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Perseverance rover reveals an ancient delta-lake system and flood deposits at Jezero crater, Mars

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Observations from orbital spacecraft have shown that Jezero crater, Mars, contains a prominent fan-shaped body of sedimentary rock deposited at its western margin. The Perseverance rover landed in Jezero crater in February 2021. We analyze images taken by the rover in the three months after landing. The fan has outcrop faces that were invisible from orbit, which record the hydrological evolution of Jezero crater. We interpret the presence of inclined strata in these outcrops as evidence of deltas that advanced into a lake. In contrast, the uppermost fan strata are composed of boulder conglomerates, which imply deposition by episodic high-energy floods. This sedimentary succession indicates a transition, from a sustained hydrologic activity in a persistent lake environment, to highly energetic short-duration fluvial flows.

Mars is currently cold and hyper-arid; liquid water is not stable at its surface. However, orbital and rover observations of features including valley networks, sedimentary fans and ancient lake beds indicate the planet once had a warmer, wetter climate (1–3). Uncertainties remain about the character, timing and persistence of aqueous activity (and therefore potential habitability) on early Mars. The Mars 2020 mission, whose main component is the Perseverance rover, is the first step in a planned multi-mission campaign to return Martian samples to Earth and examine them for potential

biosignatures (4). The 45-km diameter Jezero crater was selected as the landing site based on orbital images, which showed geomorphic expressions of two sedimentary fan structures (western and northern) at the edges of the crater (5, 6). These were inferred to be river delta deposits that formed in an ancient lake basin during the Late Noachian or Early Hesperian epochs on Mars (~3.6–3.8 Ga) (5–9) (Fig. 1 and fig. S1). Spectroscopic observations from orbit have detected phyllosilicates and carbonates, minerals indicative of past aqueous environments (6, 7, 10). Rover investigations on

the surface could provide insight into the evolution of Jezero's ancient lake system and the timescale of liquid water residence on the surface.

The Perseverance rover landed on the floor of Jezero crater on 18 February 2021. The landing site, informally named "Octavia E. Butler," is ~2.2 km from the SE-facing erosional scarp of the western fan deposits, a planned target for the mission (Fig. 1 and figs. S1 to S5). During the first 3 months of the mission, we obtained images of the western fan using the Mastcam-Z camera and the Remote Micro-Imager (RMI) of the SuperCam instrument (11–14) (Figs. 1 to 4; figs. S2 to S4, S6, and S7; tables S1 and S2). We use these long-distance images to investigate the stratigraphy and sedimentary characteristics of the fan deposits, and interpret their implications for the ancient lake in Jezero crater.

Kodiak butte

Images of a prominent butte (an isolated flat-topped hill) located ~1 km south of the main fan deposit (Fig. 1), which we informally named Kodiak, record ancient sedimentary processes at Jezero crater. We interpret Kodiak butte as an erosional remnant of an originally more extensive fan deposit, due to the morphological similarity of Kodiak butte to the main fan exposures, and the near identical elevation of its top (15). A mosaic of the ESE-facing wall of Kodiak (Figs. 1 and 2 and fig. S2) shows two main outcrop areas with three distinct sedimentary layer types: a series of inclined strata sandwiched between layers comprised of horizontal strata, described in detail below. There is no evidence for later dislodgement or rotation of blocks, such as faults or slippage, and therefore we interpret the observed stratigraphy as reflecting the original depositional geometry.

Kodiak butte consists of two outcrop sections that expose five distinct stratigraphic bodies, which we designate k1 to k5 (Fig. 2). The unit k1 is 17 m thick vertically and extends horizontally at least 70 m to the northern butte margin visible from Perseverance (Fig. 2, A to C). The lowest visible part of k1 consists of plane-parallel horizontal to low-angle thinly bedded strata. These show recessive weathering, characteristic of readily eroded fine-grained lithologies (mudstones or sandstones). Overlying these is a ~10-m-thick series of strata comprised of steeply inclined beds with apparently southward dips at angles up to 35°. Individual beds, defined by variations in erosion, have apparent thicknesses from 10 to 50 cm. We infer their primary lithology to be finer-grained than a conglomerate, possibly sandstone, with scattered cobbles. A second unit of dipping strata (k2, 3 m thick) immediately overlies the uppermost strata of k1.

In the southern portion of Kodiak, sedimentary units (k3, 13 m thick) and (k4, 10 m thick) show similar geometries to those in k1 (Fig. 2, D to F). In its lower section, k3 consists of thinly bedded, gently dipping, and horizontal strata. These

show recessive weathering, again indicating mudstones or sandstones. These pass upwards into a distinct 7-m-thick section of inclined beds that dip consistently to the south. Locally, these dipping beds contain isolated boulders and cobbles (up to 40 cm in diameter) (Fig. 2F). At their base, these beds show a downward asymptotic decrease in inclination and pass into lowermost horizontal strata. Overlying the inclined beds across a sharp subhorizontal truncation surface, k4 shows low-angle to locally cross-stratified subhorizontal strata. The overlying unit k5 erosively truncates k4 (Fig. 2E). Unit k5 consists of unsorted conglomerates, which contain boulders up to 1.5 m in long axis, implying a marked change in depositional regime.

