Landscape formation at the Deuteronilus contact in southern Isidis Planitia, Mars: Implications for an Isidis Sea? G. Erkeling[1], D. Reiss[1], H. Hiesinger[1], M. A. Ivanov[2], E. Hauber[3], H. Bernhardt[1] [1]Institut für Planetologie (IfP), WWU Münster, Wilhelm-Klemm-Straße 10, 48149 Münster, Germany; [2]Vernadsky Inst. RAS, Moscow, Russia; [3]German Aerospace Center (DLR), Berlin, Germany; (gino.erkeling@uni-muenster.de / +49-251-8336376)

Introduction: Two of the most widely studied landforms that are associated with a putative ocean that filled the northern hemisphere of Mars are (1) the Vastitas Borealis Formation (VBF) plain units that cover a large portion of the northern lowlands of Mars, and (2) a candidate paleoshoreline, e.g., the Deuteronilus contact, which represents the outer margin of the VBF. The VBF and the Deuteronilus contact are interpreted to result from a short-lived Late Hesperian ocean that readily froze and sublimated. Similar landforms are also present in the impact basin of Isidis Planitia and suggest formation processes comparable to those that formed the VBF and the Deuteronilus contact in the northern lowlands.

Our study of the Deuteronilus contact in Isidis revealed geologic evidence that possibly supports the existence of a Late Hesperian / Early Amazonian Isidis Sea. For example, there are numerous valleys that are incised into the plains of the southern Isidis basin floor between 82˚/90˚E and 3˚/6˚N and trend a few tens of kilometers to the north, following the general topographic gradient toward the center of Isidis Planitia. The valleys originate exclusively north of the Libya Montes highlands [e.g., 1-3] and are indicative of Late Hesperian fluvial activity [1,4,6], which was spatially and temporarily distinct from intense and repeated Noachian fluvial activity in the Libya Montes [1-4,6]. A few of the valleys reach the Deuteronilus contact [e.g., 7,8] and continue as sinuous ridges in the Isidis Interior Plains (IIP) (Fig. 1). The Deuteronilus contact is characterized by an onlap of the IIP onto the Isidis Exterior Plains (IEP), i.e., the IIP are superposed on the IEP and are therefore younger than the IEP.

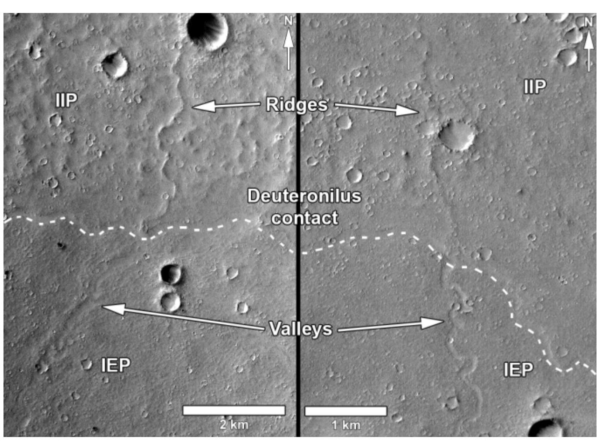

Fig. 1: Deuteronilus contact at the southern Isidis basin floor. Valleys trend to the north toward the Deuteronilus contact. Across the contact, the valleys (negative relief) transition into sinuous ridges (positive relief). Sun illumination from left/west.

Therefore, the ridges are stratigraphically younger than the valleys (Fig. 2). Because the valleys transition into ridges on the stratigraphically and topographically higher terrain, their formation is difficult to explain by formation scenarios based on relief inversion proposed for sinuous ridges elsewhere on Mars [e.g., 9-11] and Earth [e.g., 12,13].

Based on our investigations we propose an alternative fluvio-glacial formation scenario for the morphologic-geologic setting at the Deuteronilus contact. We suggest that the ridges could be glacial meltwater or subglacial streams (eskers) similar to possible eskers identified elsewhere on Mars and Earth [e.g., 14-17] and that their formation is associated with a stationary ice sheet of a proposed Late Hesperian Isidis sea that readily froze and sublimated and resulted in the formation of the IIP [4,6]. The proposed formation scenario has also implications for the formation of the Isidis thumbprint terrain (TPT) [e.g., 5,6] that is located in the IIP.

Relief inversion: In our study area we found little evidence for relief inversion, and there are key differences to inverted relief settings identified elsewhere on Mars and Earth: (1) Reasonable doubts that relief inversion caused the valley / ridge setting along the Deuteronilus contact are based on the occurrence of the ridges in the topographically higher and stratigraphically younger terrain of the IIP (Fig. 2). (2) The valleys and ridges appear in two geologic units that were likely formed by different processes and at different times, which is unusual for geologic settings characterized by topographic inversion. Valleys and ridges are usually present in one geologic unit that is exhumed in the vicinity of the ridges and preserved at the former valley floors. (3) The morphologic setting indicates that the location of the ridges is strongly associated with and controlled by the loca-

