Relief Inversion at the Deuteronilus Contact of the Isidis Basin, Mars: Implications for the Formation of the Isidis Interior Plains G. Erkeling[1], D. Reiss[1], H. Hiesinger[1], M.A. Ivanov[2], H. Bernhardt[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

Introduction: The southern Isidis basin rim is characterised by the fluvially dissected mountainous terrain of the Libya Montes (Fig. 1A, red unit) [e.g., 1-4] and the southern parts of the knobby Isidis interior plains (hereafter IIP) that contain the Isidis thumbprint terrain (TPT) (Fig. 1A, blue unit) [e.g., 5,6]. Both geologic units are divided by a plain unit that occurs along the basin margin (Fig. 1A, green unit). These plains were a candidate landing site for the Mars Exploration Rover (MER) mission [7] and are referred to as Late Hesperian plains HBu2 [8], terminal plains [1], transitional plains [9,10] and Isidis exterior plains [4,6].

The Isidis exterior plains (hereafter IEP) represent a transition from the highlands to the lowlands and show clear and well defined boundaries to the Libya Montes highland terrain (Fig. 1B) and the IIP (Fig. 1B). Some sections of the highland/lowland boundary appear as cliffs, which have been interpreted as part of the Arabia contact [e.g., 4,11,12]. The boundary between the IEP and the IIP has been discussed as a part of the Deuteronilus contact [e.g., 11,12]. The contact is characterized by an onlap of the IIP onto the IEP, i.e., the IIP are superposed on the IEP.

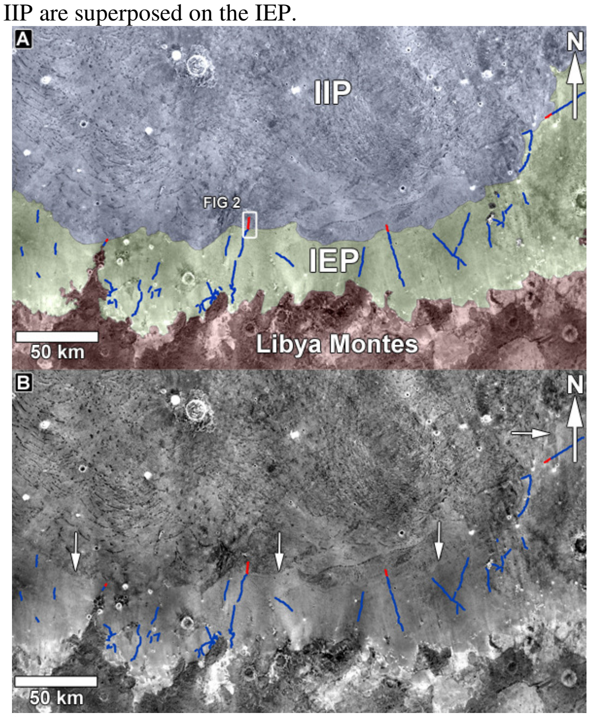

Fig.1: Southern Isidis basin rim. A. Libya Montes highland terrain (red unit), IEP (green unit) and IIP (blue unit). Valleys (blue lines) trend toward the center of the Isidis basin and appear as ridges (red lines) within the IIP. B. Thermal Emission Infrared Spectrometer (THEMIS) IR-Night mosaic. The Deuteronilus contact is shown by white arrows.

Small valleys that are incised into the IEP originate exclusively north of the Libya Montes and trend tens of kilometers to the north following the topographic gradient toward the center of the basin. The valleys either terminate on the smooth IEP or continue across the Deuteronilus contact (Fig. 1A,B) and occur then as ridges in the IIP (Fig. 2).

We present the results of our morphologic investigations of small valleys that are incised into the smooth IEP at the southern Isidis basin rim between 84˚/90˚E and 3˚/5˚N. The valleys 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]. The ridges north of the Deuteronilus contact represent a continuation of the small valleys, show similar morphologies to terrestrial eskers and are most likely associated with the formation of the smooth IIP.

