Headline Article
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Young Tectonic Events in Martian Chaotic Terrain

--- Study of a faulted landslide in Aureum Chaos and its ramifications.

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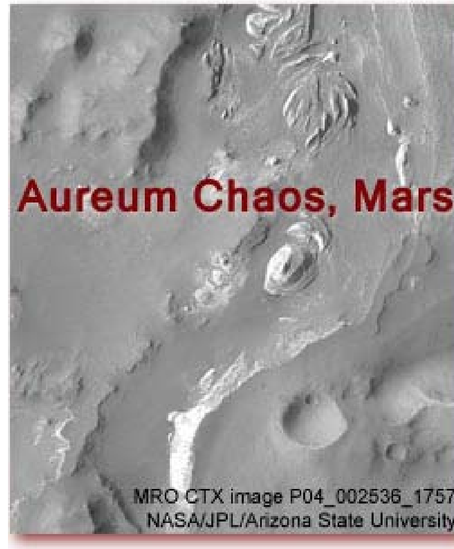


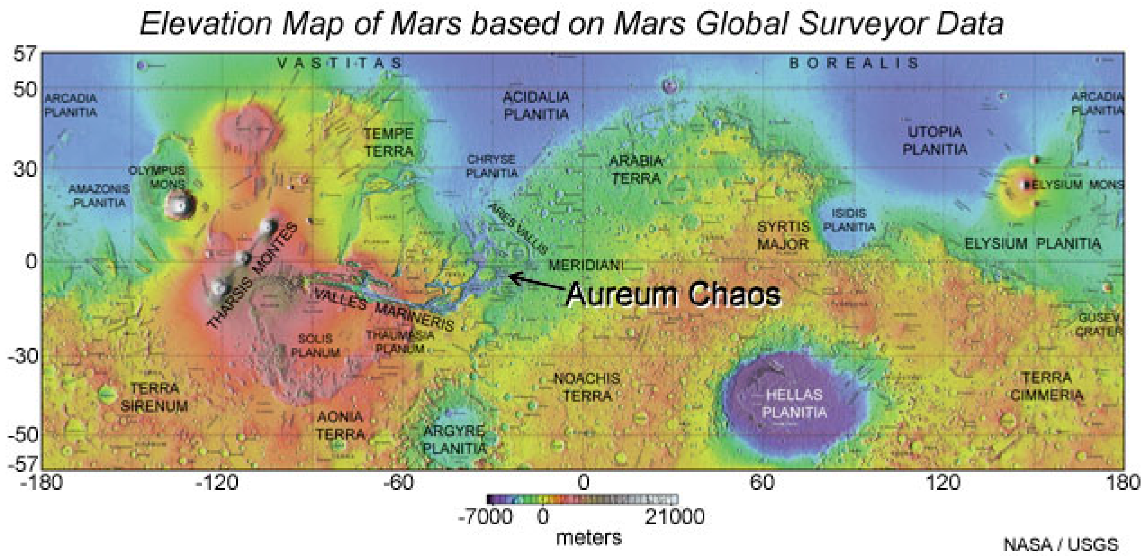
Examples of recent tectonic activity and subsidence on Mars are expressed in Aureum Chaos, the area of chaotic terrain east of Valles Marineris. So say researchers who have studied the layered deposits of Aureum Chaos and the cross-cutting relationships between scarps, dunes, and a landslide. Mauro Spagnuolo (Universidad de Buenos Aires), Angelo Rossi (International Space Science Institute and Jacobs University Bremen), Ernst Hauber (German Aerospace Center), and Stephan van Gasselt (Freie Universität Berlin) identified fault-related geomorphic features in remote sensing data, specifically a disrupted landslide that they determine to be less than 1.9 million years old. If indeed very recent activity has occurred along faults in Aureum Chaos, then these may be very important sites for studies related to the circulation of fluid or gas through, or out of, these fractures or fissures. Both geologists and astrobiologists would be interested in the implications for the distribution of water in the crust, the aqueous alteration of minerals, and the potential for microenvironments to harbor or sustain life.