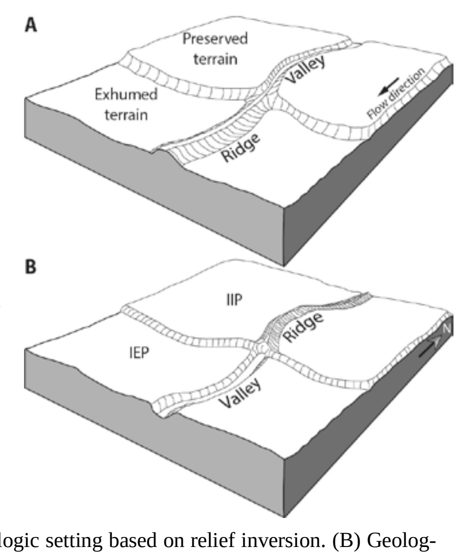

Fig. 2: (A) Geologic setting based on relief inversion. (B) Geologic setting observed along the Deuteronilus contact.

tion of the Deuteronilus contact, which is inconsistent with an earlier or later formation of the ridges than the IIP and relief inversion, respectively.

Alternative formation scenarios: It should be noted that the relief inversion scenario has fewer uncertainties in comparison to the following alternative morphologic and geologic processes, which have been proposed for ridges and positive-relief features elsewhere on Mars and Earth: (1) We could not identify any features in the close vicinity of the ridges along the Deuteronilus contact that share similarities with mud volcanoes. (2) The ridges are too sinuous to represent (exhumed) dikes. (3) None of the ridges resemble wrinkle ridges or horst and graben structures, which can be explained by contractional or extensional tectonics, respectively. (4) Eolian morphologies such as yardangs or linear dunes are inconsistent with the geologic setting and are not supported by our observations. (5) The isolated appearance of the narrow sinuous ridges is also inconsistent with patterns or series of giant ripples that form during catastrophic flooding events on Earth. (6) Glacial processes can result in ridges or ridge-like landforms, but the morphologies, dimensions and location of the ridges in southern Isidis Planitia are poorly consistent with morphologies such as kames, moraines, drumlins, fluted, ice-cored ridges or striped surfaces.

Fluvio-glacial formation scenario: We introduce an alternative formation scenario, which is based on fluvio-glacial processes and a synchronous origin of the ridges and the IIP. This scenario is based on melting and sublimation of a stationary ice sheet that possibly filled the Isidis basin and initially forms after emplacement of the IEP and with the fluvial erosion of the IEP. Valley formation and incision into IEP was short-lived due to colder and dryer environmental and climate conditions and ceased at ~3.2 Ga at the latest. At this time, outflow channels formed at a number of locations on Mars and water was ponding mainly in the northern lowlands [e.g., 8,23-29]. Water may have also been ponding in the Isidis basin, because the IIP show striking similarities such as the morphologic onlap of the Deuteronilus contact and a similar formation age to the VBF, which covers significant parts of the northern lowlands. Due to the Late Hesperian / Early Amazonian cold and dry climate, the Isidis Sea possibly froze to form a stationary ice sheet in a geologically relatively short period of time [23]. The maximum extent of the proposed Isidis Sea and the possible Isidis ice sheet that formed subsequently may correspond to the location of the Deuteronilus contact. As the Isidis basin represents a region of high eolian deposition [30,31], the proposed glacier may have been covered by a sedimentary veneer of wind-blown materials [23]. Based on this setting, the ridges may have formed in a glacial environment and possibly represent eskers. Subglacial melting resulted in transport of the water and sediments toward the glacier margin. This scenario is based on the assumption that the pressure of the glacier is high in the center of the basin and decreased toward the glacier margin. The drainage of water might have resulted in the formation of a proglacial lake, although we could not identify any lacustrine deposits along the boundary between the IIP and the IEP. We propose that the transport of subglacial water and sedimentary load preferentially appeared along the courses of the pre-existing valleys because they represented the lowest erosional level on the flat Isidis plains. After the filling of the pre-existing valleys, the courses of the subglacial streams remained more or less unchanged because of the stationary ice sheet [e.g., 17,23]. Continued deposition of sediments during melting, sublimation and retreat of the glacier led to the formation of the eskers that reflect the course of the pre-existing valleys. Finally, the ice sheet completely sublimated and eolian materials that had been previously accumulated on the glacier surface and within the glacier were deposited as supra- and intraglacial meltout or sublimation till and now represent the rough IIP.

Conclusions: Based on our findings we propose that the geologic setting along the Deuteronilus contact has a fluvio-glacial origin, including esker formation beneath a stationary ice sheet. The valleys and ridges are possibly results of (1) Late Hesperian / Early Amazonian short-term fluvial activity and (2) a Late Hesperian / Early Amazonian short-lived Isidis Sea that readily froze and subsequently melted and sublimated. Although our fluvio-glacial model cannot fully explain the geologic setting, possible alternative formation models, including relief inversion and fluvio-volcanic scenarios are even less capable in explaining the observed ridges along the Deuteronilus contact. It should be noted here that none of the formation scenarios, including our introduced fluvio-glacial formation scenario, can fully explain all the geologic observations along the Deuteronilus contact. However, we favor our fluvio-glacial model because the valleys and ridges in southern Isidis Planitia are less well explained by relief inversion, the most frequently used formation scenario for comparable landforms on Mars and Earth.

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