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Life on Mars: Colonies of Photosynthesizing Mushrooms in Eagle Crater? The Hematite Hypothesis Refuted

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Abstract

Throughout its mission at Eagle Crater, Meridiani Planum, the rover Opportunity photographed thousands of mushroom-lichen-like formations with thin stalks and spherical caps, clustered together in colonies attached to and jutting outward from the tops and sides of rocks. Those on top-sides were often collectively oriented, via their caps and stalks, in a similar upward-angled direction as is typical of photosynthesizing organisms. The detection of seasonal increases and replenishment of Martian atmospheric oxygen supports this latter interpretation and parallels seasonal photosynthetic activity and biologically-induced oxygen fluctuations on Earth. Twelve "puffball" fungal-shaped Meridiani Planum spherical specimens were also photographed emerging from beneath the soil and an additional eleven increased in size over a three-day period in the absence of winds which may have contributed to these observations. Growth and the collective skyward orientation of these mushroom and fungus-like specimens are indications of behavioral biology; though it is impossible to determine if they are alive without direct examination. Reports claiming these Eagle Crater spheres consist of hematite are reviewed and found to be based on inference as the instruments employed were not hematite specific. The hematite-research group targeted oblong rocks which were mischaracterized as spheres, and selectively eliminated spectra from panoramic images until what remained was interpreted to resemble spectral signatures of terrestrial hematite photographed in a laboratory, when it was a "poor fit." The Eagle Crater environment was never conducive to creating hematite and the spherical hematite hypothesis is refuted. By contrast, lichens and fungi survive in Mars-like analog environments. There are no abiogenic processes that can explain the mushroom-morphology, size, colors and orientation and growth of, and there are no terrestrial geological formations which resemble these mushroom-lichen-shaped specimens. Although the authors have not proven these are living organisms, the evidence supports the hypothesis that mushrooms, algae, lichens, fungi, and related organisms may have colonized the Red Planet and may be engaged in photosynthetic activity and oxygen production on Mars.

Key Words: Lichens; Fungi; Algae; Mushrooms; Eagle Crater; Life on Mars; Astrobiology; Extremophiles; Mars Simulated Environments; Water on Mars; Hematite; Oxygen, Atmosphere; Photosynthesis; Meteors

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I. Mushroom-Lichens - Oxygen on Mars: The Hematite Hypothesis Refuted

During the first 100 days of its mission in various locations in Eagle Crater (Meridiani Planum), Mars, the rover Opportunity photographed thousands of mushroom-shaped, lichen-like specimens, with features that include stems and bulbous caps, a sample of which are presented here (Figures 1-9). These specimens are attached by thin stalks to the sides and tops of rocks, and those top-side are often collectively oriented in a similar upward-angled direction, jutting above these rocks, as might be expected of colonies of organisms engaged in photosynthesis. Moreover, in subsequent photographs, some specimens on the top-sides appear to bend and arch downward (Figure 9). Those on the sides and some on the tops of these rocks or upon the soil were often oriented horizontally or were bent downward as if due to the pull of gravity on their top-heavy bulbous caps.

There are no terrestrial analogs or abiogenic or weathering processes which can sculpt high density masses of mushroom-shapes with thin stalks and bulbous caps out of rock, salt, or sand, and which orient skyward, above their substrates, in the same or similar upward angled direction—as documented by an extensive abiotic-image search, using relevant key words (see Methods). In addition, weathering and winds would be expected to destroy not sculp these specimens if they were abiogenic.

Mars is often buffeted by powerful winds, and is seismically active (Banerdt et al. 2020), whereas these thin stems are an estimated 1-2 mm in diameter and up to 6 mm in length with top-heavy spherical caps. If consisting of sand, minerals or salt, then powerful winds, Mars-quakes, meteor strikes, or the turbulence created by Opportunity's wheels or drill (See Figure 3) would cause these thin stalks to fracture and break and these bulbous caps to tumble to the surface. Instead, they have remained standing, and are oriented upward, which suggests they recently developed and are in a state of continual renewal and engaged in photosynthesis. In favor of this hypothesis, the authors provide photographic evidence of 23 spherical specimens, photographed in Meridiani Planum, 12 of which emerged from beneath the soil and 11 which increased significantly in size over a three-day period (Figure 10).

Furthermore, a team of 14 established experts in astrobiology, astrophysics, biophysics, geobiology, microbiology, lichenology, phycology, botany, and mycology have identified specimens *resembling* terrestrial algae, lichens, fungi, and mushrooms in the Gale Crater (Joseph et al. 2020a), also located near the equator. Also observed were what appear to be open-cone-like gas-bubble vents--associated with photosynthesis-oxygen respiration (Bengtson et al. 2009; Sallstedt et al. 2018)--and which were photographed adjacent to mushroom and lichen-like surface features (Joseph et al. 2020a).

