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Research Paper

Putative Martian Microbes Formed Plentiful Ooids on Mars.

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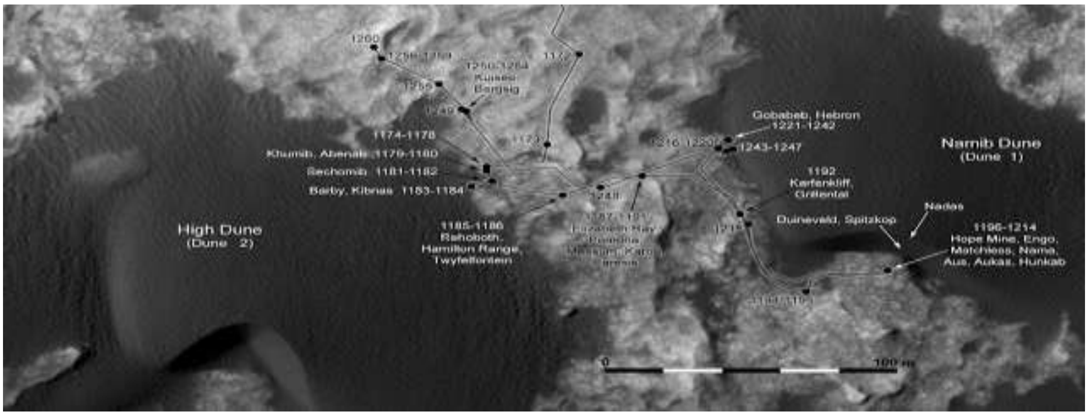
ABSTRACT:*NASA's Mars Rover Curiosity discovered plentiful indigenous spherical ooids at High Dune and Namib Dune in Bagnold dune field, Gale Crater, Mars. The Martian ooids measure about 0.2 mm to 0.5 mm in diameter. Colors of the Martian ooids are various, including white, yellow translucent, green, grey, and yellow. The Martian ooids should have been formed by microbes, because ooids of Earth have recently been found to be formed by microbes and microbial borings are found in ooids of Earth and of Mars. The Martian ooids are unlikely to have been formed by non-biological mechanisms, because there was no highly agitated water at the discovery sites.*
Keywords: *Martian microbes; Martian ooids; Life on Mars; Past life on Mars*

I. INTRODUCTION

NASA's Mars Rover Curiosity visited Bagnold dune field in Gale Crater, Mars, to study sands there from December 2015 to February 2016 (from Sol 1182 to Sol 1260; see Figure 1 and http://www.hou.usra.edu/meetings/lpsc2016/pdf/2298.pdf).

Figure 1: Route map of Mars Rover Curiosity from Sol 1172 to Sol 1260



Wider geological context of Bagnold Dune is seen in these two photos:http://mars.nasa.gov/msl/multimedia/images/?ImageID=7640
http://photojournal.jpl.nasa.gov/catalog/PIA16064

During its visit there, Curiosity Rover did a lot of science on Martian sands there, including the morphology, mineralogy, and chemistry of the sands. This article focuses on the rover's discovery of putative ooid sand there. Curiosity rover used its Mars Hand Lens Imager (MAHLI) to acquire a lot of microscopic images of the sands there. Many of the microscopic images show ooids, some of which are marked in the following figures in the result section below.