Inclined beds in k1 display a downward asymptotic decrease in apparent dip angle and pass gradually into underlying gently dipping and horizontal strata (Fig. 2). At the top, the transition from inclined beds to subhorizontal beds also shows a gradual change in dip (Fig. 2C). This geometric arrangement of strata shows that k1 consists of a single depositional unit with a tripartite architecture: we identify the lower gently dipping beds as bottomsets, the inclined beds as foresets, and the uppermost horizontal layers as topsets (see fig. S8D for a schematic diagram). Similar to k1, we interpret the k3 inclined beds to be foresets that pass downward, with decreasing apparent dip angle into subhorizontal strata we interpret as bottomsets. Overlying k3, subhorizontal strata of k4 then represent topsets. The sharp discontinuity between k3 and k4 is distinct from that observed in k1 where the transition appears to be continuous.

We interpret this distinct tripartite bedding geometry (bottomsets, foresets and topsets) of the units k1 to k4 as representing deposition in steeply fronted Gilbert-type deltas (supplementary text and fig. S8) (16, 17). The thicknesses and lateral extents (>70 m) of the foreset units are too great to be explained by formation as dunes formed by underwater currents or as lateral accretion deposits in fluvial bars. The presence of cobbles and boulders in the foreset strata (Fig. 2F) is inconsistent with their formation as aeolian dunes. In a Gilbert delta, topset strata are fluvial deposits formed in delta top environments. The foreset strata represent deposits formed by gravity-driven flow processes on steeply dipping delta fronts. Bottomset strata represent finer-grained sediments deposited in areas immediately lakeward of the delta front. The transition from topset to foreset (the topset breakpoint) constrains the lake level at the time of deposition. The thickness of the foreset units provides a lower limit of 10 m water depth in this portion of the Jezero lake basin at that time. The bases of topset strata in units k1 and k4 are respectively at ca. –2500 m and –2490 m elevation (below the reference equipotential), corresponding to past lake levels at the time of deposition (Fig. 5).

Elevation differences suggest that units k3 and k4 are

stratigraphically higher, and hence younger, than k1 (Fig. 2). Examination of the exposures on both faces of the butte indicates a similar architecture with two differences: a discontinuity above k3 foresets (not present in k1), and the presence of the terminal boulder-rich unit k5 that truncates k4 topsets (absent above k1 or k2). These differences indicate that k1-k2 units on one side of the scarp, and k3-k4 units on the other side, are not the same stack of layers (fig. S2). This rules out the possibility of a fault being the explanation for the offset in elevation.

The orientation of foresets indicate an apparent southward progradation in this sector of the western fan (i.e., the delta advanced toward the south) during episodes of stationary or slowly decreasing lake level. The subhorizontal topset truncation of underlying foreset units between k3 and k4 may reflect a drop in lake level. In contrast, the stacking of delta units k1-k3 stratigraphically on top of one another indicates an overall lake level rise of ~10 m before the truncation by k4. Thus, the observed geometries in Kodiak indicate delta growth into a lake system with fluctuating lake levels.

Previous studies have proposed that Jezero crater hosted an open-lake system with the water level at an elevation of -2395 m (5); this inference is derived from the observations that the inlet valley (feeding the western fan) and the breaching valley (that dissects the eastern rim of the crater) have approximately the same elevation of -2395 m. However, our results indicate that the lake level during deposition of units k1 to k4 (ca. -2500 m and -2490 m) was ~100 m below the inferred open-system lake level (Fig. 5). Thus, Jezero lake was closed (no outlet river) at the time of the delta progradation at Kodiak, which is a hydrological system conducive to short-term fluctuations in the lake level. Nevertheless, the overall stratigraphy indicates progradation of the western delta system and long-term lake level regression.

The western fan

Images of the SE-facing erosional front of the western fan expose sedimentary geometries within the uppermost fan deposits at several locations, at the top of ~60-m-tall scree-covered hillslopes (Fig. 1 and figs. S3 to S5). In a RMI mosaic (Fig. 3), the upper section of the northernmost hillslope exposes three sedimentary bodies (a1 to a3) that consist of conglomerates and finer-grained rocks (the grain size is not resolved). The lowermost unit a1 has an apparent thickness of 7 m and is composed of 10- to 30-cm-thick tabular-bedded strata, which show an apparent dip to the SW. At its northern margin, a1 exhibits steeply inclined beds (up to 30°) (Fig. 3D) that likely represent either lateral accretion sets formed in a large fluvial channel bar, or delta foresets.

A distinct coarse-grained lenticular unit a2 overlies a1; it is approximately 30 m wide and asymmetric with a maximum thickness of 9 m at its southern edge, thinning to less than a

meter to the north. Unit a2 is dominated by unsorted, clast-supported conglomerates of cobbles and boulders (Fig. 3C). The deposit is structureless locally displaying faint layering. Clasts show no preferred orientation or size segregation visible in images. The largest boulder, ~1.5 m on its long axis, casts a shadow below it, implying that it is embedded in the outcrop, so did not roll down from the upper slope. A shape assessment of 24 boulders shows that 13 are rounded and 11 are angular (14). Size measurements of 333 boulders/cobbles (figs. S6 and S7) indicate a distribution with a median size (D_{50}) of 16.4 ± 2.2 cm and a D_{84} (84% of clasts are smaller) of 25.9 ± 2.2 cm (Fig. 3E) (14).

We infer that unit a2 was deposited from rapidly decelerating high velocity flood flows that can transport boulders, based on its lack of sorting, large clast sizes, absence of well-developed stratification, and disorganized but clast-supported fabric. This interpretation is based on well constrained observations of flood deposits on Earth (18, 19). The rounding of some of the largest clasts indicates that they have undergone abrasion by collisional processes during fluvial transport. The lens-like shape of the conglomerate body a2 suggests that it is a channel fill. Assuming its dimensions represent the formative fluvial channel, the channel was 3–10 m deep. We estimate discharge rates using two methods: a Mars-modified version of the Darcy-Weisbach equations for river flows (20, 21) and the velocity threshold necessary to lift the largest clasts observed (14). Both methods give consistent results with velocities of 1.6 to 8.6 m s⁻¹ and discharge rates of 70 to 3000 m³ s⁻¹ (table S3) (14).