Oxygen has also been detected in the atmosphere and within soil samples on Mars (Leshin et al. 2013; Ming et al. 2014; Rahmati et al. 2015; Sutter et al. 2017; Valeille et al. 2010). Although a variety of hypothetical abiogenic scenarios have been proposed which "could have contributed.... could have contributed... could contribute... could be a candidate..." (Hogancamp et al. 2018) for the generation of Martian oxygen "such as abiotic photosynthesis" (Franz et al. 2020) it is well established that the primary source of oxygen, on Earth, is via the photosynthetic activity of cyanobacteria (blue-green algae) and water living and land-based plants (Canfield 2014; Hall and Rao, 1986) including lichens (Vinyard et al. 2018; ted Veldhuis et al. 2020) which are fungal-algae composite organisms. Hence, there is substantial evidence of oxygen in the atmosphere and soil of Mars whereas surface features which resemble oxygen-gas vents adjacent to lichen-like formations have been observed in Gale Crater (Joseph et al. 2020a), and as detailed in this report, vast colonies of lichen-like specimens possibly engaged in photosynthesis have been observed in Eagle Crater and which may be respiring oxygen.

It's been inferred that the spheres of Eagle Crater, and by extension, the vast colonies of lichen-mushroom-sphere-shaped specimens consist of hematite (see Squires et al. 2004). However, a number of investigators have rejected the spherical hematite hypothesis (Burt, et al. 2005; Dass 2017; Joseph 2014; Knauth et al. 2005; Rabb 2018; Small 2015). In a presentation at the Lunar and Planetary Society and paper published in the journal Nature, Burt, Knauth and Woletz (2005) referred to the spherical hematite claims as "inappropriate." According to these scientists the hematite "interpretation for features observed at the Opportunity landing site on Mars contains so many contradictions and problems that an alternative explanation seems necessary.... unlike all known terrestrial concretions... they are uniformly spherical... uniform in their size distribution (concretions have no implicit restrictions as to maximum or minimum size), and uniform in their distribution in the rocks... The frequent analogy to hematitic spheroids is inappropriate" (see also Knauth et al. 2005).

Terrestrial spherical hematite does not have a mushroom-lichen-like shape or a bulbous cap atop an elongated stalk jutting upward from rocks as if engaged in photosynthesis; and which are the defining features of the specimens presented here. Moreover, there is no evidence that the stalked-mushroom-shaped specimens or a single isolated sphere lying loosely atop the soil within Eagle Crater, were individually or selectively examined and analyzed by Opportunity's suite of sampling instruments for the presence of hematite. Instead, individual samples *inferred* to contain hematite consisted of oblong rocks (see Figure 6 in Belle et al. 2004). Claims about hematite were also based on the spectral signatures of false colors (Soderblom et al. 2004), panoramic images, and claims about the averaging of high and low "temperatures" (Klingelhöfer et al. 2004) when the temperature sensors had failed (Glotch and Bandfield 2006); and with spectra selectively eliminated until what remained was interpreted as similar to the spectral signature of hematite photographed in a laboratory (Christensen et al. 2004), when the results were a "poor fit" for hematite and there were significant problems with calibration (Glotch and Banfield, 2006).

As admitted by Glotch and Banfield (2006): "The gradual change of the instrument response function over the course of the mission combined with the failure of temperature sensors on the on-board calibration targets ...necessitated a change in... the instrument calibration... Figure 3b shows the Mini-TES hematite spectrum recovered using a magnetite-derived hematite target spectrum. There is a poor fit to the 450 cm 1band width and position of the emissivity minimum. Additionally, there is a poor fit to the 390 cm 1feature that is present in the test spectrum."

The hematite hypothesis also rests upon the high concentration of iron detected within the soil (Bell et al 2004; Klingelhöfer et al. 2004, Squires et al. 2004). Lichens have high concentrations of iron (Bajpai et al. 2009; Hauck et al. 2007), and many species feed on iron (Bosea et al. 2009; Fredrickson et al. 2008; Gralnick & Hau 2007). The presence of iron does not prove the hematite hypothesis, but instead may provide a substrate for biological proliferation.

Furthermore, the Martian mushroom-shaped spheres atop rocks and upon the soil are a different color and smaller than terrestrial hematite (Bell et al. 2004; Soderblom et al. 2004), averaging 0.6 to 6 mm in size and diameter (Herkenhoff et al., 2004) which is also the characteristic size of a variety of terrestrial lichens (Armstrong 1981, 2017) including the specimens presented here. Nor does terrestrial hematite have a mushroom shape and stem and grow upward and outward from the tops of rocks.