II. RESULT

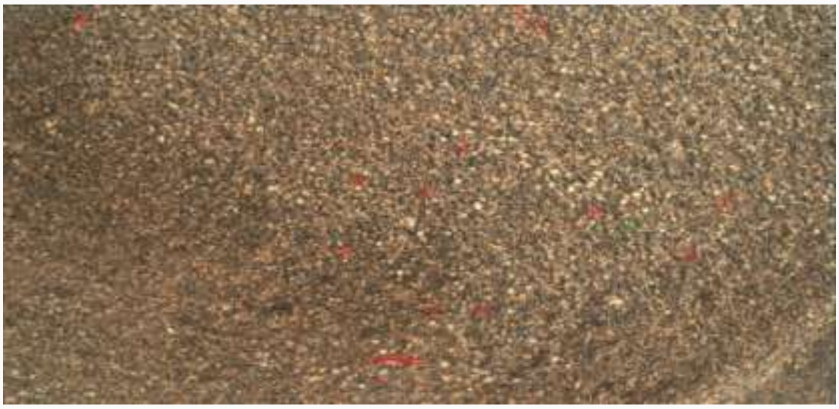
Figure 2: Martian ooids at High Dune

Figure 2was acquired by NASA's Mars rover Curiosity on Dec. 3, 2015 (Sol 1182) near High Dune, Gale Crater, Mars. Eight red arrows and 17 yellow lines mark ooids. They are about 0.5 mm in diameter. Scale bar: 2 mm. Image width: ~3.3 cm. Above figure in the largest size:
https://www.flickr.com/photos/fossil_lin/30445874575/sizes/o/
Image Credit: NASA/JPL-Caltech/MSSS
Image source:mars.nasa.gov/msl/multimedia/raw/?rawid=1182MH00036500104...
Location: the left side in http://i.imgur.com/VK79Uz2.jpg
For comparison with ooids of Earth that resemble Martian ooids, see Figure 8 and photos in
http://wretchfossil.blogspot.tw/2016/01/earthly-ooids-for-comparison.html .

Figure 3: Well-preserved ooids at Namib Dune

NASA's Mars Rover Curiosity acquired the above microscopic image (Figure 3) on Jan. 19, 2016 (Sol 1228) at Namib Dune in Bagnold dune field, Gale Crater, Mars. Seventeen red arrows point to well-preserved ooids. The ooidsmeasure about 0.25 mm to 0.5 mm in diameter. Scale bar: 2.2 mm. Image width: ~3.5 cm.
Above figure in the largest size:https://www.flickr.com/photos/fossil_lin/30409147796/sizes/o/
Image Credit: NASA/JPL-Caltech/MSSS
Image source: mars.nasa.gov/msl/multimedia/raw/?rawid=1228MH00016300004...
Context: beside the scoop trench inhttp://mars.jpl.nasa.gov/msl/multimedia/images/?ImageID=7658

Figure 4: Well-preserved ooids in sieved sample



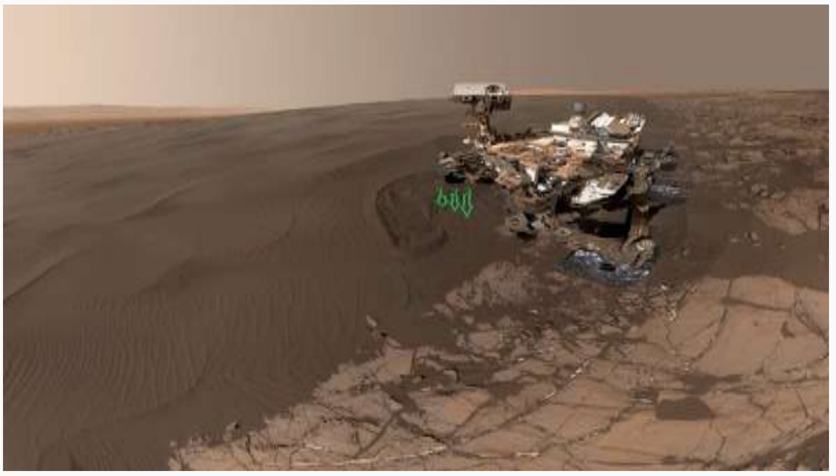
Above figure (Figure 4) in the largest size:https://www.flickr.com/photos/fossil_lin/30445873175/sizes/o/
NASA’s Mars Rover Curiosity acquired the above microscopic image on Jan. 19, 2016 (Sol 1228) at Namib Dune in Bagnold dune field, Gale Crater, Mars. Twelve red arrows point to well-preserved ooids. These ooids measure 0.2 mm to 0.4 mm in diameter. Scale bar: 1.8 mm. Image width: ~2.8 cm. The rover dumped the scooped and sieved particles onto the ground after analyzing similar particles for their chemistry and mineralogy in its laboratory instruments. Image Credit: NASA/JPL-Caltech/MSSS
Image source: mars.nasa.gov/msl/multimedia/raw/rawid=1228MH00017000004...
Context: Dump Pile A in
http://planetary.s3.amazonaws.com/assets/images/4-mars/2016/20160210_MAHLI_1241_Namib_sample_area.jpg
Additional images of well-preserved ooids at Namib Dune:
http://wretchfossil.blogspot.tw/2016/02/really-great-science-at-namib-dune-mars.html
http://wretchfossil.blogspot.tw/2016/02/mars-rover-dumped-ooids-onto-rock.html