Unit a3 overlies a2; a3 is generally finer-grained than a2, up to 10 m thick, and extends ~80 m laterally. Unit a3 shows horizontal to low angle stratification, with some local cross-stratification. Unit a3 contains isolated cobbles and boulders; including a 50 cm diameter boulder that is being eroded from the outcrop (Fig. 3C). Based on the presence of planar stratification and cross-stratification, we infer unit a3 to be a sandstone with outsized clasts. If the a2-a3 contact is gradational, then these units are part of the same depositional sequence and a3 may record the waning stage of the fluvial flood flow. Alternatively, a3 could represent a second, lower energy event in which the flux of boulders was reduced.

Stratigraphic relationships between a1-a3 and underlying units are not well constrained because the exposure is debris-covered (Fig. 1G). However, the lowest part of the hillslope does expose one set of beds that are inclined to the east (Fig. 1G). The inclined beds could be either delta foresets, as observed at Kodiak and hypothesized from orbital images (22, 23), or they could represent a landslide block, as their dip is similar to the local slope.

Additional coarse-grained deposits are visible at scarps b to d (Fig. 1 and fig. S5). Scarp b is a 15-m-tall cliff that exposes two distinct sedimentary bodies (Figs. 1, C and D, and 4). The

lower unit comprises 10- to 40-cm-thick parallel planar sub-horizontal beds b1, which we infer to consist of sedimentary rocks that are finer-grained than conglomerate. Unit b1 is overlain by a unit b2, a conglomerate of unsorted cobbles and boulders (Fig. 4C) with varying degrees of rounding. Unit b2 shows faint inclined bedding (Fig. 4) and truncates unit b1 at a discontinuous, scoured contact at its base. The scarps at locations c and d (Fig. 1, E and F) expose units like those at b, with subhorizontal finer-grained strata overlain by coarser-grained, likely cobble-boulder conglomerates. The stratal geometry shown by these outcrops is similar to that observed in the uppermost section at Kodiak k5. Subhorizontal strata such as b1 could then represent delta topsets similar to k4.

The unconsolidated boulder-rich deposits observed at the scarp tops contain many rounded, scattered boulders (figs. S9 and S10 and supplementary text). We interpret these unconsolidated disorganized deposits as residual lags resulting from weathering of underlying boulder conglomerates and sandstones (Fig. 3). Comparison with geological maps constructed from orbital images (14) indicates that these unconsolidated deposits are part of the Delta Blocky unit, which comprises much of the upper surface of the western fan and is defined by positive relief elongate ridges and the presence of numerous clasts. This unit has previously been interpreted as inverted fluvial channel-belt deposits (8, 15, 22, 23) (fig. S1). Based on our rover images, we interpret the boulder-bearing units a2-a3, b2 and k5 as fluvial deposits that represent locally preserved sections from these well-developed fluvial channel-belt deposits.

We use orbital and multi-spectral Mastcam-Z observations of the western fan exposures to investigate the mineralogy and provenance of the boulder conglomerates (figs. S11 and S12 and supplementary text). These data indicate that the boulder conglomerates and the blocky deposits are dominated by low calcium pyroxene (LCP), unlike other sections of the fan stratigraphy which are dominated by phyllosilicates and olivine (fig. S11). This interpretation is consistent with the source of the boulders/cobbles as being either the LCP-bearing crater rim of Jezero, and/or the widespread exposures of LCP-rich crust >60 km upstream of Jezero crater (fig. S11) (7, 24). An igneous rock source would be consistent with the boulders' massive shape and apparent lack of internal fabric. Substantial transport distances from distant sources is consistent with the presence of rounded boulders (14, 25), whereas the source of angular boulders could be more proximal, such as the crater rim.

Implications for hydrologic evolution and sample return

Our rover images constrain the hydrologic evolution of Jezero crater, and potentially wider early Mars climate and habitability. The delta architecture at Kodiak indicates

deposition in a closed lake system, under fluctuating water levels and changing styles of flow during later stages. This indicates that the climate on Mars at that period (late Noachian or early Hesperian) was warm and humid enough to support a hydrologic cycle on the martian surface, at least episodically.

The presence of coarse-grained material (cobbles and boulders) in steep foresets is characteristic of Gilbert-type deltas prograding into deep lake systems (16, 26, 27) (fig. S6). The highest lake elevation recorded by the transition from topsets to foresets at Kodiak has an altitude of about -2490 m (Fig. 5), well below the lake levels previously proposed of -2395 m and -2250 m based on the basin topography (5, 23, 28). The Kodiak delta deposits are located 5 km away from the outlet, and they correspond to a regression to lower lake levels because they formed after a large part of the delta was already deposited. Our results do not exclude periods of higher standing lake levels in the crater, but do imply that any such periods occurred prior to the one recorded at Kodiak. Our observations of Kodiak indicate that the delta front extended ~1 km further south than the main western fan scarp. Delta deposits could have originally extended further eastwards as well.