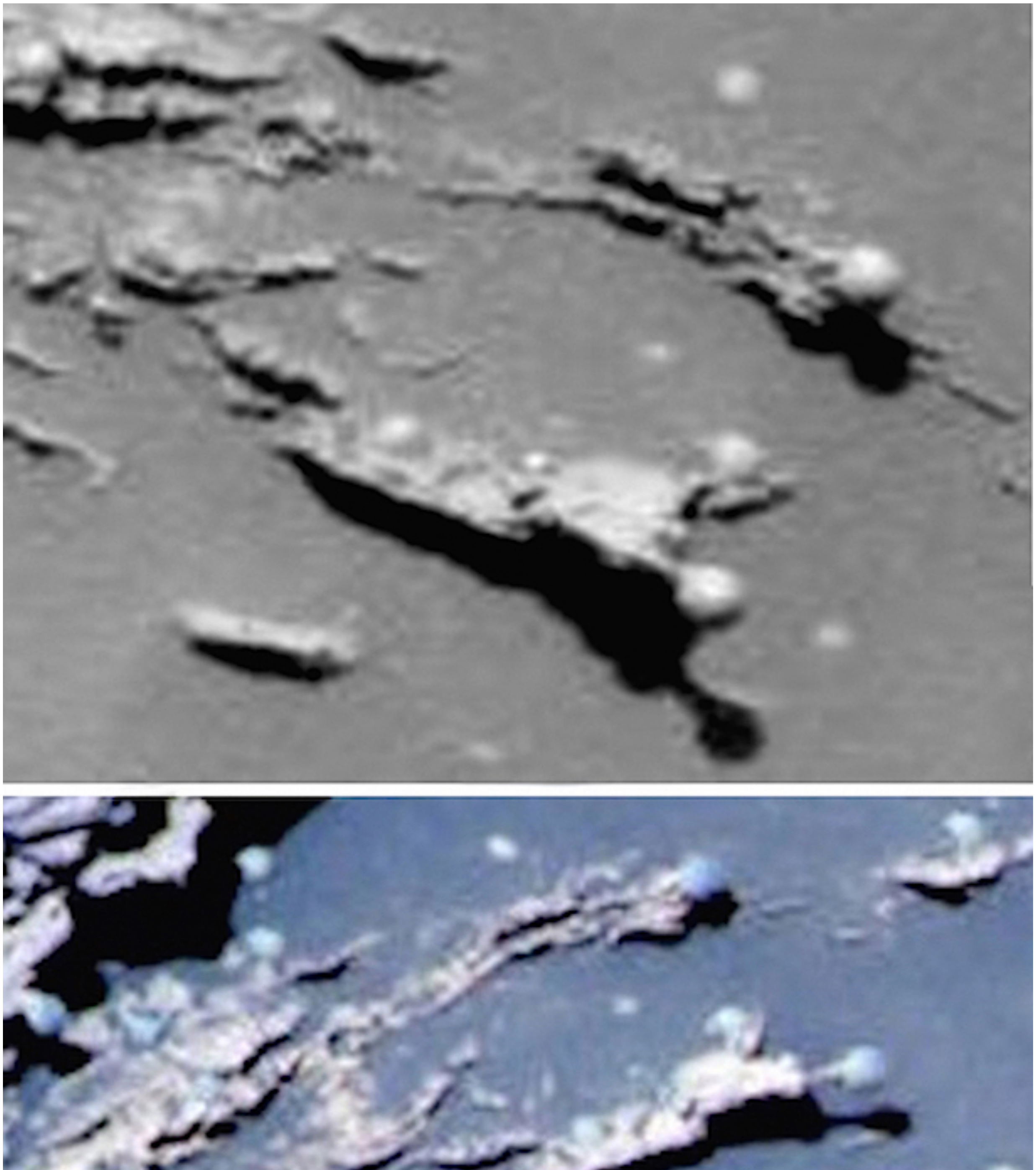

Figure 1. Opportunity - Sol 40 (top) Sol 37 (bottom). Note similar elevated angled orientation of mushroom-like specimens photographed growing on an unknown (fungi-like) substrate above the Martian surface in Eagle Crater. These "mushrooms" are up to 8 mm in length, with stems approximately 1 mm (or less) in width.

Figure 2. Opportunity - Sol 88. These "mushrooms" are up to 8 mm in length, with stems and apothecia approximately 1 mm to 3 mm in width, with what may be bulging hyphae along the rock surface. The bulbous cap may be a spore producing fruiting body. Note "bore hole" (see Figure 3).

Given the colors, size, favored locations, mushroom shapes, thin flexible stalks, large bulbous caps, evidence of growth, flexibility, and movement, and the collectively similar skyward angled-orientation of these colonies as if engaged in photosynthesis (Figures 2, 4-9), coupled with evidence of oxygen most likely produced secondary to photosynthesis, it is reasonable to argue that the specimens presented in this report *may* represent evidence of life on Mars.

II. Methods and Results

The Eagle impact crater is 22 meters in diameter, is likely several billion years in age, and located in a large plain known as Meridiani Planum. The rover Opportunity landed on Mars at 1.95°S 354.47°E, in Eagle Crater on January 25, 2004, 10 meters below the crater's rim. At near equatorial latitude there are about 12.4814 terrestrial hours of sunlight on the first day of summer and 12.2299 hours on the first day of Martian winter. Temperatures are estimated to reach highs of 20°C (68°F) during the summer to lows of -73°C (-99.4°F) at night (see http://quest.nasa.gov/aero/planetary/mars.html).

