent from oldest to youngest, suggesting that the amount of water was also decreasing during formation. The stratigraphically oldest lobe (Topset-lobe 01, Figure 3) is heavily degraded and does not show many distributary channels. Abundant bright polygonally-fractured materials along the front of lobe 01 are rare in Libya Montes and have been interpreted as Al-rich phyllosilicates, particularly montmorillonite [4] and/or beidellite [5,8]. The topographic setting in a closed basin, the lobe morphologies and strong evidence for hydrous alteration supports the interpretation of this feature as a delta.

The fan-shaped deposit located in the center of the 60-km crater (Figure 4) very likely shows a late-stage depositional event in the 60-km crater and also indicates that a possible lake did not exist during the crater formation. The orientation of the lobes perpendicular to the parallel valleys suggests that the materials have been deposited significantly later. Also the rim of the 60-km crater was already breached at -3100 meters elevation and did not allow ponding up to -2500 meters, the level of the alluvial fan. However, four distinct lobes of the fan-shaped deposit and Fe/Mg phyllosilicates present in the stratigraphically oldest lobes are possibly the result of repeated events of erosion, transport and deposition, and suggest a complex formation history. The general morphologic setting of the fan on a steep slope and not in a basin is more comparable to an alluvial fan. Finally, fluvial activity responsible for the formation of the alluvial fan was still active (~<3.6 Ga, [4]) but waning and insufficient to form a lake.

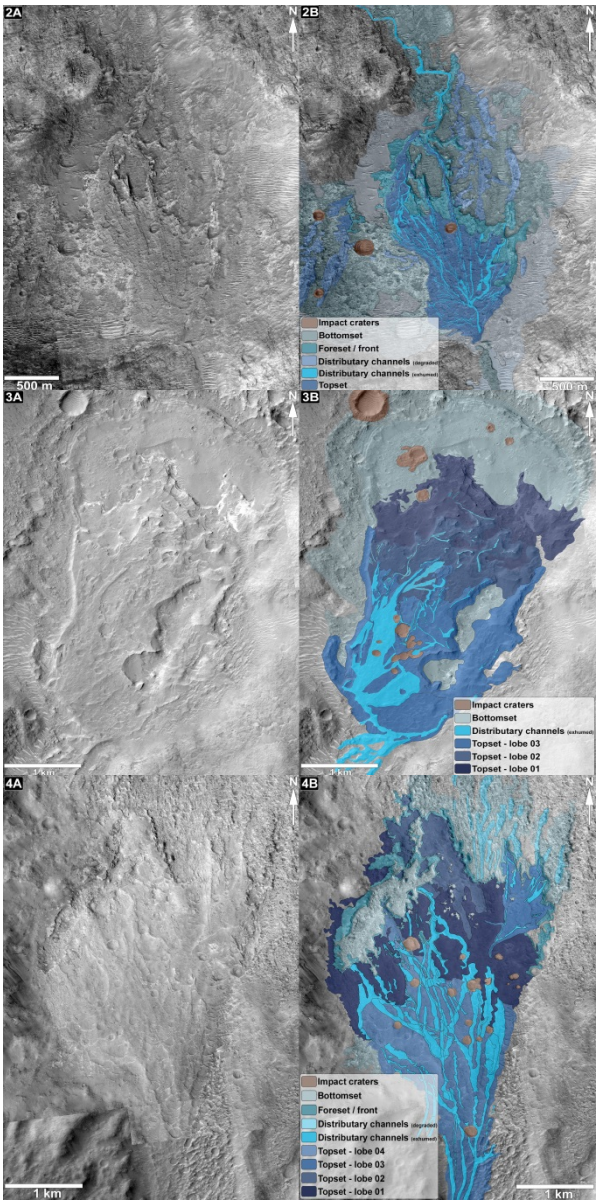

Fig. 2-4: HiRISE-based morphologic maps of (2AB) a small-scale open-basin paleolake with fan-shaped deposits, (3AB) deltaic deposits at the outlet of the 60-km crater, and (4AB) an alluvial fan.

Conclusion:

We interpret the morphologic–geologic setting and associated mineral assemblages of the 60-km crater-lake site as resulting from repeated fluvial activity, multiple lake-size standing bodies of water and an environmental change over time toward decreasing water availability.

References: [1] Crumpler and Tanaka, 2003, *JGR, 108*, ROV 21-1. [2] Erkeling, et al., 2010, *EPSL, 294*, 291-305. [3] Jaumann et al., 2010, *EPSL, 294*, 272-290 [4] Erkeling, et al., 2012, *Icarus, 219*. [5] Bishop et al., 2013, *JGR, 118,* 487–513 [6] Erkeling et al., 2011 *MEPAG*, RFP round VI; NKB-269-122010 CDP [7] Erkeling et al., 2014, *1st ExoMars 2018/2020 LSSW*, Madrid [8] Tirsch et al., 2015, *46th LPSC*, this issue.