Reference:

- Spagnuolo, M. G., Rossi, A. P., Hauber, E., and van Gasselt, S. (2011) Recent Tectonics and Subsidence on Mars: Hints from Aureum Chaos, *Earth and Planetary Science Letters,* v. 312(1), p. 13-21, doi: 10.1016/j.epsl.2011.09.052.
- **PSRDpresents:** Young Tectonic Events in Martian Chaotic Terrain --**Short Slide Summary** (with accompanying notes).

A Place on Mars Called Aureum Chaos

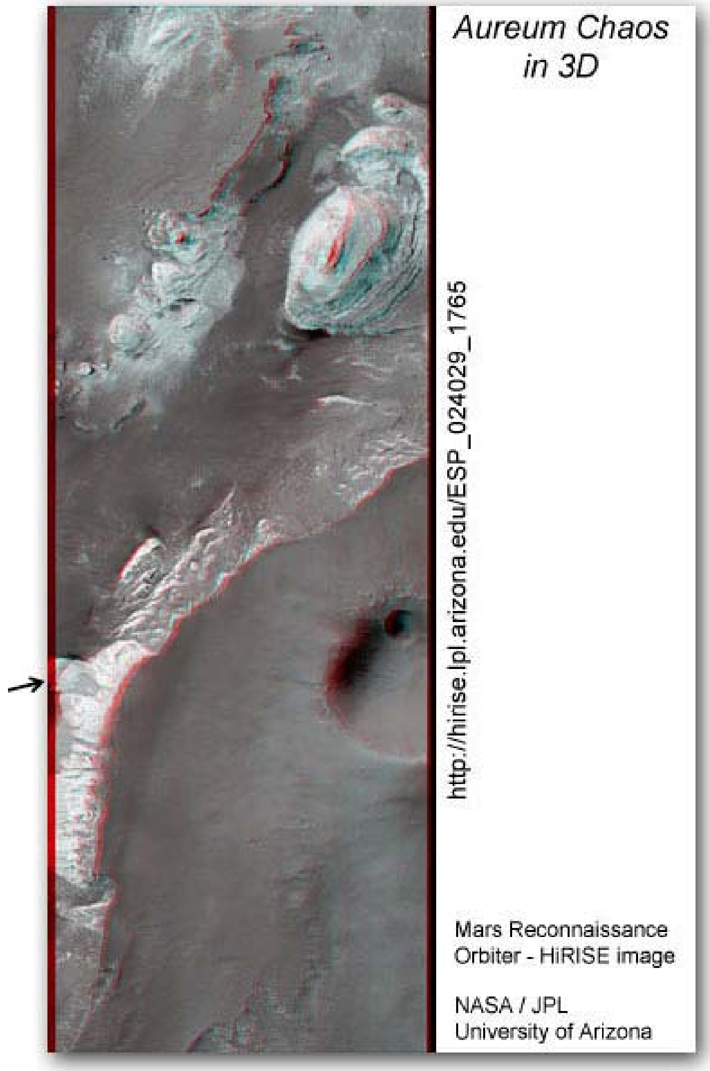
Located near the boundary between the southern highlands and northern lowlands on Mars, Aureum Chaos is a basin (71,000 km^2 in area) east of Valles Marineris (at 4 °S, 27 °W). The lowlands and curved, grooved troughs of Aureum Chaos are punctuated by broad, eroded plateaus and hills that are randomly oriented, earning its moniker "chaotic terrain." Models suggest the removal of subsurface material (possibly groundwater or melting ice) caused the overlying surface to collapse, releasing flood waters and forming the chaotic patterns. The rock in this region is layered, as seen from remote sensing mapping, and could have originated as layers of fallen dust or volcanic ash, as sand carried here by Martian winds, or as sediments deposited in ancient springs or a lake (just to name a few of the theories). Collectively these rocks are referred to as "interior layered deposits" or "layered sedimentary deposits" and they were first recognized in **Mariner 9** images. Previous work suggests most, if not all, of these layers formed, perhaps during several episodes, after the structural collapse that formed the chaotic terrain during the late **Hesperian**.

