Orbital stratigraphic analysis of the Eberswalde sedimentary fan: comparison with the Jezero delta, Mars

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Introduction:

Mars 2020's rover *Perseverance* landed in Jezero crater, Mars, in February 2021, where two deltaic sedimentary bodies were observed from orbital data [1]. The western delta of the crater has been well studied and is now well constrained from both *in situ* and orbital imagery. It formed in a closed-lake as a Gilbert-type delta, showcasing the distinctive topset-foreset-bottomset architecture [2].

Given the improved understanding of the Jezero western fan, it is important to investigate whether such delta architectures are widespread on Mars and whether comparable morphologies can be identified elsewhere. Trying to shed some light on this issue, we focused on another martian sedimentary structure of similar size and volume: the Eberswalde sedimentary fan.

The Eberswalde crater (24.3° S, 326.5°E), located immediately northeast of the Holden crater, along the fluvial network connecting *Argyre Planitia* to *Ares Vallis* displays a remarkable fan-shaped body (~115 km²) featuring meandering channels in its western part. These deposits were likely emplaced during the Hesperian [3], [4] in a closed-basin lake setting [5]. The volume of the fan is similar to that of Jezero's western delta, the thickness of sediment is about 50 to 100 m in both cases [3], which makes it an interesting starting point for a comparison to Jezero system.

Methods:

This study is focused on the geomorphological and stratigraphic analysis of the Eberswalde fan using orbital imagery. The Eberswalde crater was previously considered among the potential landing sites of MSL & Mars 2020 missions, resulting in good HiRISE coverage of the area. Thanks to this data, we have access to images with a resolution of up to 0.25 m/pix on the whole fan area.

The HiRISE orthoimages were taken as stereo pairs, allowing the creation of stereo-derived DTM, thus giving access to topographic information. Contour lines and topographic profiles can therefore be extracted in the QGIS software. Using the DTM and the Three-Points-Method plugin in QGIS, it is possible to measure the apparent dip angles of the outcropping layers. This plugin extracts the elevation data from three points placed along the layer and calculates the dip angle and strike of said layer. Dipping layers were already observed by Goudge *et al.* (2017) [6] on Jezero's western delta before rover data, showing that it is possible to observe them from orbit. On Eberswalde, we measured the dip angles for 37 strata on the front of the fan, and did from 2 to 9 measurements per strata (for a total of 147 measurements), to account for the imprecision of the DTM, and extracting the mean value for each bed. The measurement uncertainty for dip angles using the Three-Points-Method on HiRISE-derived DTM is estimated at ±1-2°, potentially up to ±3° for low-angle beds. These uncertainties are significant

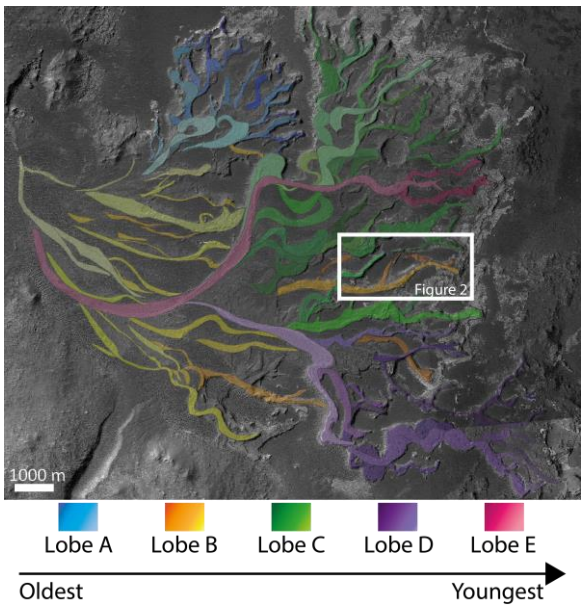

***Figure 1**: Map of the meandering exhumed channels on the Eberswalde sedimentary fan and their stratigraphic relationships, from oldest to youngest lobes (colored scale) [3]. White box represents the studied area of **Figure 2**. (HiRISE – MRO).*

when distinguishing subtle foreset geometries and must be considered when interpreting the absence of inclined strata.