Figure 5: Most particles in this photo are ooids.

NASA's Mars Rover Curiosity acquired the above image (Figure 5) with Mars Hand Lens Imager (MAHLI) on Jan. 23, 2016 (Sol 1231) at Namib Dune in Bagnold dune field, Gale Crater, Mars. Most of the particles in this image are eroded ooids. Red lines mark some of the ooids. They measure 0.2 mm to 0.4 mm across. Image width: ~2.8 cm. Largest-sized figure:https://www.flickr.com/photos/fossil_lin/30445875115/sizes/o/
Image Credit: NASA/JPL-Caltech/MSSS
Image source: www.flickr.com/photos/105796482@N04/24483811912/
NASA's image: http://mars.jpl.nasa.gov/msl/multimedia/images/?ImageID=7659
Context: Dump Pile B in

http://planetary.s3.amazonaws.com/assets/images/4-mars/2016/20160210_MAHLI_1241_Namib_sample_area.jpg

Figure 6: Geological Context for Ooids at Namib Dune



Three green arrows point to three spots where Mars Rover Curiosity scooped samples for chemical and mineralogical analyses with onboard instruments SAM and CheMin. After analyses, some samples were dumped onto ground and imaged with Mars Hand Lens Imager. The material imaged in Figures 3, 4, and 5 are from arrow 1 (Figures4 & 5) and arrow 2 (Figure 3). Image Credit: NASA/JPL-Caltech/MSSS
NASA's full-sized image with description: http://mars.jpl.nasa.gov/msl/multimedia/images/?ImageID=7658

Figure 7: Microbes bored holes in these ooids.

Microbes of Earth often bore holes in ooids (Ref. 1, notes 1, 2, 3). Microbes on Mars did the same thing in this figure (Figure 7), which is the same as Figure 2 above. In the red circles are Martian ooids with holes bored by Martian microbes. Such borings prove indirectly the existence of microbes. Image width: ~3.3 cm. Largest-sized figure: https://www.flickr.com/photos/fossil_lin/24749890260/sizes/o/
Context: the left side in http://i.imgur.com/VK79Uz2.jpg
Image Credit: NASA/JPL-Caltech/MSSS Image source:
http://mars.nasa.gov/msl/multimedia/raw/?rawid=1182MH0003650010402637C00_DXXX&s=1182
More evidence for microbial borings: http://wretchfossil.blogspot.tw/2016/04/more-martian-microbes-boring-holes-in.html

Note 1: "The ooids have the same pattern of microboring alteration across the region. The surface and outer cortex of the ooids are punctuated with unfilled microborings, whereas the inner cortex contains two morphologies of aragonite cement filling the microborings." (quoted from the abstract of article in Ref. 1)
Note 2: "Examination of such micritic ooids by scanning electron microscopy often shows evidence of

microbial borings later filled by fine cement.” (quoted from Wikipedia article on ooids)
Note 3: Example of Earthly microbes boring holes in ooids:
http://wretchfossil.blogspot.tw/2016/09/microbial-borings-differentiate-ooids.html

Figure 8: Earthly ooids identified during field trip

Original description: "Mega ooids! Dave's finger for scale." The above photo (Figure 8) shows ooids in China Ranch, California, USA. Red lines in the photo mark ooids that have been eroded into hemispheres. Image source: the last fifth photo in http://daveandiztakeonthewest.blogspot.tw/2012/11/china-ranch-and-stretchoween.html

Figure 9: These spheres differ from ooid spheres.