1. Search of the Eagle Crater Image Data Base for Mushroom-Shaped Spheres

Methods: Throughout the first 100 Sols (Martian days) of its surface mission at Eagle Crater, the rover Opportunity transmitted to Earth several thousand images captured via its Microscopic Imager and Navigation and Panoramic Camera (see https://mars.nasa.gov/mer/gallery/all/opportunity.html). These included photographs of soil, crevices, rocks and thousands of mushroom-shaped and other spherical specimens.

Based on morphology and location, and as determined by the authors, three different types of spherical specimens can be observed; A) Thin stemmed specimens, topped with spherical caps (AKA "Martian mushrooms") which (based on parameters provided by Herkenhoff et al. (2004) and Joseph et al, (2019) appear to be up to 6 mm in diameter, with stems up to 6 mm in length and 1-2 mm in diameter and attached to the tops of rocks jutting skyward and on the sides of rocks oriented horizontally or downward; B) Round and "lemon-shaped" spheres upon the soil surface, some with long stems or short stalks or no discernible stalk (AKA "blue berries") up to 6 mm in diameter; C) Gray spheres embedded within thick wavy layers of what appears to be a calcium-cement-like matrix.

Unfortunately, neither NASA or the Opportunity team in their published reports provided any detailed metrics about these images or the specimens depicted, other than inferences and estimates as to the size of the surface spheres (Herkenhoff et al., 2004), and the estimated size of a few rocks and outcrops. Therefore, it was impossible to precisely determine the exact height, size, orientation, or density of the mushroom-like specimens which are the focus of this report.

Results: Based on surface features, 185 photos, photographed on 36 separate days in different locations, and depicting, collectively, several thousand stemmed-mushroom-shaped and other spherical specimens, were selected for detailed inspection. These 185 photos were enlarged by 300% and visually inspected to identify the presence of clearly discernible mushroom-lichen-like features which included a visible stalk topped with a spherical cap.

Several thousand specimens which resembled mushrooms and that were clustered together and attached via their stems to the tops of rocks, could be viewed via these 185 images which were photographed on Sol 28, 32, 35, 36, 37, 38, 39, 40, 41, 46, 50, 63, 69, 71, 73, 74, 80, 81, 84, 85, 86, 87, 88, 97. It was determined, based on a visual inspection of these photos and parameters provided by NASA, that the abundance of specimens with features similar to mushrooms appeared to be greatest near the top sides of the crater rims facing the rising sun, and lowest in the crater floor.

Thirty photos, photographed on Sol 37, 40, 81, 84, 85 and 88, were determined to depict the most obvious visual evidence of mushroom-lichen-like features. These were subject to additional visual inspection by all the authors of this report and it was noted that these specimens have hollow stalks (Figure 3) typical of stemmed plants and various species of lichen (e.g. *Cladonia squamosa*) and which serve to transport water and nutrients upward from soil and rock and which is distributed to the above ground portions of the organism.

Illustrative examples photographed on Sol 37, 40, 85 and 88 via the rover Opportunity's Navigation and Panoramic Cameras are presented. Mushroom-shaped, lichen-like specimens, attached by stalks to the surface and upon rocks, photographed on Sols 37, 40 were observed to be oriented (pointed) in a similar upward-angled direction. Clusters of several dozen specimens, photographed on Sol 84 and attached by stalks atop a number or rocks, were also found to be directionally oriented at the same or a similar upward angle above these rocks. The same is true of thirty-six specimens photographed on Sol 88 on the topside of a single rock; and collectively, several hundred specimens photographed at various locations on Sol 85 and jutting upward above these rocks, are oriented, depending on location, at a similar skyward angle. These photos have been enlarged by 200% (Sol 37, 40) and 150% (Sol 85, 88). Based on published parameters (Herkenhoff et al., 2004; Joseph et al. 2019), these mushroom-lichen shaped specimens are estimated to range up to 8 mm in height and length.

2. Abiotic Image Search

Methods: To determine if there are any terrestrial abiotic structures which resemble these specimens, a Google and Bing image search was conducted by three of the authors, using A) key words "rocks" or "minerals" or "hematite" or "salt" or "sand" or "weathering" plus "mushroom" or "mushroom shape" or "domed" or "diapir" and B) by inserting Figures 1-2 into the Google "Search by image" function. Lastly, C) a "scholar.google" search was conducted, using the same key words, and the photos/figures from relevant articles examined.

Results: Thousands of pictures of abiotic specimens were visually examined, including photos of salt diapir, hematite, serpentine, shale, and granitoid rock. Not one of these abiotic specimens resembled, in size, shape and form, the mushroom-lichen-like specimens photographed in Eagle Crater. The only terrestrial analogs for the specimens presented in this report are the fruiting bodies of mushrooms and lichens; i.e. living organisms.