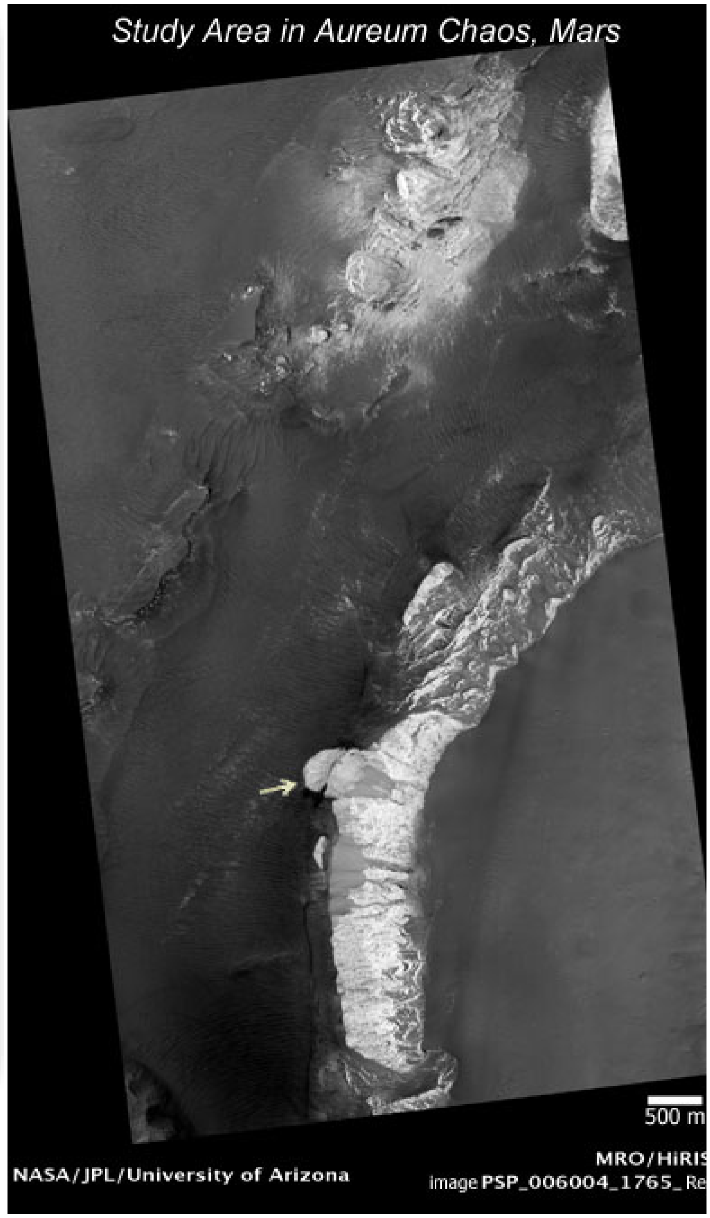


Elevation map of Mars based on data from the Mars Orbiter Laser Altimeter (MOLA) on NASA's Mars Global Surveyor spacecraft. Lowlands have colors of purple, blue, and green. Highlands are in yellow, organge, red, and white. Aureum Chaos (see arrow), near the boundary between the southern highlands and northern lowlands, is the area of chaotic terrain studied by Spagnuolo and coauthors. Click the map for a high resolution version from the U.S. Geological Survey.

