3D photogrammetric evidence for trace fossils at Vera Rubin Ridge, Gale Crater, Mars.

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On sol 1922 and 1923, NASA's Mars Science Laboratory (MSL) rover (Curiosity) mission in Gale Crater, using its microscopic imager (MAHLI) returned over 84 images to Earth of enigmatic metallic dark-toned features on a rock the MSL team refer to as *Haroldswick* located near the top edge of Vera Rubin Ridge, once the site or shoreline of an ancient fresh water lake in Gale Crater 3.5 billion years ago. Remarkably, the *Haroldswick* rock and dark-metallic toned features are part of at least five such similar rock fragments that are located in close proximity to each other (1) (2). All these fragments have similar morphological features resembling terrestrial trace fossil burrows meandering through their host rock matrix. The elongated metallic tube-like features are the first of their kind ever observed on Mars. Meanwhile the MSL rover team refers to the dark features as *sticks* or *crystals* and contend the shapes are characteristic of gypsum crystals that form when salts become concentrated in water, such as in an evaporating lake. However, we note the data from MSLs traverse and analyses of the lacustrine mudstone and sandstone sediments indicate that this lake was a fresh water lake, not a salty one. We also note that lake sediment salts are not metallic in appearance. While an attempt was made on sol 1921 using MSL's APXS and Chemcam's LIBS instrument to target and obtain spectra from the metallic tube like features, no useable data was obtained before MSL mission planners decided to move the rover on sol 1923 to another target 11 meters away.

Methods: On Earth, trace fossils (ichnofossils) are formally identified on the basis of their 3D morphology. We used a 3D photogrammetry-based imaging program to look at and identify key features on *Haroldswick* from different angles. Since terrestrial burrows are the most common trace-fossil category, comprising galleries, tunnels, shafts, chambers that have been excavated by animals within an unconsolidated substrate, we first concentrated our efforts on these. On Earth, trace fossil burrows can range in size from nanometer to meter-scale features. The preservation classification system in ichnology uses the relationship of the burrow in association with the sedimentary surface. According to this criterion the traces can be exogenic on the sediment surface, or endogenic, within the sediment itself and sometimes both indicating bioturbation.

Discussion:

We used trace fossil identification criteria established by Knaust et al (3) to examine *Haroldswick* for possible evidence linking it to the ancient bioturbation by multicellular life forms on Mars. The color and texture of the structures on the surface of *Haroldswick* are clearly darker from the host rock. The elongated structures superficially resemble Ordovician period *Planolites* and *Thalassinoides*-like trace fossil burrows. Upon close inspection of the elongated tube-like features on *Haroldswick*, they appear to emerge and descend into the host rock just as terrestrial counterparts do. The largest (estimated to be 10mm in length) of the elongated structures on *Haroldswick* appears to have false-branching structures that intersect others. This observation argues against a shrinkage crack filling origin. Other trace fossil features on *Haroldswick* are the occurrence of small holes in the host rock that are not cemented but resemble terrestrial trace fossil burrow apertures.

If our hypothesis is correct in its interpretation, it means ancient Mars evolved microbial and multicellular life perhaps a billion years prior to Earth. A fresh water lake on Mars 3.5 billion years ago suggests Mars may have been the first blue marble in the solar system, not Earth.