3. Search for Life, Wind, Dust Storms, Dust Devils: Sol 1145 to 1148

Methods: It has been previously reported that 15 specimens similar to "puffballs" (AKA "blue berries") have been photographed by the rover Opportunity in Meridiani Planum, increasing in size and emerging from beneath the coarse-grained rocky-sandy surface as based on comparisons of Sol 1145 and Sol 1148 (Joseph et al. 2019). Those authors interpreted this as evidence of biological growth but could not completely rule out wind. It's been estimated that the movement of coarse-grained Martian soil requires wind velocities of 70 m/s at least one m above the surface, but that velocities of 40 m/s may "occasionally" displace coarse-grained sand and soil (Jerolmack et al. 2006). Although on Earth, 20 km/h winds can displace fine grained sand (Kidron and Zohar, 2014) these specimens are buried in coarse-grained rocky soil. Therefore, it's possible that pronged winds with velocities of 40 to 70 m/s may have uncovered these specimens and contributed to what appears to be growth.

To verify and replicate the observations of Joseph and colleagues (2019) and to rule out wind or other abiotic contributions to these observations, three of the authors searched the Opportunity Raw images data base for evidence of wind or soil displacement. All photographs from the Panoramic Camera (Sol 1145, 1146, 1147, 1148), the Front Hazcam (Sols 1145, 1146, 1148), Navigation Camera (Sol

1146) and Microscopic Imager (Sols 1145, 1148) were visually examined for evidence of wind-blown dust in the air, dust devils, dust storms, or wind-driven soil displacement or buildup. NASA's data base was also reviewed and a search was conducted for reports of any wind in Meridiani Planum on these dates.

Results: Comparing Microscopic Imager photographs on Sols 1145, 1148, reveals that 12 specimens emerged from beneath the coarse-grained soil as they were not visible on Sol 1145; and that an additional 11 specimens increased in size. Therefore, in comparison to the 15 identified by Joseph et al (2019) an additional 8 specimens were observed to either emerge from beneath the soil or increase in size, for a total of 23. All surrounding soil in Sol 1145 and 1148 appears to be coarse (vs fine) grained with no evidence of displacement or buildup.

No winds or dust storms in Meridiani Planum were reported by NASA on Sols 1145, 1146, 1147, or 1148. Likewise, as based on a visual examination of all photos between Sol 1145 and 1148 there is no evidence or comparative evidence of wind, dust storms, or dust devils or the accumulation or displacement of dirt, sand, or dust, or soil buildup or "filling in" and no evidence that soil is higher or lower on one side of any of the specimens as might be expected if subject to powerful directional winds.

III. Discussion

4. Martian Mushrooms, and Eagle Crater

Over forty experts have previously identified, by name, "puffballs," "mushrooms" and "lichens" that had been photographed in the Eagle Crater (Joseph 2016). In this report the authors have identified and presented over 200 specimens, a sample of thousands photographed within the Eagle Crater, which closely resemble mushroom-like organisms and lichens. These specimens range from 3 to 8 mm in length and diameter, have thin hollow stalks and bulbous caps; and colonies, including those on adjacent rocks, are angled upward, above these rocks via their stems, in a similar direction which is typical of photosynthesizing organisms. It was also noted that the density of mushroom-shaped spheres appears to be greatest near the top side of the crater rims facing the rising sun, and lowest in the crater floor as based on Sol-photograph dates as related to parameters provided by NASA. Moreover, typical of numerous stemmed/stalked plants and lichens these mushroom-like-stalks are hollow (Figure 3) and tubular; a finding incompatible with any abiotic explanation (e.g. hematite, salt, minerals), but which in terrestrial plants serves to draw up, distribute and store water and nutrients obtained from the soil.

In 1978, Levin, Straat and Benton reported "green patches" photographed during the 1976 Mars Viking Missions, which they believed might be lichens. The Viking Labeled Release experiments also detected activity consistent with biology at two locations, Utopia Planitia and Chryse Planitia, over 4,000 miles apart (Levin & Straat 1976, 1977); possibly that of lichens and algae (Levin et al. 1978). Condensation and sublimation of ground frost (Wall, 1981) and water within regolith was also detected via the Viking's suite of instruments (Biemann et al., 1977).

Joseph and colleagues (2020a) have also identified numerous specimens resembling green and blue-green algae, lichens, and open-cone-gas vents, photographed by the rover Curiosity in Gale Crater. This crater also appears to be subject to varying degrees of moisture and displays evidence of water pathways and a history of being filled with water.

The lichen-like species presented here were photographed by the rover Opportunity in Eagle Crater, located in Meridiani Planum which is 2 degrees south of the Martian equator in an area known as Terra Meridiani. Gale crater is also located near the equator. The equatorial region has a warmer climate than Utopia and Chryse Planitia perhaps reaching highs of 20°C (68°F) during the day to lows of -73°C (-99.4°F) at night.