Results:

Extensive meandering exhumed channels are visible on the orbital imagery of the Eberswalde sedimentary fan (**Figure 1**). It is possible to distinguish five lobes, through cross-cutting relationships and topographic data, that were emplaced at different times (**Figure 1**) [3]. The meandering planform of the Eberswalde channels differs from that on the Jezero delta, where channels are rectilinear [7], indicating a difference in the fluvial regime that controlled the development of these drainage systems.

The beds outcropping at the front of the Eberswalde fan, and stratigraphically underlying the meandering channel deposits, follow the contour lines nearly everywhere (**Figure 2a**). These beds are subhorizontal (dip angles around 0° to 5°, locally up to 8°), and contrast with the steeply inclined foreset strata typical of Gilbert-type deltas (**Figure 2**), as previously suggested based on lower-resolution HRSC data [3]. This marks a significant distinction from Jezero western fan, where steep strata were observed, both from orbit [6] and *in situ* [2].

To summarize, from the orbital data, two main phases can be distinguished: (1) a basal phase, characterized by subhorizontal beds that crop out at the front of the fan, and (2) an overlying fluvial unit. We describe these units without bias towards any specific genetic model at this stage.

Preliminary conclusions:

The geomorphologic and stratigraphic data of the present study points towards the Eberswalde sedimentary fan having a different depositional history than the Gilbert-type delta observed in