The boulder conglomerates in units a2, b2 and k5 (Fig. 1) indicate repeated flood episodes of variable intensities. These deposits are distinct from the low- to moderate-energy fluvial deposits characteristic of river-dominated deltas (19). Their stratigraphic positions overlying delta deposits indicate that they are also unlikely to be sediment gravity flow deposits formed in a deep lacustrine setting. We cannot determine whether the boulder conglomerates were deposited when a lake still existed in Jezero crater. Their geometry is consistent with fluvial deposits on Earth that show downstream transition to gravel-to-sand Gilbert-type underwater foresets (29). The lowermost boulder conglomerates we observe are at an elevation of about -2490 m, similar to that of the lake level deduced from foresets at Kodiak. Therefore, these fluvial floods could have formed when the lake was around this level, or at a lower level. Alternatively, the widespread boulder conglomerate deposits could represent a younger depositional system that overlies deltaic strata.

Our results indicate a temporal transition in the energy regime of fluvial systems feeding the western fan, from sustained fluvial activity that built delta deposits prograding into the Jezero crater lake, to episodes characterized by high discharge fluvial flows capable of mobilizing meter-scale boulders over potentially tens of km transport distances. Subhorizontal topset beds at Kodiak (and possibly b1) are relatively homogenous deposits compared to the boulder conglomerates, and are likely sandstones, consistent with deposition by sandy rivers. The presence of occasional boulders in the Kodiak foresets points to locally higher intensity

flow conditions, but the boulder conglomerate units record much higher magnitude flood episodes. Local discharge rate estimates (70 to $3000\text{ m}^3\cdot\text{s}^{-1}$) for the floods are consistent with those previously estimated from braided fluvial channels observed upstream in Neretva Vallis (9). Nevertheless, these are late-stage deposits formed from more intermittent, energetic flows than the topsets they overlie, so our discharge rates cannot be used to estimate the formation time required for the entire delta fan.

The mechanism responsible for the flood events is unknown. The presence of rounded boulders demonstrates that substantial abrasion of clasts occurred during fluvial transport. This evidence, coupled with the presence of multiple flood episodes with similar boulder sizes as in unit a2, exclude megafloods such as those proposed for martian outflow channels (30). Flood episodes could have formed by a variety of processes (18, 31) such as intense rainfall events, rapid snowmelt episodes [from either a climatic origin (1, 3) or heating by volcanism or impact (32, 33)], or through progressive building of glaciers and glacial lakes in the watershed creating episodic surges (31). Thus, the transition in flow intensity at Jezero crater may be related either to paleoclimatic shifts (global or regional), or changes in watershed hydrology.

The Jezero crater deposits provide information which could be extrapolated to other paleolakes on Mars (2, 26, 34). Favorable climatic conditions for rivers and lakes are already known to have also been present at Gale crater (2, 35). However, the conglomerates in Jezero crater require much higher energy environments than those in Gale crater, where the median clast size is $<1\text{ cm}$ and the largest clasts are $<10\text{ cm}$ (35) (Fig. 3E). A transition to drier conditions at Gale crater has been suggested to explain a change in mineralogy from clay- to sulfate-bearing minerals, and alternating eolian and fluvial deposits (36, 37). However, in Gale crater no fluvial flood deposits have been observed stratigraphically overlying the lacustrine deposits of the Murray formation (2), contrasting with the hydrologic evolution of Jezero crater.

Our results inform sampling strategies for Perseverance in Jezero crater (supplementary text). First, boulders $>1\text{ m}$ in diameter provide an opportunity to analyze and collect samples from crustal rocks sourced from outside Jezero that must predate the rocks within the crater (4, 24). These likely contain records of the ancient Martian interior. Second, the finer-grained bottomset strata, which are known from orbital data to contain Fe/Mg smectite clays (6, 7, 10), have high potential to preserve organic matter or potential biosignatures (38–40).

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Data from the OMEGA instrument on Mars Express, used in fig. S11, are available at <https://pds-geosciences.wustl.edu/mex/mex-m-omega-2-edr-flight-v1/mexomg-0001/data/> in the “gem04” and “gem22” directories. Data from the HiRISE instrument on MRO, used for Fig. 1 and figs. S1 and S9 to S11, are available at https://hirise-pds.lpl.arizona.edu/PDS/EDR/ESP/ORB_036600_036699/ESP_036618_1985/, https://hirise-pds.lpl.arizona.edu/PDS/EDR/ESP/ORB_037100_037199/ESP_037119_1985/, https://hirise-pds.lpl.arizona.edu/PDS/EDR/PSP/ORB_002300_002399/PSP_002387_1985/, and https://hirise-pds.lpl.arizona.edu/PDS/EDR/PSP/ORB_003700_003799/PSP_003798_1985/. The CRISM data used for fig. S11 are available at https://pds-geosciences.wustl.edu/mro/mro-m-crisp-3-rdr-targeted-v1/mrocr_2101/trdr/2007/2007_029/hr1000040ff/hr1000040ff_07_if1831_trr3.img. The Context Camera image mosaic of Jezero used in Fig. 5 and fig. S1 is available at the United States Geological Survey https://astrogeology.usgs.gov/search/map/Mars/Mars2020/JEZ_ctx_B_soc_008_orthoMosaic_6m_Feq_latTs0_lon0. The Entry, Descent, Landing (EDL) image used in fig. S5 is available at <https://mars.nasa.gov/mars2020/multimedia/raw-images/>. Our cobble size measurements, used to produce Fig. 3E and fig. S7, are provided in data S1.