Among the early researchers to investigate the **tectonics** and mass-wasting features, including landslides, in and around Vallis Marinaris and Martian chaotic terrain were Baerbel Lucchitta (U. S. Geological Survey, Flagstaff) and her colleagues. Their late-1970s hypotheses, based on **Viking Orbiter** imagery of landslide/mudflow features, included the idea of collapse of ice-cemented, saturated rock walls initiated by Marsquakes. They made geologic maps, counted craters to determine relative ages, and measured sizes and volumes of features based on the 150–300 meters/pixel resolution of the Viking Orbiter frames. Since then researchers have mapped the area using data from NASA's Mars Orbiter Laser Altimeter (MOLA) and the European Space Agency's High Resolution Stereo Camera on Mars Express (HRSC, about 12-25 meters/pixel). Fast forward to today's datasets coming from the **Mars Reconnaissance Orbiter's** HiRISE camera with resolution of about 30 *centimeters*/pixel. Quite a zoom factor! These high-resolution datasets are giving researchers unprecedented views of the surface in the chaotic terrain.

Orbital remote sensing is also revealing the composition of the materials in Aureum Chaos. Using the Mars Global Surveyor Thermal Emission Spectrometer, the Mars Reconnaissance Orbiter CRISM visible/near-infrared spectrometer, and the European Space Agency's Mars Express/OMEGA visible/near-infrared spectrometer, researchers have identified hematite- and sulfate-rich layers, and clays—water-related weathering products. These findings are consistent with Aureum Chaos as a basin and potentially an ancient playa that may have held a temporary lake. An alternative model for the suite of layered rocks favors groundwater evaporation. The timing of formation of the clays versus sulfates and the duration of aqueous alteration are hot topics of research and debate. Hence, this area is important both geochemically and structurally, and the data from current missions are allowing new insights to the history of water and tectonic activity that have modified or deformed this area of Mars.