It's been hypothesized that Eagle Crater has been repeatedly exposed to flowing surface water and precipitation (Bell et al. 2004; Herkenhoff et al. 2004; Squyres et al. 2004). As theorized by Squyres and colleagues (2004): liquid water may have been abundant at Meridiani Planum which "suggests that conditions were suitable for biological activity for a period of time in Martian history." Thus, we see evidence of what may be Meridiani Planum stromatolites fashioned by cyanobacteria perhaps billions of years ago (Rizzo and Cantasano, 2009). In addition to bacteria, Squyres et al (2004) suggests that Eagle Crater could have been colonized by eukaryotic "filamentous microorganisms." The mushroom-shaped lichen-like formations presented in this report also appear to be "filamentous" as some have what may be hyphae extending along and bulging beneath the subsurface and which emerge as thin stalks topped by bulbous caps (Figures 2, 3).

The specimens presented in this report have been previously referred to as "Martian mushrooms" (Joseph 2014) and clearly resemble lichens (Dass, 2017, Joseph 2016, Joseph et al. 2019); though their exact identity is unknown. Lichens are composite life forms and maintain a symbiotic relationship involving fungi (mycobiont) and algae/cyanobacteria (photobiont), the former of which is largely responsible for the lichens' mushroom shape, thallus, and fruiting bodies (Armstrong 1981, 2017, 2019; Armstrong and Bradwell 2010; Brodo et al. 2001). To speculate: the bulbous mushroom-like cap of the specimens presented here, may represent the fruiting body of the lichen whereas the remainder of the lichen inhabits the subsurface for which there is considerable evidence in the form of what may be bulging hyphae which snakes just beneath the surface (Figures 2-3).

Many of the mushroom-shaped specimens appear to lack a crustose thallus which is a lichen characteristic (Armstrong, 2017, 2019; Armstrong and Bradwell 2010; Kidron 2019). Martian organisms, however, would be expected to adapt and evolve in response to the unique Martian environment. The crustose thallus could be endolithic or buried in the surface layers of rock and soil (see Figures 1-3).

On the other hand, in contrast to the green-algae-like specimens of Gale Crater (Joseph et al. 2020a) and the observation of Levin et al (1978) who reported "green patches" in Viking photographs, algae-like specimens have not yet been observed in Eagle Crater or identified in Meridiani Planum. However, Figure 1(A) in Soderblom et al. (2004) depicts pools of "blue" completely surrounded by masses of compacted "green" sphericles on the floor of the Eagle Crater. If these were true colors, the obvious interpretation is the "blue" represents pools of water and the surrounding layers of "green" are green algae.

There is every reason to suspect that Eagle Crater, where these mushrooms features were photographed, may be periodically exposed to ground water and water-mist precipitation. There are indications that water on Mars may be stored in underground aquifers (Malin and Edgett 2000), and sequestered in Martian rocks, hydrated minerals, or locked within frozen ground (Plaut et al., 2007; Mustard et al., 2012; Kieffer et al., 1976; Farmer et al., 1977). Martian rocks and regolith, which are porous with crevices, cracks, and voids, also appear to contain water ice (Biemann et al., 1977; Mellon and Phillips 2001).

Figure 3. Opportunity - Sol 88. Bore hole drilled by the Opportunity's rotary blade (RAT) into the overlying rock. All but one of the "mushrooms" (lower left beneath the red circle) were destroyed by the RAT, except for their hollow stems/stalks 2-3 mm beneath the surface of the rock (Note center of red circle). The "mushroom" at the lower left of the circle protrudes from the surface (note shadow) indicating it was flexible and was pushed aside by the drill or it grew after the bore hole was fashioned. These hollow stems/stalks are a common feature of numerous species of stalked/stemmed plants and lichens and which serves to transport water and nutrients upward from rock and soil.

5. Sources of Water

Depending on seasonal-orbital and temperature variations, water frozen within top soils, rocks, and regolith, may melt. Humidity and rising temperatures may also increase subsurface/surface pressures thereby forcing ice to liquify and water to pool upon the surface (Mellon and Phillips 2001) as depicted in figure 1(A) of Soderblom et al. (2004) which shows pools of blue surrounded by green on the floor of Eagle Crater. Surface water would then seep back beneath the surface, or turn to mist or freeze and for which there is documented evidence in the wheel wells of the rover Curiosity; i.e. frozen pure water ice (Joseph et al, 2020b).

Four major reservoirs of Martian water have also been identified, based on data provided by the orbital Atmospheric Chemistry Suite, and the Mars Science Laboratory and it's Environmental Monitoring Station, i.e. in the northern and south poles (Kieffer et al., 1976; Farmer et al., 1977), in Martian clouds (Spinrad et al. 1963; Masursky et al., 1972; Whiteway et al., 2009; Moores et al. 2015) which likely consist largely of water as do the clouds of Earth (Pruppacher and Klett 2010; Hu et al. 2010); within atmospheric vapors (Farmer et al., 1977; Korablev et al., 2001; Smith et al., 2001) and in the upper atmosphere which is subject to "large, rapid seasonal intrusions of water" (Fedorova et al. 2020).