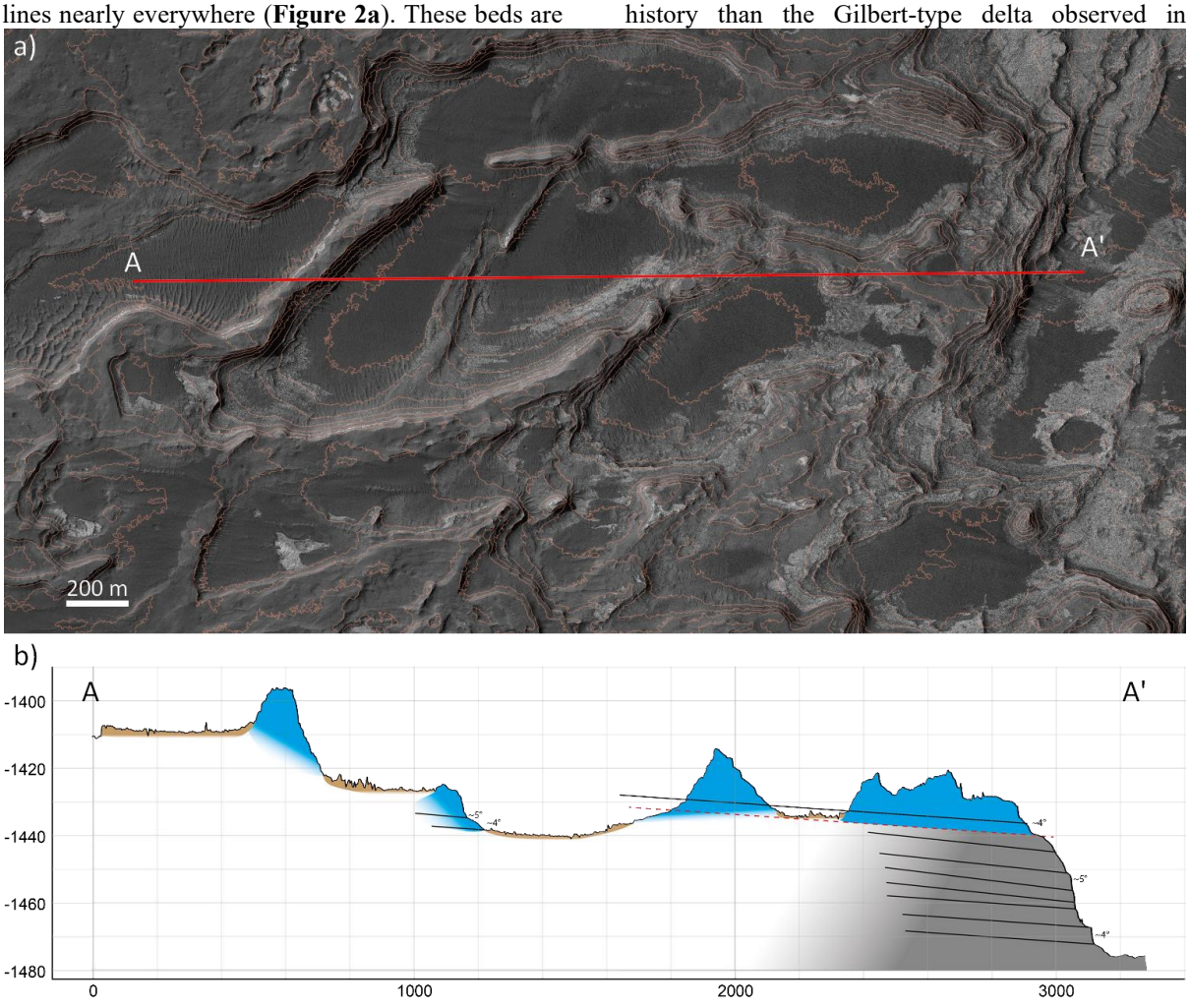

Figure 2: ***(a)*** *Close-up of an area on the Eberswalde sedimentary fan. Contour lines at 5 m are extracted from the stereo-derived HiRISE DTM (HiRISE – MRO). Red line: log line AA' of the cross section in (b).*

(b) *Interpreted cross-section of log AA' with dip angles measured using the DTM reported on the section. Grey zone represents the lacustrine beds, blue the fluvial beds (recognizable also on the orbital imagery), and brown zone is the dust-covered areas. The red dashed line represents the possible discontinuity contact between the fluvial and lacustrine phases.*

Jezero. It is thus necessary to understand how the Eberswalde fan formed. Two hypotheses can be proposed so far:

- The fan emplaced in two separate phases, an initial lacustrine phase followed by a late-stage fluvial phase characterized by meandering rivers, with a gap between these two stages. In this scenario, the channels associated with the lakebeds may not be preserved or could be buried beneath subsequent deposits. Further investigation is necessary to elucidate the transition mechanism between these two distinct phases.
- Evidence suggests that Eberswalde is a shoal-water delta, formed in a shallow lake, possibly as an aggradational delta [8], contrasting with the progradational nature of the Jezero delta. This interpretation is supported by comparison to the Valimi Formation (Greece), a lacustrine shoal-water delta system with overlapping lobes, subhorizontal internal stratification, and limited foreset development. Such systems develop in high-accommodation but shallow-water conditions, promoting vertical aggradation. This interpretation requires further investigation into the mechanisms by which the sediment deposition and accommodation space interacted to maintain shallow lake conditions and promote vertical aggradation without significant topographic steps.

These preliminary interpretations suggest that the depositional processes leading to the formation of the Eberswalde fan were significantly different from those at Jezero, highlighting the need for further detailed investigation. This study evaluates the relative merits of competing scenarios through stratigraphic analysis and comparison with terrestrial analogues, specifically the shoal-water deltas of the Valimi Formation, in Greece [9]. The aim is to assess the plausibility of each scenario and determine the most likely interpretation for the Eberswalde fan formation.

The Jezero delta should not be assumed to represent a universal martian deltaic model, highlighting the importance of studying additional sedimentary fans to better constrain the history of liquid water on Mars. The in-depth study of other martian sedimentary fans is fundamental for a better understanding of the availability of liquid water at the time they formed and the representativeness of Jezero crater in this history.

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