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# UP AND DOWN WENT JEZERO LAKE: SIGNIFICANT RESULTS FROM THE FIRST EVER SEQUENCE STRATIGRAPHIC ANALYSIS ON MARS

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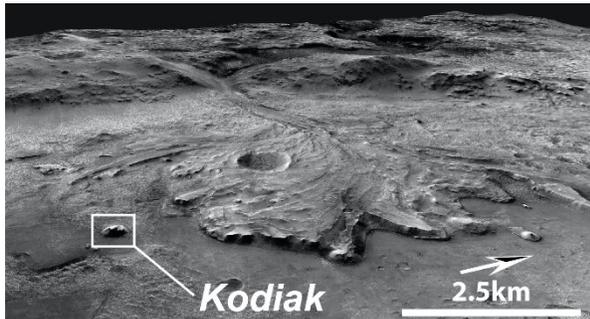
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**UP AND DOWN WENT JEZERO LAKE: SIGNIFICANT RESULTS FROM THE FIRST EVER SEQUENCE STRATIGRAPHIC ANALYSIS ON MARS.** G. Caravaca<sup>1,\*</sup>, G. Dromart<sup>2</sup>, N. Mangold<sup>3</sup>, S. Gupta<sup>4</sup>, L.C. Kah<sup>5</sup>, C. Tate<sup>6</sup>, R.M.E. Williams<sup>7</sup>, S. Le Mouélic<sup>3</sup>, O. Gasnault<sup>1</sup>, J.F. Bell III<sup>8</sup>, O. Beyssac<sup>9</sup>, J.I. Nuñez<sup>10</sup>, N. Randazzo<sup>11</sup>, J.W. Rice<sup>8</sup>, L.S. Crumpler<sup>12</sup>, A. Williams<sup>13</sup>, P. Russel<sup>14</sup>, K.M. Stack<sup>15</sup>, K.A. Farley<sup>16</sup>, A. Cousin<sup>1</sup>, S. Maurice<sup>1</sup>, R.C. Wiens<sup>17</sup>.

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**Introduction:** Since the landing of the *Perseverance* rover in February 2021, remote observations of the main delta front and its remnant, the Kodiak butte (Fig. 1), took place until the rover drove out of sight. These imaging campaigns have been critical in i) confirming the Gilbert-delta nature of the sedimentary fan [1, 2] ii) assessing the depositional settings of the area [2] and even iii) proposing discharge rates for associated fluvial activity [3]. Here, we summarize our findings regarding the first ever sequence stratigraphic analysis on another planet than Earth, based on Kodiak observations [2]. We notably highlight fluctuations of the lake-level in the order of 5-10m occurring at the time of Kodiak build-up.



**Fig. 1** “Bird’s eye” view of the western fan in Jezero crater (CTX basemap), and position of the Kodiak butte, ~1km SSE from the main scarp of western Jezero delta.

**Principles of Sequence Stratigraphy:** Sequence stratigraphic analysis is commonly used in terrestrial Geology (particularly in Economic Geology), but never in the Planetary field until now [2]. It is used to discern a succession of events recorded in the sediments in relation to variations of accommodation (the space available for deposition of sediments) at various scales of time and space [4].

This is done by characterizing the geometries of the deposits and mapping their boundaries, in order to identify (un-)conformities and prisms called system tracts. These system tracts are linked to episodes of increasing (transgressive -TST- and highstand system tracts -HST-) or decreasing accommodation (lowstand

system tract or LST) and are commonly observed on Earth as the evocative “Vail’s slug” [5].

On Earth, accommodation is linked to tectonic subsidence and fluctuation of the base level (or sea level). However, on Mars, tectonic subsidence is negligible [6]. Therefore, providing a sequence stratigraphy framework on Jezero delta will be a direct proxy for the base (i.e., lake) level rises and falls.

**Results at Kodiak:** The Kodiak butte displays well identified vertical successions of bottomsets, foresets and topsets, characteristic of a Gilbert delta [2]. This succession has been observed to repeat laterally around the butte. This permits us to distinguish three distinct Units (0 to 2; with 1 and 2 illustrated in Fig. 2) that correspond to three individual deltaic mouth bars. These mouth bars were emplaced individually and successively across time and space as the delta was built into Jezero crater.

Within these units, we focused on the foreset to topset transition, which is referred as an “offlap break”. This specific area marks the transition from subaqueous (foreset) to subaerial (topset) realms and represent the pale-shoreline of the delta at the time of deposition. We are mapping these offlap breaks in Fig. 2 on the east face of Kodiak to perform a shoreline migration analysis. Additionally, we observe the associated geometry of the slope curvature of the foresets (after [7]). On Kodiak’s east face we identify two stratal geometries (Fig. 2a, a third is visible on Kodiak’s north face, as illustrated in [2]): Exponential and Sigmoid wedges.

Exponential wedges (red in Fig. 2a) have an exponential lower end, but straight upper foresets and an unconformable relation with truncating topsets. They are also associated with shorelines migrating horizontally or downward, never upward. This geometry is associated with pure progradation, which means that the sediments were deposited strictly at the front of the delta during invariant or falling lake levels.

Sigmoid wedges (orange in Fig. 2a) are similar to Exponential wedges, except that their top is more rounded, giving them an overall sigmoidal shape. In this

part, they share a conformable relationship with topsets; with some topsets even actually transition laterally into foresets. They are associated with shorelines migrating generally upward. This geometry is associated with progradation and aggradation, which means the sediments were deposited on the front *and* on top of the delta, during episodes of lake-level rise.