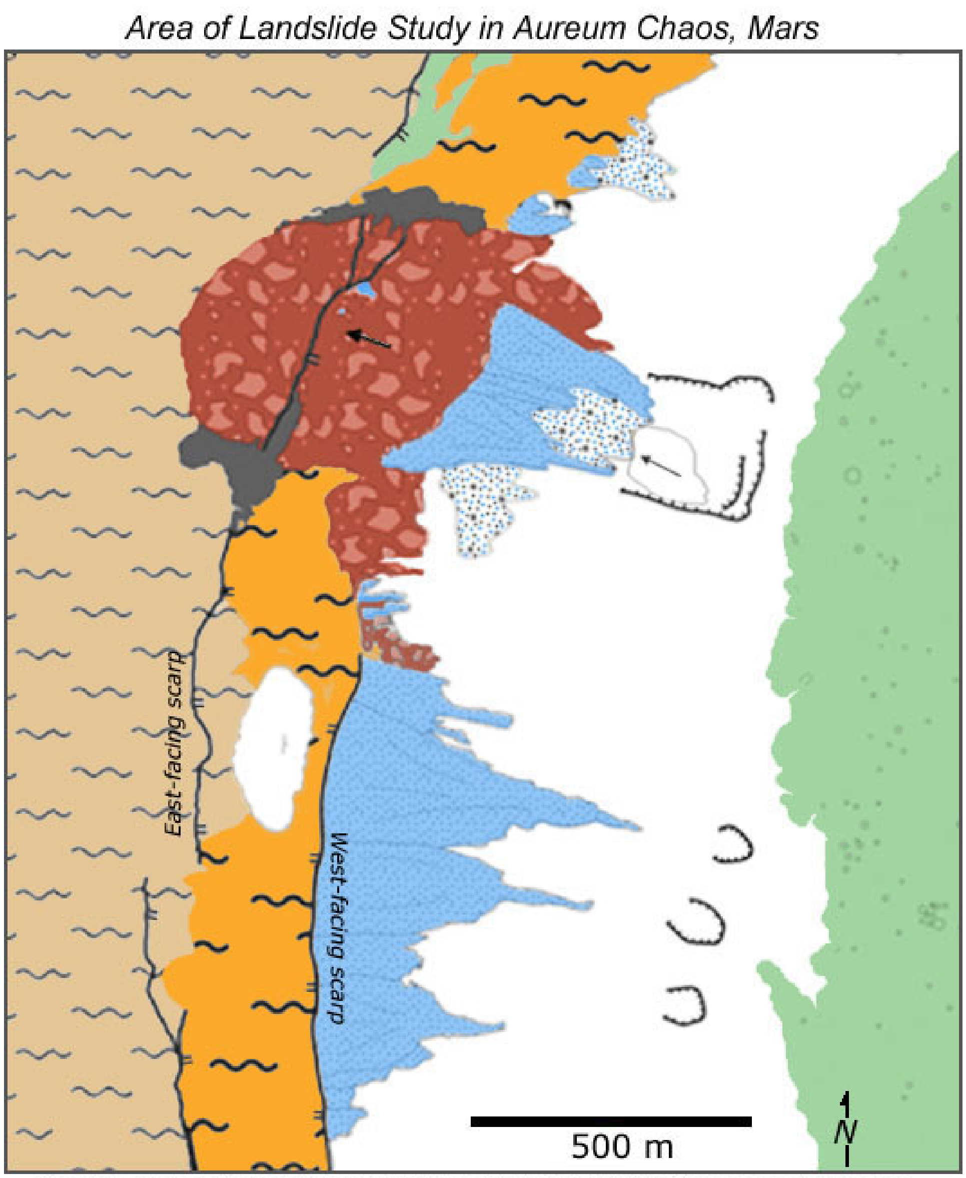


[LEFT] The chaotic terrain in Aureum Chaos is shown in this 3D image based on data from the HiRISE camera on NASA's Mars Reconnaissance Orbiter spacecraft. The arrow shows part of the landslide studied by Spagnuolo and colleagues. **[RIGHT]** Key area studied by Spagnuolo and colleagues in Aureum Chaos. Arrow shows landslide of light tone deposits that appears to be cut by a fault. Click either image for a high resolution version.

Faulting a Landslide

Mauro Spagnuolo and colleagues studied the layered deposits of Aureum Chaos at a 480-meter-high wall (West-facing scarp) and found a landslide that appears to be disrupted by a fault. Using MRO HiRISE data, MOLA data, and derived digital elevation models they determined **stratigraphic** relationships and a chronology of geologic events.

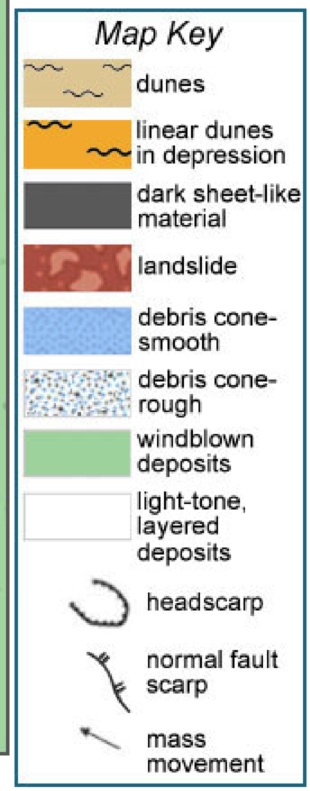
The large image/map overlay, below, shows the units described by Spagnuolo and team: Windblown deposits up on the plateau (green), light-tone layered deposits (white) bounded by the West-facing scarp (black line), landslide deposits (red) cut by fractures that line up with an East-facing scarp (black line), debris cones both rough-textured and smooth-textured (blues), dark sheet-like material that extends and fills the interdune area (dark grey), linear dunes that cover the ground in the long depression between scarps (gold), and a lowland field of dark transverse dunes (light gold). Use the buttons to change between the image and the map.



Roll over or click the buttons, below, to view the HiRISE image (PSP_006004_1765) or the geomorphic map from the work by Spagnuolo and colleagues.