SUPPLEMENTARY MATERIALS

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Materials and Methods

Supplementary Text

Figs. S1 to S12

Tables S1 to S3

References (41–76)

Data S1

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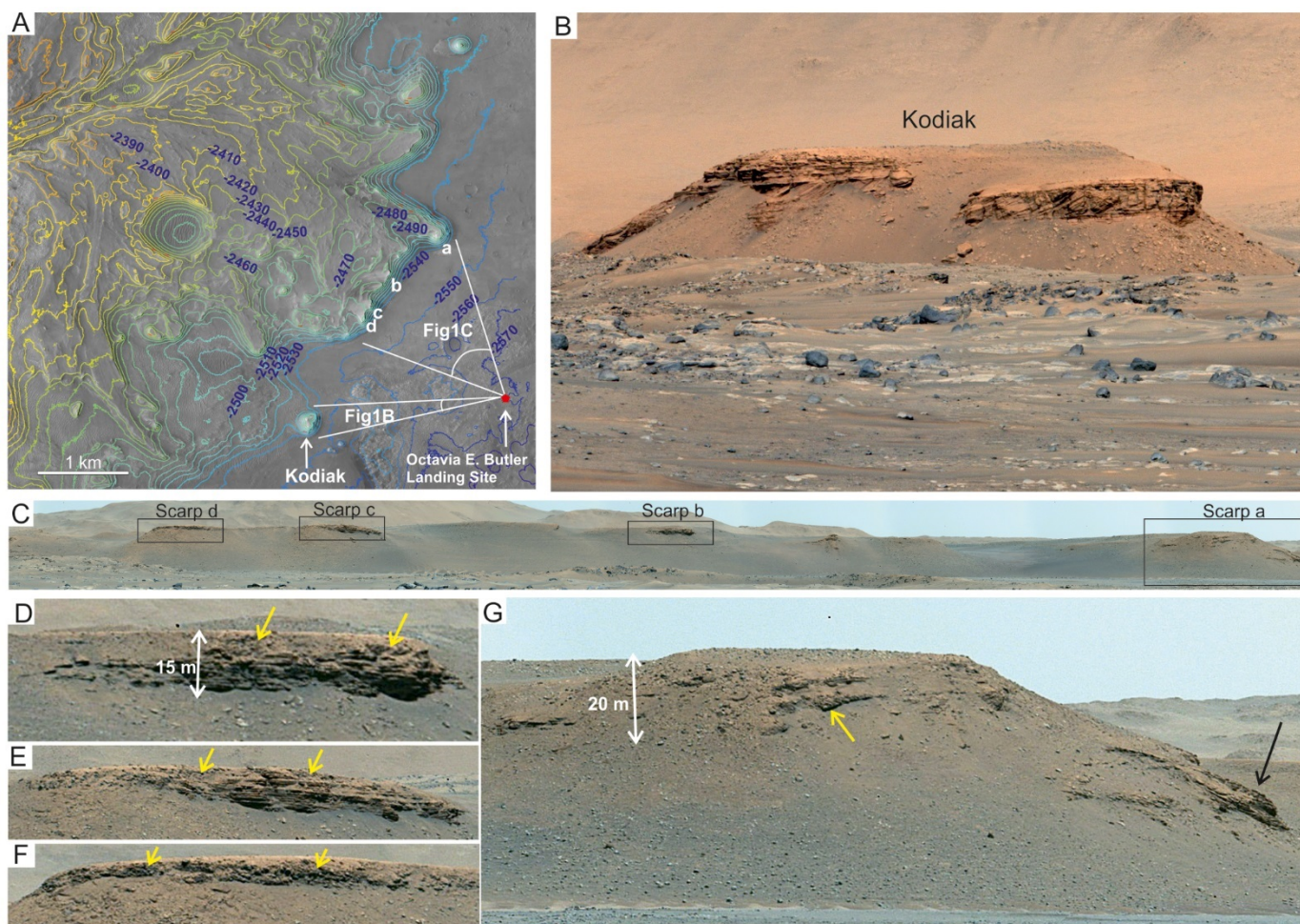


Fig. 1. Orbital and rover context observations of the Jezero crater western fan. (A) High Resolution Imaging Science Experiment (HiRISE) mosaic (14) with 10 m elevation contours from a digital elevation model (DEM) (14) showing the western fan inside Jezero crater and the landing site, informally named Octavia E. Butler (red dot). White arcs represent the fields of view of (B) and (C). (B) The butte informally named Kodiak, imaged from a distance of ~2.24 km by Mastcam-Z. (C) Mastcam-Z enhanced color mosaic of the delta front, taken from a ~2.20 km distance with black boxes indicating scarps of interest. (D to G) Each scarp viewed in the corresponding 110 mm focal length Mastcam-Z images. Yellow arrows indicate the location of boulder-rich material shown in Figs. 3 and 4. The black arrow in (G) indicates an exposure with dipping strata.