Figure 9 shows spheres that are different from ooids. Original description: "The Utah concretions shown on the left range in diameter from one twenty-fifth of an inch to 2 inches (1 mm to 50 mm), while the Martian versions on the right all measure less than one-fifth of an inch (5 mm) in diameter. (Scale of photos is different.)" (Quoted from http://www.innovations-report.com/html/reports/earth-sciences/report-30313.html)

Image source: http://www.bev.ba/MOMARAFO/ET/krater/blueberries/usa_stone_balls1.html

Figure 10: Eroded Martian ooids expose characteristic interior.

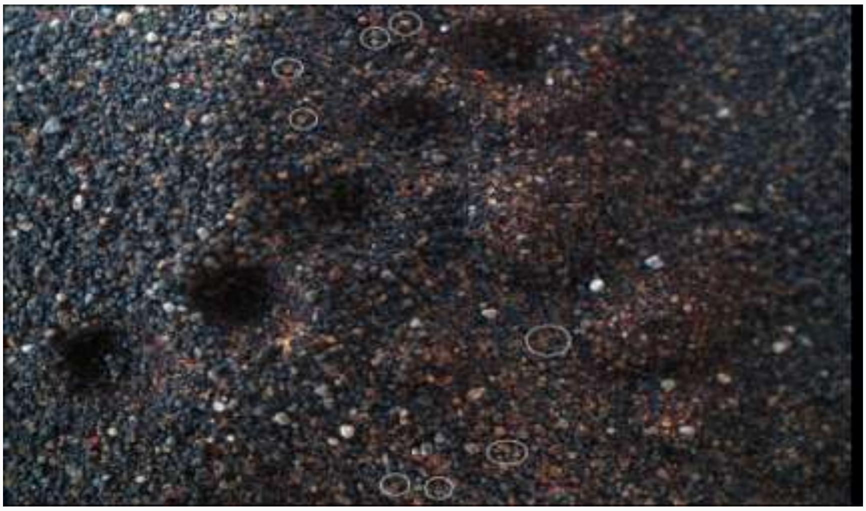


Figure 10is a microscopic image taken at Namib Dune in Bagnold dune field, Gale Crater, Mars. In the white circles are ooids that have been eroded into hemispheres. Red arrows point to nucleus of ooids. The ooid at top left exposes its concentric layers and nucleus. The hemispheres measure 0.2 mm to 0.4 mm across. Scale bar: 1.6 mm. Image width: ~2.7 cm. For comparison with Earthly ooids that have been eroded into hemispheres, see Figure 8 above. Above figure in the largest size: https://www.flickr.com/photos/fossil_lin/30445874495/sizes/o/
Above image is enlarged from https://www.flickr.com/photos/lunexit/24626790060/in/dateposted/
Image Credit: NASA/JPL-Caltech/MSSS/2di7 & titanio44 NASA's original raw image:
http://mars.nasa.gov/msl/multimedia/raw/?rawid=1242MH0005620020403663C00_DXXX&s=1242 (flipped 180 degrees into the above image)
History of the material: from scoop 2 in http://planetary.s3.amazonaws.com/assets/images/4-mars/2016/20160210_MAHLI_1241_Namib_sample_area.jpg,
then transported to Dump Pile D in the same photo.
See additional image of nuclei in Martian ooids:http://wretchfossil.blogspot.tw/2016/10/nucleus-of-ooids-on-mars.html

III. DISCUSSION

In paragraphs A to E below, this article discusses putative ooids discovered on Mars and their possible formation by microorganisms.