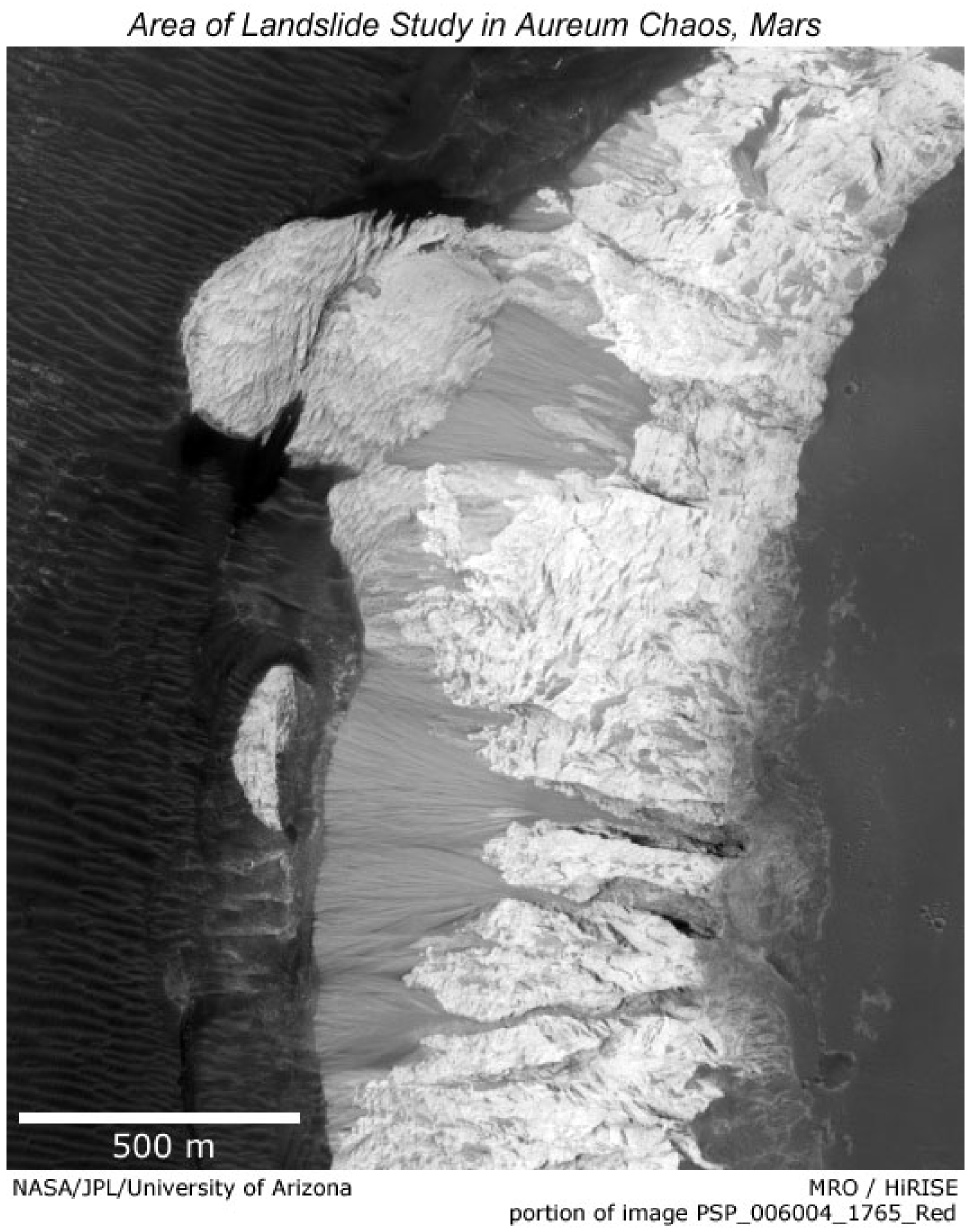
Show the map

Show the image



Geomorphology Map adapted from Spagnuolo *et al.* (2011) *Earth and Planetary Science Letters*, v. 312, p. 13-21, doi:10.1016/j.epsl.2011.09.052.

Image view of the study area and landslide with overlapping geomorphic sketch map.



Roll over or click the buttons, below, to view the HiRISE image (PSP_006004_1765) or the geomorphic map from the work by Spagnuolo and colleagues.