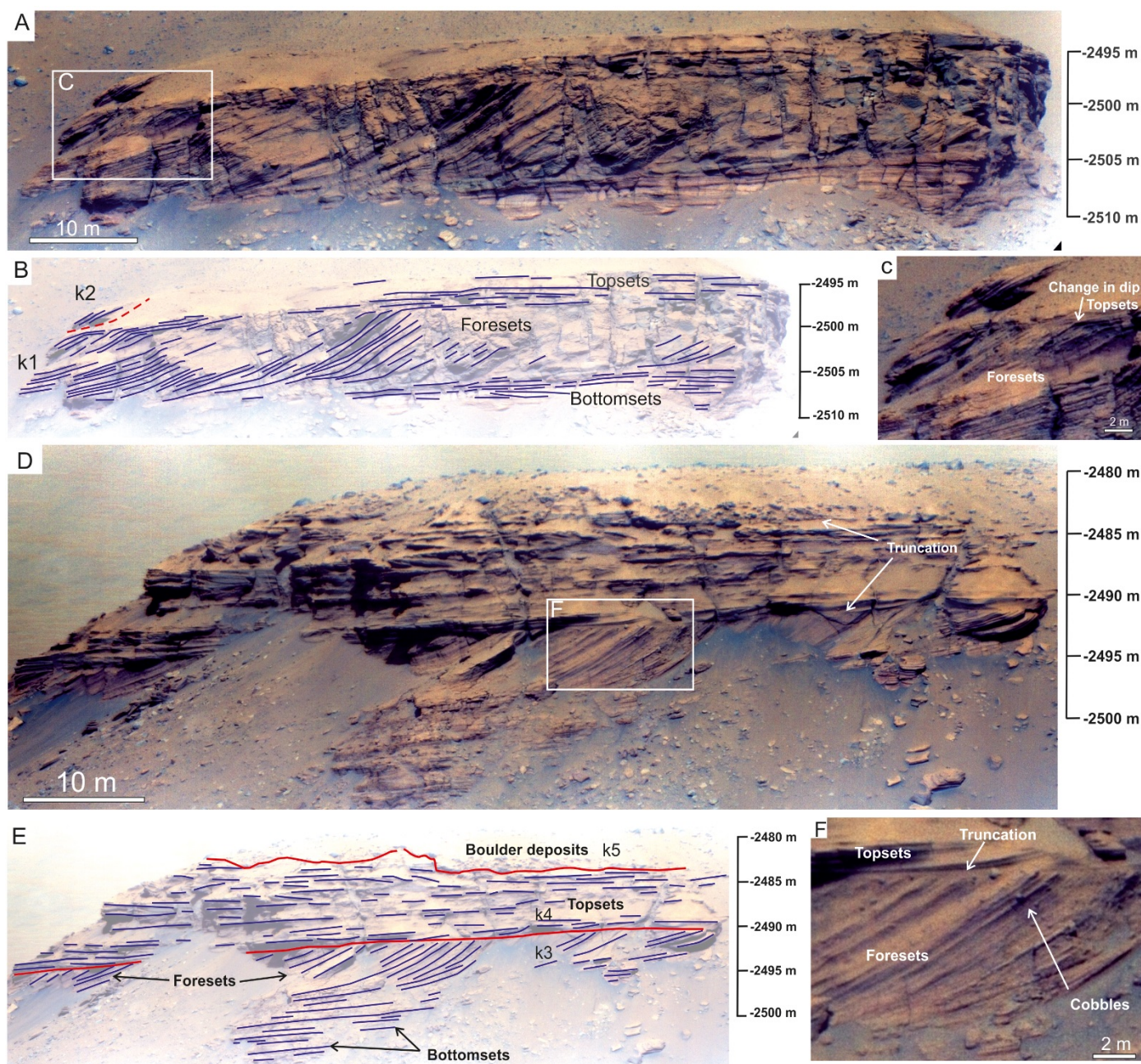


Fig. 2. Stratigraphy of Kodiak butte. (A and D) Zoomed images of the two scarps of Kodiak (see fig. S2 for wider context). Elevation scales were inferred from a HiRISE DEM (14) and have systematic uncertainties of ± 2 m. White boxes indicate regions shown in more detail in other panels. (B and E) Interpreted line drawings of the main visible beds (blue lines for individual beds and red lines for discontinuities), overlain on the same images. Units k1 to k5 are labeled and discussed in the text. (C) Zoomed image of k1 showing the change in dip from subhorizontal beds (topsets) to inclined beds (foresets). (F) Zoomed image of the foresets in k3. This unit has a coarse texture with several cobble-size clasts (white arrow). The erosional truncation of k3 by k4 is labeled.