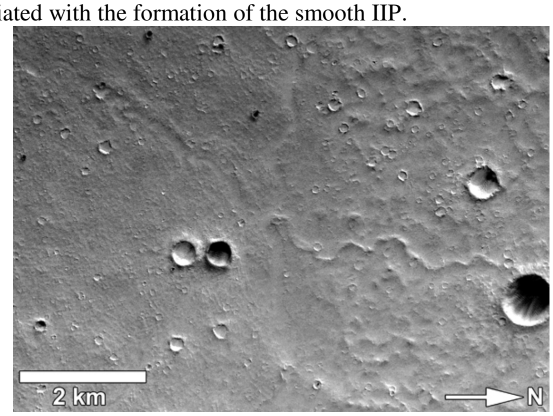

Fig. 2: Relief inversion at the Deuteronilus contact at the southern Isidis basin rim. A valley trends to the north toward the Deuteronilus contact. Across the contact, the morphology changes and a sinous ridge represents the continuation of the valley.

Morphology and stratigraphy: Most of the valleys incised into the smooth IEP occur along the southern Isidis rim. Only a few valleys have been identified on smooth plains elsewhere in the Isidis region [6]. These valleys originate near the boundary between the IEP and the Libya Montes. Although the source of most valleys is difficult to trace, the valleys do not cross distinct topographic breaks in slope at the boundary between the Libya Montes and the IEP, such as the cliffs of the Arabia contact, indicating that they are not connected with the Libya Montes valley networks. In addition, model ages show that the valleys were formed between ~3.3. and ~2.7 Ga [4,6] and therefore significantly later than the dendritic valley networks identified in the Libya Montes, which ceased to form at the Late Noachian/Early Hesperian boundary [2]. The upstream section of the valleys is characterised by a network of valley segments tens of meters wide and kilometers long. Possible main valleys and associated tributaries are difficult to distinguish. The midstream section mostly shows individual and elongated valleys that trend tens of kilometers toward the center of the basin, associated tributaries are absent. Some valleys become faint, shallow and segmented throughout the IEP. A few kilometers south of the Deuteronilus contact, which represents the lower end of the IEP, the general slope toward the center of the Isidis basin flattens. Here some of the valleys show sinous sections. The downstream sections of the valleys are either characterized by valleys getting progressively shallower and terminating on smooth IEP or by the continuation of the valleys as ridges across the Deuteronilus contact through the IIP (Fig. 2). Ridges continue only for a few kilometers toward the basin center, show variations in width and hight (<15m) and have rounded crests but also show the similar sinuousity of the valleys.

Formation scenarios: Our morphologic observations indicate that the formation of the ridges is associated with the formation of the IIP. Therefore, we consider three formation scenarios for the ridges, including (1) a volcanic scenario based on the filling of Isidis with (Syrtis) lavas [13-14], (2) the formation of the IIP by mud volcanism from the center of the basin [15], (3) a fluvio-glacial scenario, which is based on melting and sublimation of a stationary ice sheet that possibly filled the Isidis basin and which is comparable to the formation of terrestrial (subaqueous) eskers [16-18].

Syrtis lavas and mud volcanism: The IIP are discussed by multiple authors as the result of volcanic formation processes, including the proposed filling of the Isidis basin by Syrtis lavas [e.g., 13-15]. In such case, the observed relief inversion is a result of initial cementation by a diverse range of processes, including degassing, cooling and sublimation and subsequent erosion and exhumation by water or wind to its present state [e.g., 19]. As wind is the dominant process on Mars to remove less resistant surrounding materials [20,21] it may have played a role in the exhumation of the ridges. However, wind erosion might be inconsistent with the inversion of relief along a sharp boundary such as the Deuteronilus contact. Uncertainties also exist for the formation by lava flows that possibly drained into the pre-existing valleys and were eroded afterwards by fluvial erosion, which is a common scenario for relief inversion on Earth [19,22,23]. Fluvial landforms, in particular typical twin lateral streams [19] that could have resulted in erosion of surrounding materials are absent within the IIP [1,4,6]. Although we do not exclude a volcanic formation, considerable uncertainties remain, including, i.e., the distribution of the IIP in the center of the basin, which does not support inflow of lava from Syrtis. There is also less evidence that the Libya Montes acted as a source region for the IIP, because volcanic sources are absent in the highlands [1-3]. However, also mud volcanism [15], which could explain the occurrence of the IIP in the center of the basin [15] unlikely could result in the continuation of valleys as ridges.