Show the map

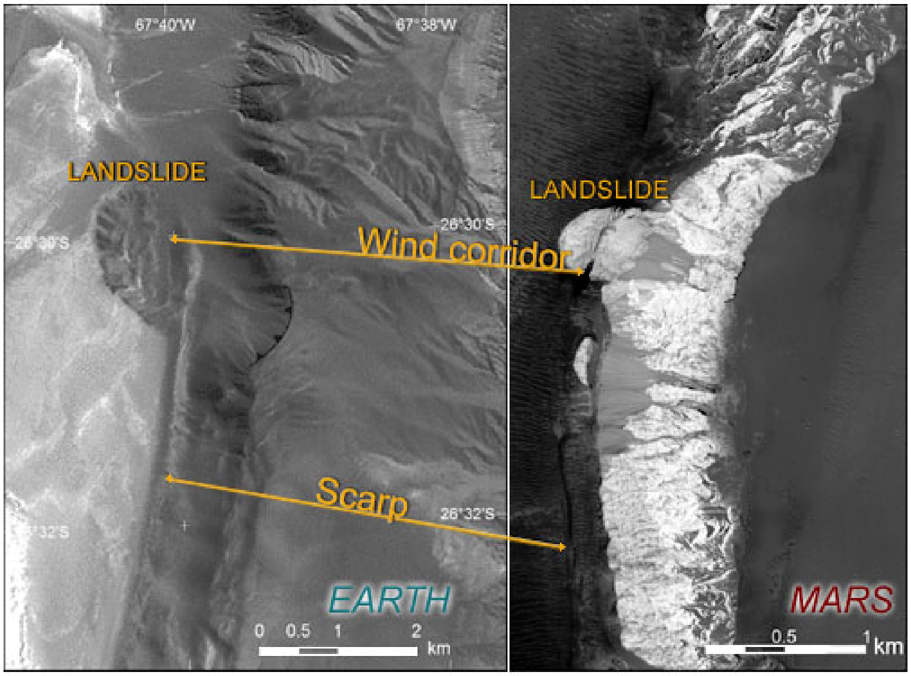
Show the image

Image view of the study area and landslide with overlapping geomorphic sketch map.

The team set out to answer the questions: How old is the landslide? When was it cut? Neither the landslide nor the nearby debris aprons have impact craters that would allow the researchers to determine the ages of the surfaces. So they counted craters and determined the crater size-frequency distributions of bordering surfaces on the plateau, including the windblown deposits, and the lowland surface below the dunes. They fit these crater distributions to **isochrons**, which are defined as the size distribution of craters found on a surface of a specified age, if no other processes have obliterated or altered the surface. Spagnuolo and colleagues fit their data to isochrons based on the methods established in 2001 by William K. Hartmann (Planetary Science Institute, Tucson, AZ) and Gerhard Neukum (Freie Universität Berlin). This method resulted in an estimated age of 4.43 ± 0.23 million years for the windblown plateau deposits and 7.74 ± 0.68 million years for an older plateau surface (off the map as shown) and an age of 1.87 ± 0.36 million years for the lowland surface below the dunes. Spagnuolo and colleagues found that some dunes in the lowland dune field have broken crests, cut by a scarp. Hence, these results suggest the West-facing scarp and the landslide are younger than ~2 million years old. Though the crater counting method is well established, these ages are approximate, and will remain that way until radiometric dating of the rocks themselves give absolute ages. Nonetheless, 2 million years is a reasonable estimate and very modern in Martian geologic time.

The researchers say the Martian landslide and its regional setting resemble terrestrial avalanches in dry environments on Earth. The images, below, show an example of Aureum Chaos compared with the Argentinian Southern Puna plateau. Landslides and rock avalanches in the Puna high plateau are typically triggered by tectonic events. The terrestrial landslide is cut by a normal fault that generated a fracture and a wind corridor, analogous to the Aureum Chaos landslide.

