THE UNEXPECTED ORIGIN OF THE BRANCHED RIDGES AT ANTONIADI CRATER, MARS. N. Mangold[1], L. Tornabene[2] S. J. Conway[1], A. Guimpier[1], A. Noblet[1], P. Fawdon[3], E. Hauber[4], A. Pommerol[5], N. Thomas[5], and the CaSSIS team [1]LPG, CNRS, Univ Nantes, UMR6112, France, nicolas.mangold@univ-nantes.fr, [2]Inst. Earth & Space Exploration, Western Univ, Ontario, Canada, [3]Open University, Milton Keynes, UK, [4]DLR, Berlin, Germany [5]Univ Bern, Physikalisches Institut, Switzerland.

Introduction: Antoniadi basin is a 330 km diameter Noachian basin localized in the eastern Arabia Terra that contains a network of ridges with a tree-like organization (Fig. 1). Branched ridges, such as these can form by a variety of processes including the inversion of fluvial deposits, thus potentially highlighting aqueous processes of interest for understanding Mars' climate evolution. Here, we test this hypothesis by analyzing in details data from Colour and Stereo Surface Imaging System (CaSSIS), High Resolution Imaging Science Experiment (HiRISE) and High Resolution Stereo Camera (HRSC).

Context and age: Antoniadi's interior plains are filled by deposits interpreted to be Hesperian or younger and volcanic in origin, possibly coeval with the volcanic episodes of the nearby Syrtis Major Planum [1]. The branched ridges lie on these plains and to the south of a 28 km-diameter well-preserved crater devoid of any signs of fluvial erosion (Fig. 2). This crater also predates the branched ridges because the plains material buries its southern ejecta. While some erosion has affected the ridges, there is no indication of exhumation of these ridges from layers below the current plains surface. The crater size frequency distribution of the plains gives a model age of 2.5±0.5 Gy, using diameters of 200 m to 2 km. Thus, the branched ridges are Early Amazonian or younger, adding to their interest if they formed by fluvial activity.

Morphology: The branched ridges show a suite of peculiar morphological characteristics. Their texture at HiRISE scale (25cm/pixel) is rubbly with the occurrence of blocks up to ~1 m in size and a complete lack of layering (Fig. 3) in all 5 HiRISE images where they are present. The branched ridges appear darker than the plains on which they lie. The ridges are organized as a dendritic network reaching a Strahler order of 4, i.e. the degree of hierarchy from the shortest branches (of order 1) counting the number of junctions. Assuming tributary flows, this organization indicates a northward flow direction. Ridges are up to 10 km long and 10-200 m wide without any obvious trends in width, i.e. ridges are not wider with increasing Strahler order. The order 1 branches are also peculiar in plan-view shape. They frequently display lobate shapes and are up to 100 m wide, which is wider than the ridge measured after the junction with several order 1 branches (r1 in Fig. 3).

North of the main pattern, a 500 m wide sinuous ridge present in the middle of the plain displays the same internal texture (rubbly) suggesting that it formed by the same process (white arrow at the top of Fig. 1).

Topography: A HiRISE elevation model shows that branched ridges are between 1-5 m high, although erosion can explain some variations in height among the ridges. The local slope is of 0.2° toward South, and thus contrary to the apparent network organization (assuming tributary flows). Straight ridges trending SW-NE could be tectonic features (Fig. 1). The branched ridges are also present on some of the lowest areas of these plains, but there is no evidence of terminal fans nor of erosional features affecting the plains in their more elevated areas.

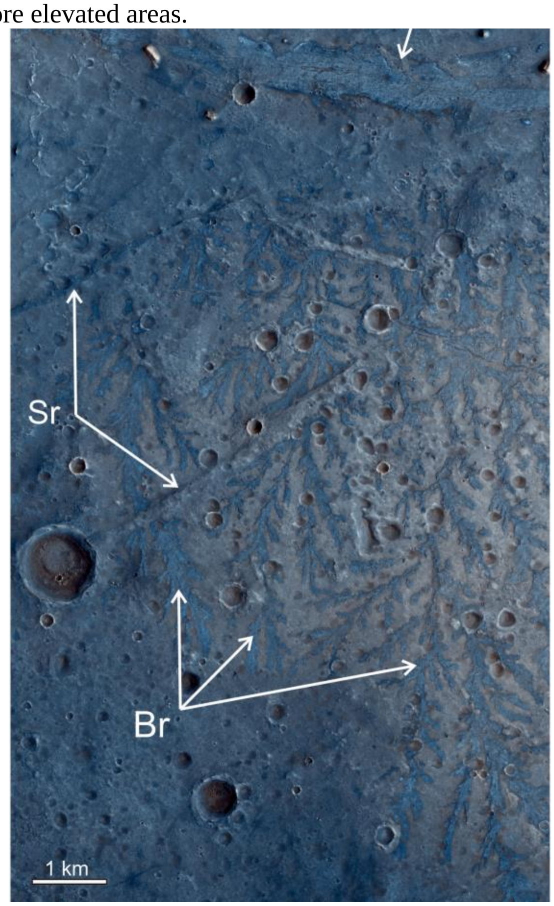

Fig. 1: Close-up of the CaSSIS color image (MY35_010430_024) of the branched ridges (Br) in Antoniadi basin. Straight ridges (Sr) are interpreted as localized tectonic/volcanic uplift.