Stationary ice sheet: Based on our morphologic observations, we propose the following fluvio-glacial scenario for the formation of relief inversion at the Deuteronilus contact: After the emplacement of the IEP in the Hesperian between ~3.3 and ~2.7 Ga [4,6] but before the emplacement of the IIP (~<2.7Ga) [4,6], the small valleys have been incised (Fig. 3A) by late stage fluvial activity [4]. As the valleys originate exclusively on the smooth IEP they do not represent a continuation of fluvial transport from the highlands to the floor of the Isidis basin. In addition, absolute model ages indicate a formation significantly later than the Late Noachian / Early Hesperian Libya Montes fluvial activity. Some of the valleys become faint on the IEP and terminate south of the Deuteronilus contact. Consequently, they were not superposed by the younger IIP and are not connected with possible ridges. However, valleys, which extended farther toward the basin center were superposed by the IIP and occur now as ridges. In the Early Amazonian, a stationary ice sheet (Fig. 3B) possibly filled the Isidis basin similar to the one proposed that might have filled the northern lowlands and resulted in the formation of the Vastitas Borealis Formation (VBF) [24]. The maximum extent of the possible Isidis glacier may correspond to the location of the Deuteronilus contact at which the valleys continue as ridges (Fig. 3B,C). In a geological short period, the glacier could be covered by a sedimentary veneer due to sublimation and deposition of wind blown materials [24]. Subglacial melting resulted in preferential transport along the pre-existing valleys, which may have served as paths for the transport of materials. Because the pressure increased toward the basin center, water and materials were transported toward the glacier margin. The drainage of water should have resulted in the formation of a proglacial lake [16], although we could not identify any lacustrine deposits along the boundary between the IIP and the IEP. However, during melting and retreat of the glacier toward the basin center (Fig. 3C), materials were deposited along the pre-existing valley course and may have resulted in the formation of a ridge that reflects the course of the pre-existing valley (Fig. 3D). Complete sublimation of the possible glacier finally resulted in the deposition of the rough IIP [24].

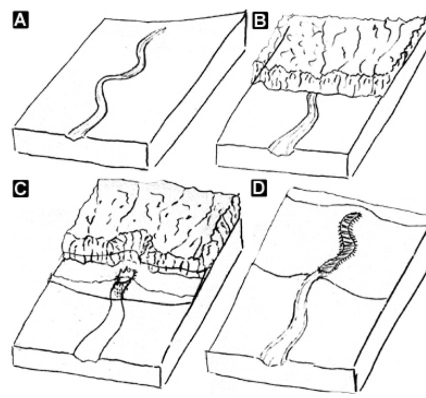

Fig. 3: Relief inversion at the Deuteronilus contact is explained by fluvio-glacial scenario. A. Valley incision. B. Formation of stationary ice sheet. C. Retreat of glacier and deposition on materials due to subglacial melting and subaqueous deposition D. Formation of Deuteronilus contact and ridges.

Conclusions: Our observations suggest that (1) small valleys were formed earlier than both the IIP and the ridges, (2) the ridges represent the continuation of the small valleys but are formed later as a result of the formation of the IIP (3) the ridges show similar morphologies to terrestrial eskers, i.e., rounded crests and variations in width and hight [17-19]. Although the scenario we propose could perhaps better explain how the relief inversion was formed than an alternative volcanic formation scenario can do, in particular when compared with terrestrial analogs [16-19,22,23], significant parts remain uncertain and speculative, including, i.e., the lack of sources of the frozen sea [4,25], the thickness of the possible glacier (esker heights relate to about 1/20 of the ice cover) [13] and the direction of the drainage of water and materials.

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