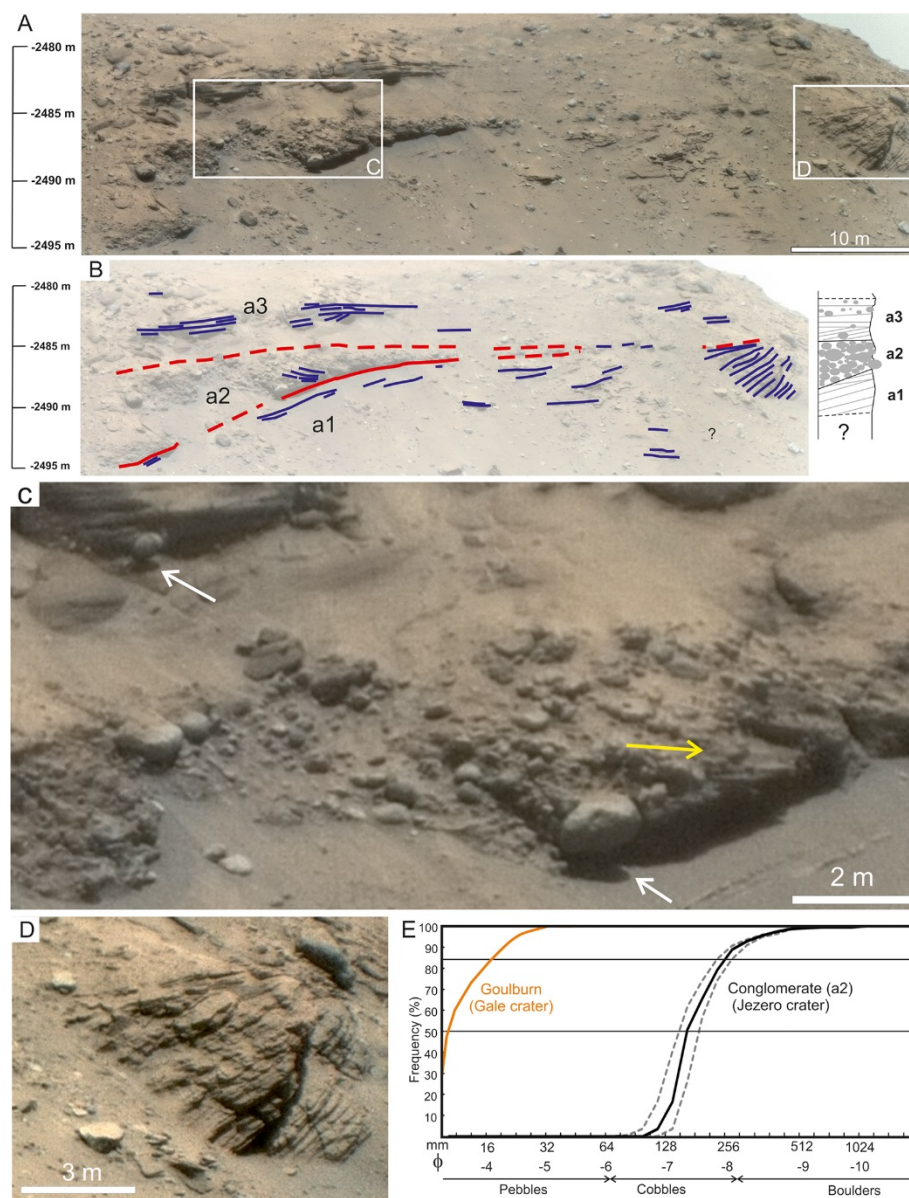


Fig. 3. Stratigraphy of the western fan scarp a. (A) RMI mosaic of the western fan scarp a (see Fig. 2C and fig. S3 for wider context). Elevation scale as in Fig. 2. White boxes indicate regions shown in more detail in other panels. (B) Interpreted line drawing of individual layers (blue lines) and main boundaries (red lines) between sedimentary bodies labeled a1 to a3. A simplified stratigraphic column of these three bodies is shown on the right. (C) Zoomed image of the boulder-bearing units a2 and a3. White arrows indicate the shadow cast beneath two boulders hanging from the bedrock. Right of the lowermost hanging boulder, an incipient oblique bedding is visible (yellow arrow). Unit a3 might be the result of an amalgamation of two or more depositional sequences. (D) Zoomed images of a1 showing dipping layers organized as co-sets of dipping beds with an apparent dip of up to 30°. (E) Cumulative histogram, on a logarithmic scale (ϕ indicates a scale defined by \log_2 increments), of the measured sizes of 333 clasts (black) compared to the conglomerate Goulburn measured at Gale crater by the Curiosity rover (orange) (35). Dotted lines indicate the uncertainty around clast size measurements (14).