For example, Fedorova and colleagues (2020)--employing three infrared spectrometers which are part of the Atmospheric Chemistry Suite on the ExoMars Trace Gas Orbiter spacecraft-- examined atmospheric spectra between 15 to 100 km above the surface to analyze water vapor profiles. During the Spring and Summer, water levels increased to supersaturation and with thick ice clouds forming 15 to 40 km above and supersaturated layers 80 to 100 km and intermittently 50 to 60 km above the southern and northern hemisphere. They determined that "large portions of the atmosphere are in a state of supersaturation" thus replicating the findings of other scientists (Maltagliati et al. 2011; Todd et al. 2017)

Columns of water vapor have been observed every spring and summer from orbit (Read and Lewis, 2004; Smith, 2004; Todd et al. 2017), and which are transported from the north toward the equator (and thus to Eagle Crater) by southerly winds (Harri et al. 2014). Moreover, these vapors have a precipitable water content of at least 10–15 pr μm (Smith, 2004), and depending on humidity (Harri et al. 2014) appear to reach saturation in the early morning hours thereby inducing a mist-like precipitation which may provide moisture to organisms dwelling in Eagle Crater.

Moreover, the stems of these "Martian mushrooms" appear to be hollow (Figure 3)—a feature typical of numerous species of plant and lichen. These hollow tubes serve to draw up water and nutrients from the underlying substrate, and which is then stored or distributed to the remainder of the organism. Hence, even during periods of diminished moisture, water may be stored within these tubes, or drawn up from within the regolith or soil, with the heat of the organism serving to melt any adjacent frozen-water supplies.

6. Photosynthesis and Seasonal Fluctuations in Martian Oxygen

Cyanobacteria (algae) produce oxygen via photosynthesis (Graham et al. 2016). It is believed that early in the course of evolution, Earthly eukaryotes acquired, via horizontal gene transfer, cyanobacterial genes, which triggered the development of pigmented plastids and organells that made it possible for plants and algae-symbiotes to evolve, engage in photosynthesis and secrete oxygen as a waste product (Buick 1992; Holland 2006), thereby fashioning Earth's oxygen atmosphere.

Molecular oxygen in the atmosphere of Mars was first detected by the Herschel Space Observatory in 2010 (Hartogh et al. 2010). Franz and colleagues (2017) have estimated that the mean volume of Martian atmospheric oxygen is 0.174%. This is similar to the levels of oxygen, on Earth, during the Paleoproterozoic "Great Oxidation Event" ~2.2 to 2.0 bya (Bekker et al. 2004; Farquhar et al. 2011). It was during this "Event" when atmospheric oxygen rose to >1% of modern levels on Earth, an accumulative byproduct of oxygenic photosynthesis and the respiration of oxygen by cyanobacteria (blue-green algae) -- and related species (Buick 2008; Nisbett and Nisbett 2008; Olson 2006)--which may have first appeared on Earth 3.8 bya (Uyeda et al. 2016).

Initially, however, photosynthesis was anoxygenic, with H_2 and iron being employed as oxygen acceptors (Eigenbrode and Freeman 2006; Olson 2006; Sleep and Bird 2008). Lichens have high concentrations of iron (Bajpai et al. 2009; Hauck et al. 2007) and iron is abundant on Mars. Iron and H_2, therefore, may have and may still serve as receptors for Martian organisms engaged in photosynthesis.

As cyanobacteria and related photosynthesizing Earthly species proliferated, they formed symbiotic relationships and oxygen respired slowly built up in the oceans, soil and atmosphere culminating in the "Great Oxidation Event" and reaching levels comparable to and then surpassing those on modern day Mars.

Lichens produce oxygen via photosynthesis (Vinyard et al. 2018; ted Veldhuis et al. 2020). As noted, lichens are a symbiotic organism consisting of at least one green alga or cyanobacterium (photobiont) which makes possible oxygen photosynthesis, and at least one fungus (mycobiont), the latter of which is largely responsible for the lichens' thallus, fruiting bodies, mushroom shape, and bulbous cap (Armstrong 2017, 2019; Brodo et al. 2001; Tehler & Wedin, 2008). Molecular analyses, however, indicate that the lichen consortia also include a wide range of bacterial communities within the photobiont zone and on the lichen-surface such as *Sphingomonas, Methylobacterium,* and *Nostoc,* as well as a variety of eukaryotic Rhizaria, Amoebozoa, and Metazoa (Graham et al. 2018). Squires et al (2004) has argued that eukaryotes may have evolved on Mars and features resembling fossilized metazoa have been identified in Gale Crater, though if they are abiotic is unknown (Joseph et al. 2020a). These symbiotic relationships have proven vital in the ability of the lichen to survive life neutralizing and water stressed environments (Armstrong 2017; Margulis and Fester, 1991; Kranner et al. 2008) and which promote mutual metabolism, energy conversion and enhance the respiration of oxygen via photosynthesis.