A. Are they ooids?

A1. Putative Martian ooids match ooids of Earth. An ooid consists of a nucleus (a fragment of shell, a grain of sand, etc.) around which material is deposited in concentric layers to form roughly spherical grains. A website named Sandatlas has the following webpage for 20 types of sand on Earth: http://www.sandatlas.org/sand-types/ Of the 20 types of sand on Earth, only ooid sand matches the material described in Figures 2 to 5, because those Martian ooids are unique for their combination of spherical shape, similar size of 0.2 mm to 0.5 mm in diameter, and various colors that include white, yellow translucent, green, grey, and yellow. These features can be seen by comparing Figures 2 to 5 with the 20 types of sand on Earth. The combination of these features is also seen in nearly every Focus Merge Data Product at

http://mars.nasa.gov/msl/multimedia/raw/?s=1231&camera=MAHLI
and http://mars.nasa.gov/msl/multimedia/raw/?s=1228&camera=MAHLI

Such shape, size, and color are characteristic of ooid sand.

A2. Putative Martian ooid sand is seen not only at High Dune (Figure 2), Namib Dune (Figures 3, 4, 5), but also seen at many other places in Gale Crater(see http://wretchfossil.blogspot.tw/2016/06/numerous-martian-microbes-produced.html). The environment of Gale Crater over 3.5 billion years ago was a freshwater lake near the Martian equator (see http://authors.library.caltech.edu/60940/). Such concentration, distribution and environment fit those of ooid sand on Earth. Regarding geological context of Martian ooids, Martian wind had blown the ooids in the above figures away from the site where they were originally formed (see third paragraphinhttp://mars.jpl.nasa.gov/msl/multimedia/images/?ImageID=7658). Anyway, geologists do not need geological context in order to correctly identify ooids (see Figure 8).

A3. Ooid spheres differ from other kinds of spheres in sizes, colors, and internal structures. Ooids of Earth are mostly 0.25 mm to 1 mm in diameter (note 1). Martian ooids at Bagnold Dune measure 0.2 mm to 0.5 mm in diameter (Figures 2 to 5).However, "On Mars, most of the hematite rocks ("blueberries") are about 0.16 inches (4 millimeters) in diameter, and no larger than 0.24 inches (6.2 millimeters). By contrast, Earth spherules exhibit a large range of sizes, not limited to only a quarter of an inch." (Quoted from the ninth paragraph in http://news.nationalgeographic.com/news/2014/02/140224-mars-blueberries-water-meteorite-space-science/) .The colors of Martian ooids include white, yellow translucent, green, grey, and yellow as shown in figures above. Other kinds of spheres do not show all of these colors.

Regarding internal structures, ooids contain nucleus and concentric layers (Figure 10), which are not often seen in other kinds of spheres. Ooids are not "impact spherules", because no mechanisms allow meteorite impacts to form spherules with nucleus and concentric layers.

In view of the above, yes, they are ooids.

Note 1: See the third paragraph inhttps://en.wikibooks.org/wiki/Historical_Geology/Ooids_and_oolite
and the first paragraph in http://www.sandatlas.org/ooid-sand/.

B. Were the Martian ooids formed by microbes?

Regarding the formation of ooids, there are non-biological hypotheses, in which ooids get their spherical shape owing to highly agitated water (Ref. 3), such as sea waves pounding on the beaches, that rolls the ooids into spherical shape. However, there is no highly agitated water in lakes. The spherical Martian ooids at Bagnold Dune are unlikely to have been formed by the non-biological mechanisms, because the Martian ooids are in a former lake with no trace of a river at the discovery sites (Figure 6). On the other hand, there are ample evidences for biological formation of ooids. Some of the evidences are listed below in B1, B2, and Ref. 4 to Ref. 15. In view of the above and the microbial borings in Martian ooids (Figure 7), the Martian ooids should have been formed by microbes.

B1. Microbes of Earth form ooids in freshwater lake. Evidence: "Here, we show that photosynthetic microbes not only enhance early carbonate precipitation around the ooid nucleus but also control the formation of the entire cortex in freshwater ooids from Lake Geneva, Switzerland." (Quoted from the abstract of article in Ref. 4: "Going nano: A new step toward understanding the processes governing freshwater ooid formation", displayed at http://geology.gsapubs.org/content/40/6/547.abstract)

The water in Gale Crater of Mars was once fresh water in a lake as mentioned in paragraph A2 above.