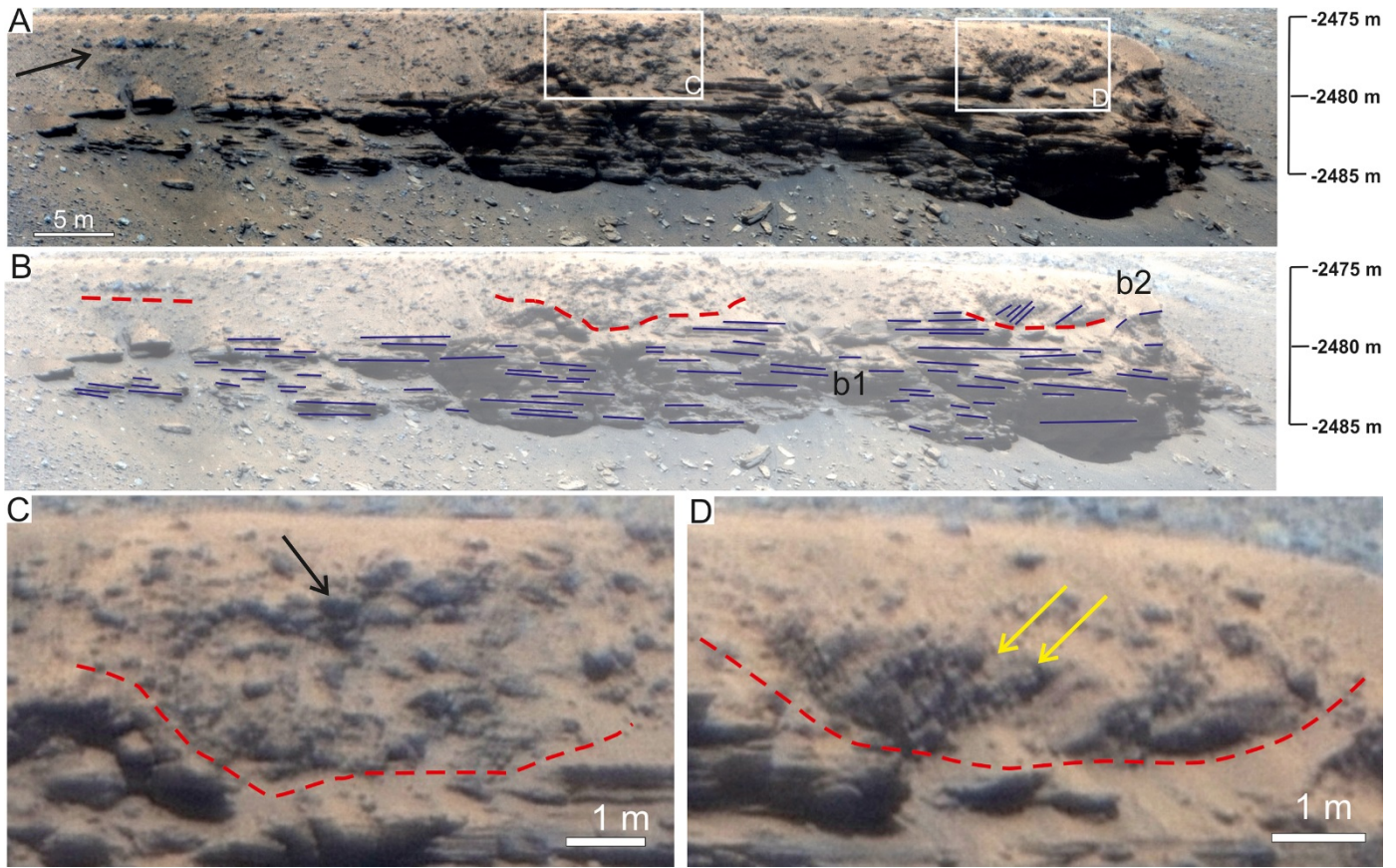


Fig. 4. Stratigraphy of the western fan scarp b. (A) Mosaic of five RMI frames of scarp b (localization in Fig. 1, mosaic in fig. S4). The black arrow at the top left indicates a thin bed with cobbles and boulders preserved in the scarp similar to the thinning of a2 in Fig. 3. Elevations scales are as in Fig. 2. White boxes indicate regions shown in more detail in other panels. (B) Line drawing interpretation of this scarp, showing individual beds (blue lines) and discontinuities (dotted red lines). Subhorizontal beds dominate the lower sedimentary unit b1. This unit displays a relatively fine-grained material, compared to overlying boulder-bearing conglomerates b2, which are present above a discontinuity (dashed red lines) interpreted as a truncation episode. (C) Zoomed image of a boulder conglomerate displaying a series of rounded boulders, piled up along a subhorizontal bed, 50 cm to 1 m in diameter, developed along a subhorizontal bed (black arrow). (D) Zoomed image of cobble-bearing conglomerates that were deposited as dipping beds (yellow arrows). The presence of bedding indicates the conglomerate exposure is not a residual lag lying on hillslopes.

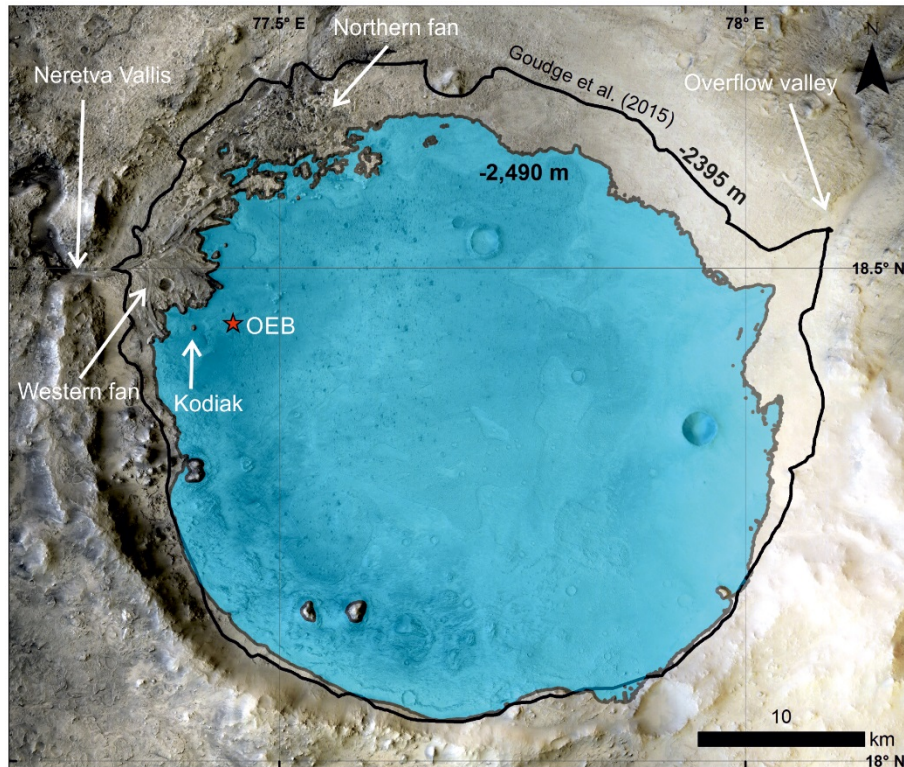


Fig. 5. Inferred paleolake level inside Jezero crater at the time of Kodiak sediment deposition. Blue shading indicates assumed lake level filled to the -2490 m gray contour following the uppermost elevation deduced from deltaic architecture at Kodiak (Fig. 2). The red star indicates Octavia E. Butler (OEB) landing site of the Perseverance rover. The black outline of the implied earlier minimum water stand, corresponding to the overflow valley breach (8), is shown for comparison. Rocks present on the crater floor might not have been emplaced during the period of lake activity. Both western and northern fans are above the inferred lake surface and the basin appears closed, 100 m below the breach to the east (labeled overflow valley). Background from the Context Camera (CTX) mosaic (14).

Perseverance rover reveals an ancient delta-lake system and flood deposits at Jezero crater, Mars

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