**Implications on Jezero paleolake-level:** Based on these data and that obtained on Kodiak’s north face [2], we are able to propose a sequence stratigraphic framework highlighting four successive hydrogeological cycles. The cycles are composed by transgressive, highstand and lowstand system tracts (in this order, Fig. 2b), illustrating successive rises and falls of the lake-level. Unit 1 (north part of Kodiak, Figs. 2a and 2b) records cycles 1 and 2, while Unit 2 (south part, Figs. 2a and 3b) records cycles 3 and 4.

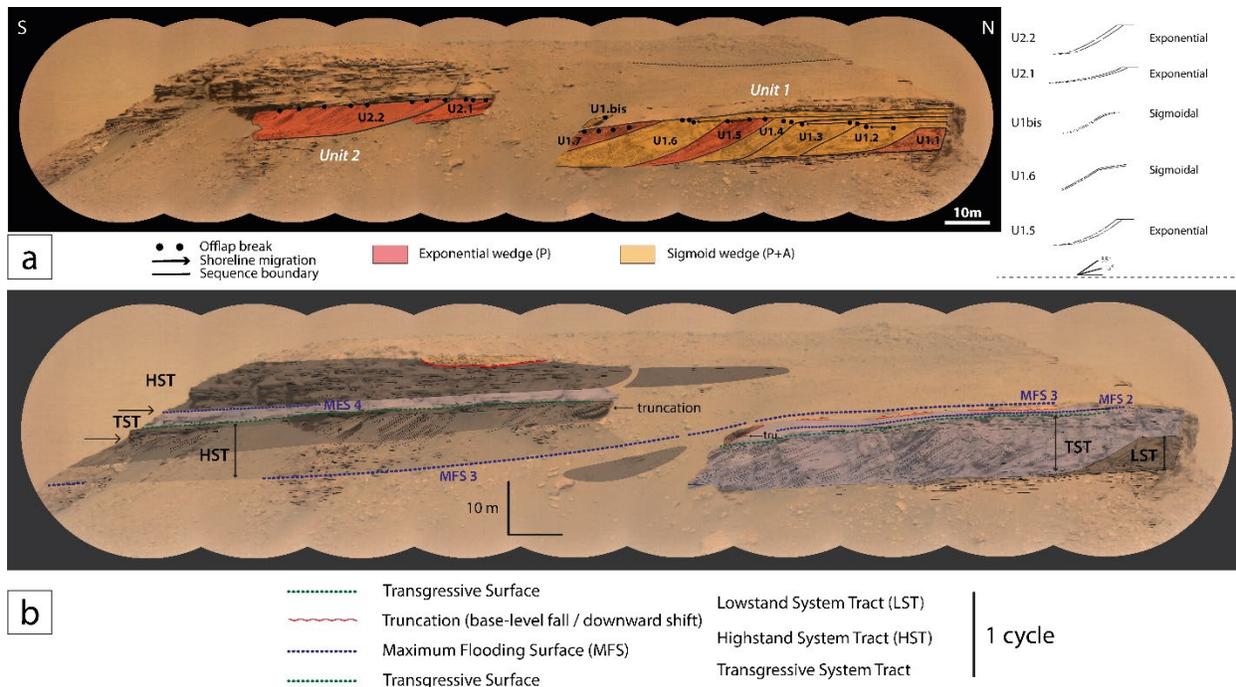
The Maximum Flooding Surface (MFS) is the highest elevation of the lake-level for each cycle. By observation of the shoreline migration, we note that lake-level fluctuates at two scales: in the order of ~2m *within* the Units/bars, and in the order of 5-10m *between* the bars. We therefore illustrate rapid fluctuations of the lake-level in Jezero at the time of Kodiak’s deposition. These fluctuations might be a response to variations in

water supply, probably linked to climate changes at the large scale, and local variations at the smaller scale (e.g., floods).

**Perspectives:** After this first sequence stratigraphy analysis, we suggest that the hierarchy of lake-level changes recorded at Kodiak could be analogous to Earth, with a possibility of an astronomical control driving those changes. This hypothesis might have strong implications to understand the controlling parameters over climate change on ancient Mars. Further work on other sites such as Gale crater will be required to test this hypothesis.

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**References:** [1] Mangold *et al.* (2021) *Science* 374(6568). [2] Caravaca *et al.* (2024) *JGRp* 129(4), e2023JE008205. [3] Mangold *et al.* (2024) *JGRp* 129(3), e2023JE008204. [4] Catuneanu (2022) *Principles of sequence stratigraphy* [5] Vail (1987), *AAPG Studies in Geology* 27(1).[6] Grotzinger *et al.* (2013) *Comparative climatology of terrestrial planets*. [7] Adams (2001) *PhD thesis*.



**Fig. 2 a)** Identification of (sub-)unit-scale wedges and their various exponential or sigmoid profiles (right; obtained on the basis of true-scale bed tracing) on eastern face of Kodiak. Offlap breaks and corresponding inferred shoreline migrations are also represented for each (sub-)unit. **b)** Schematic representation of the sequence stratigraphic prisms characterized at Kodiak, with succession of Lowstand, Highstand and Transgressive System Tracts (and associated sequence boundaries) interpreted to reflect successive meter-scale rises and falls of the lake-level through time during and in-between deposition of the different Units/mouth bars of Kodiak butte.