B2. Recent research confirms that microbes of Earth form ooids in seawater, as reported in the abstract of Ref. 5: http://www.hou.usra.edu/meetings/abscicon2015/pdf/7317.pdf

More evidences for microbes forming ooids are listed in Ref. 6 to Ref. 15 below.

C. Ooids Prove Microbial Activities.

Microbes of Earth bore holes in ooids and Martian microbes did the same thing (see Figure 7). Microbial borings in Figure 7 prove indirectly the existence of Martian microbes. Ooids are not only formed by microbes (see paragraph B) but also contain high organic matter content (Ref. 5).

D. Can the ooids and microbes be contaminants?

There is no meteorite near the sites where the Martian ooids are found (Figure 6). The ooids are individual isolated particles, unattached to any rock or meteorite. Plentiful is the amount of Martian ooids, eroded ones included (Figure 10). Martian ooids account for considerable portions of particles in the above figures. For reasons listed below, the ooids and the microbes should be indigenous, not contaminants from meteorites or other planets:

1. There is no meteorite near the ooid sites;

2. Even if there were meteorites somewhere, meteorites have never been proven to contain ooids or living microbes;

3. Gale Crater of Mars has many other places that produce countless ooids. Some of the ooids are still embedded in rocks and many others were drilled out of rocks in 2016. For examples:
http://wretchfossil.blogspot.tw/2016/06/numerous-martian-microbes-produced.html

E. Are chemistry and mineralogy necessary for identifying ooids?

Geologists usually identify ooids with visual observation without any instrument (see Figure 8).

Instruments can analyze chemical elements, molecules, mineral types and complex organics of ooids. Results from chemical or mineralogical analyses are helpful but not necessary for identifying ooids when morphological evidence is clear (see figures above). Because the Martian sands are mixtures of different types of sands blown there by wind, ooids sometimes may not be included in some samples analyzed by the rover's laboratory instruments CheMin and SAM. Ooids are usually 0.25 mm to 1 mm in diameter, so they sometimes may not pass the sieve holes to get into SAM or CheMin. Like wood, ooids can also be petrified after a long time (see https://en.wikipedia.org/wiki/Petrifactionand http://archives.datapages.com/data/bulletns/197173/data/pg/0056/0003/0600/0626a.htm).In those cases, no detection of carbonates (CO3) does not mean no ooids at the Bagnold Dune. Conversely, if carbonate is found, the molecule may have nothing to do with life. If minerals of aragonite and calcite are found, they may have nothing to do with life, either, when sample size is not large enough. So, chemical or mineralogical results themselves are not definitive for identifying ooids. Even if laboratory results contain the chemistry and mineralogy of ooids, such results may not be interpreted as coming from ooids (for example, see Fig.1 in http://aem.asm.org/content/68/8/3663/F1.expansion.html). Ooids possess complex chemistry. They contain high organic matter content (Ref. 5) and non-unique inorganic molecules (CO3, etc.). Lastly, Curiosity rover has no means by which to link sample chemistry or mineralogy to morphology of sand grains. On the other hand, ooids possess unique morphology and unique internal structures of concentric layers and nucleus. So, visual observation by experienced people is necessary and sufficient in identifying ooids.

IV. CONCLUSION

NASA's Mars Rover Curiosity discovered plentiful indigenous spherical ooids at High Dune and Namib Dune in Bagnold dune field, Gale Crater, Mars. The Martian ooids measure about 0.2 mm to 0.5 mm in diameter. Colors of the Martian ooids are various, including white, yellow translucent, green, grey, and yellow. The Martian ooids should have been formed by microbes, because ooids of Earth have recently been found to be formed by microbes and microbial borings are found in ooids of Earth and of Mars. The Martian ooids are unlikely to have been formed by non-biological mechanisms, because there was no highly agitated water at the discovery sites.

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