Comparing Landslides on Earth and Mars

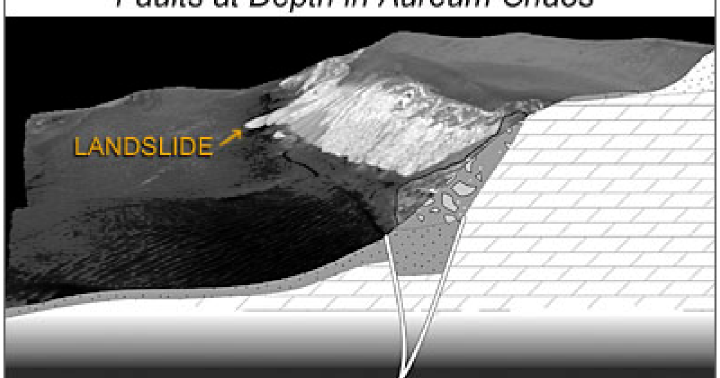


(Adapted from Spagnuolo *et al.*, 2011, *EPSL*, v. 312, p. 13-21, doi: 10.1016/j.epsl.2011.09.052.)

[Left] Landsat image of landslide in the very dry region of the Argentinian Southern Puna plateau. **[Right]** HiRISE image of lanslide in AureumChaos, Mars mapped by Spagnuolo and colleagues. In both cases a fault scarp and wind corridor have visibly modified the landslide deposits.

Young Tectonics — Active Tectonics

Hypothetical Cross Section Showing Faults at Depth in Aureum Chaos



(From Spagnuolo *et al.*, 2011, *EPSL*, v. 312, p. 13-21, doi: 10.1016/j.epsl.2011.09.052.)

Spagnuolo and colleagues suggest the scarps in their study area are steeply-dipping (almost vertical) normal faults—deep structures that may have controlled the ground subsidence so recently that they may still be active. The perspective view, on the left, shows how the faults might look below the surface. In a more recent study in Cerberus Fossae (one of the youngest fracture systems known on Mars) Gerald Roberts (University of London) and colleagues in London and Rome attribute boulder avalanches to localized ground shaking associated with recent Marsquakes. These authors also propose young tectonic activity could still be active. If tectonic processes are recent, then these may be important locations for future geophysical exploration or seismic networks on Mars. In addition, previous work has speculated that slow **dissociation** of subsurface methane ice may explain the presence of methane in the Martian atmosphere. Hence, the recent tectonic activity reported by Spagnuolo and colleagues suggests fractures or fissures could be important sites to study the circulation or release of fluids or gases, which has interesting astrobiological ramifications on the distribution and/or cycle of water in the Martian crust and the potential development of microenvironments to harbor or sustain life.

Additional Resources

Links open in a new window.

- **PSRDpresents:** Young Tectonic Events in Martian Chaotic Terrain --**Short Slide Summary** (with accompanying notes).
- Hartmann, W. K. and Neukum, G. (2001) Cratering Chronology and the Evolution of Mars. *Space Science Reviews,* v. 96, p. 165-194. [**NASA ADS link**]
- Lucchitta, B. K. (1979) Landslides in Valles Marineris, Mars, *Journal of Geophysical Research,* v. 84, p. 8097-8113. [**NASA ADS link**]
- Roberts, G. P., Matthews, B., Bristow, C., Guerrieri, L., and Vetterlein, J. (2012) Possible Evidence of Paleomarsquakes from Fallen Boulder Populations, Cerberus Fossae, Mars, *Journal of Geophysical Research,* v. 117, E02009, doi:10.1029/2011JE003816 [**NASA ADS link**]
- Sowe, M., Wendt, L., McGuire, P. C., and Neukum, G. (2012) Hydrated Minerals in the Deposits of Aureum Chaos, *Icarus,* v. 218, p. 406-419, doi: 10.1016/j.icarus.2011.12.009 [**NASA ADS link**]
- Spagnuolo, M. G., Rossi, A. P., Hauber, E., and van Gasselt, S. (2011) Recent Tectonics and Subsidence on Mars: Hints from Aureum Chaos, *Earth and Planetary Science Letters,* v. 312(1), p. 13-21, doi: 10.1016/j.epsl.2011.09.052 [**NASA ADS link**]

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