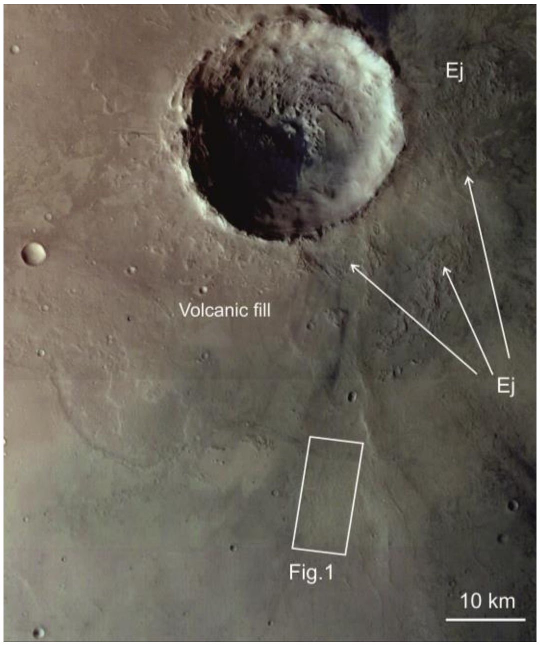

Fig. 2: Part of HRSC image (orbit 7357) showing the footprint of the CaSSIS image. The fresh crater displays ejecta to the east that are buried to the south below volcanic plains; on which the branched ridges lie.

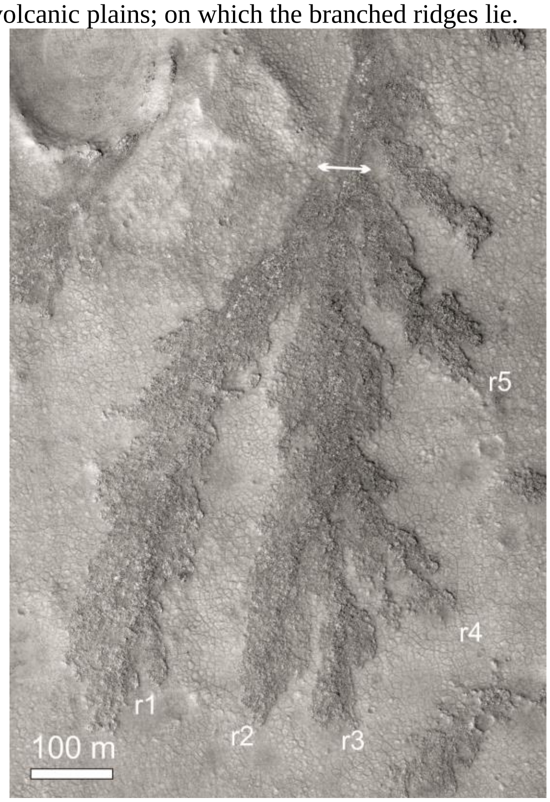

Fig. 3: HiRISE close-up of the heads of ridges displaying lobate shapes. The rubbly internal texture is common to all ridges. The double arrow indicates a location where the ridge is three times narrower than the deposits closer to the toe (HiRISE ESP_12725_2015).

Discussion and conclusion: Previous assessments of these digitate landforms favored an origin as inverted channels [2]. Yet, our observations are not consistent with this interpretation: (i) The rubbly texture lacks any layering at meter scale, a feature expressed by inverted channels as observed elsewhere on Mars [e.g., 3, 4]. (ii) The order 1 branches display a lobate shape and a larger width than higher order branches. (iii) There is no increase in width from degree 1 branches of the network towards the north as would be expected for channels with increasing discharge rates downstream. (iv) The slope towards the south is contrary to the inferred flow direction to the north assuming a tributary network. Wrinkle ridges may be evidence for post-depositional changes in topography, but these uplifts appear localized (Fig. 1). Thus, the detailed analysis of these branched ridges shows characteristics difficult to reconcile with inverted fluvial channels. Subglacial drainages are known to locally flow against topography, but rarely displays a dendritic pattern [5]. Assuming that deposition occurred along the current slope from north to south, the organization of the network requires a control by distributary channels rather than tributary ones. Distributary fluvial channels are possible for fluvial flows, but generally limited to braiding regimes or deltaic deposits, of which no further evidence is observed here. The lobate digitate shapes of the degree 1 branches are actually more in line with deposits of viscous flows, thus as terminal branches (Fig. 3). Such an interpretation is consistent with lava flows or mudflows that formed along the current topography. This conclusion would explain the presence of these landforms in an Early Amazonian plain lacking any evidence of fluvial activity. The next step in this study will be to determine the rheology of these unusual flows.

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References: [1] Tanaka K. L. et al. (2014) USGS map 3292. [2] Zaki et al. (2019) EPSC-DPS2019-244-1. [3] Burr et al. (2010) *JGR-Planets*, 115, E07011. [4] Mangold et al. (2008) *JGR-Planets*, 113, E08009. [5] Menzies, J (2002), Modern and Past Glacial Environments, Oxford.