Measurements of lichen electron transport have demonstrated that O_2 is generated by the alga and consumed internally and any excess is respired, whereas CO_2 is produced by respiration of photosynthetically generated sugars which along with fungal CO_2 are consumed by the alga (ted Veldhuis et al. 2020). More specifically, photosynthesis-produced-oxygen involves the absorption of CO_2, the transfer of multiple electrons, monotonic-OO-bond formation, OH bond cleavage, and the splitting of water molecules (H / O_2) with all excess oxygen released into the soil or atmosphere.

Martian specimens *resembling* lichens have been previously identified in the Gale Crater and Eagle Crater (Joseph et al. 2019, 2020a), including--and as reported here--vast colonies which are collectively oriented and angled skyward similar to terrestrial lichens and plants engaged in photosynthesis. In addition, apertures resembling open-cone-like gas-bubble vents were identified adjacent to the lichen-like specimens observed in Gale Crater (see Joseph et al. 2020a Figures 16, 17) and these apertures are associated with photosynthesis-oxygen respiration (Bengtson et al. 2009; Sallstedt et al. 2018). It is reasonable to assume that these and related species are respiring oxygen; and this would account for oxygen in the atmosphere and soil of Mars (Leshin et al. 2013; Ming et al. 2014; Rahmati et al. 2015; Sutter et al. 2017; Valeille et al.

2010). Almost all oxygen on Earth is produced biologically and the presence of oxygen is an obvious biomarker for life. The same reasoning should apply to Mars.

The amount of oxygen in the Martian atmosphere also shows seasonal variations, increasing by 30% in the Spring and Summer (Trainer et al. 2019). Levels of oxygen in the soil, oceans, and atmosphere of Earth, also vary according to the season and increase during the Spring and Summer due largely to fluctuations in the biological activity of photosynthesizing organisms (Keeling and Shertz, 1992; Kim et al. 2019) and as related to increases in temperature and the availability of water and water vapor condensation and precipitation (Buenning et al. 2012; Keeling and Shertz, 1992). These seasonal fluctuations on Earth parallel the Spring/Summer increases in oxygen, temperature and water availability on Mars (Fedorova et al. 2020; Read and Lewis, 2004; Smith, 2004; Todd et al. 2017; Trainer et al. 2019); and these variations on Mars in turn parallel seasonable increases in biological activity and the respiration of oxygen on Earth.

Given the evidence indicative of photosynthesis-oxygen-gas vents and what appear to be algae and lichens in the Gale Crater (Joseph et al. 2020a), coupled with what appear to be colonies of lichens in the Eagle Crater which are morphologically oriented in a manner similar to photosynthesizing lichens on Earth, it is thus reasonable to that they, and other photosynthesizing organisms dwelling on Mars, contribute to the seasonal variations in Martian oxygen, which in turn is regulated by increases in temperature and water availability. Increases in oxygen by as much as 30% during Spring and Summer is an obvious biomarker.

Although water may be stored within the lichen (depending on species), water content equilibrates with atmospheric conditions such that their photosynthetic activity, respiration and growth is determined by water availability and decreases or increases accordingly (ted Veldhuis et al. 2020). However, lichens easily survive long-term desiccated states. In consequence, lichens can be repeatedly dehydrated without any loss in their ability to engage in photosynthesis and to release oxygen into the atmosphere and surrounding soils once sufficient water is available (Vinyard et al. 2018). Lichens are well adapted to survive and engage in photosynthesis and oxygen production, on Mars.

For example, despite long term exposure to space and Mars-like analog conditions, over 70% of lichen photobionts and 84% of lichen mycobionts showed average viability rates of 71% to 84% respectively (Brandt et al. 2015; Meesen et al. 2014). Additionally, 50-80% of alga and 60-90% of the fungi symbiote demonstrating normal functioning (Brandt et al. 2015) including the ability to engage in photosynthetic activity with minimal impairment (Meesen et al. 2014). The angled-skyward orientation of the mushroom-shaped lichen-like specimens in this report should also be viewed as an indication of viability and evidence of photosynthetic activity thereby account for oxygen in the Martian atmosphere and soil.

Furthermore, Martian atmospheric oxygen and other gasses are believed to continually bleed into space (Jakosky et al. 2019). Oxygen, therefore, not only increases dramatically when the Martian environment is most conducive to biological activity, but oxygen is continually replenished; otherwise there would be no oxygen in the atmosphere or soil.

On Earth O_2 production via biological photosynthesis (Canfield 2014; Hall and Rao, 1986; Vinyard et al. 2018; ted Veldhuis et al. 2020) is the major and primary source of and which constantly replenishes soil, oceanic, and atmospheric oxygen. Hence, it is reasonable to deduce that cyanobacteria, and the Martian lichen-like organisms identified in Gale and Eagle Crater, also produce and replenish atmospheric and surface oxygen and may be responsible for the seasonal variations in oxygen on Mars.

7. Spherical Hematite Hypothesis Refuted

It's been inferred that the spheres of Eagle Crater consist of hematite (Squires et al. 2004). However, a number of investigators have recognized that the hematite hypothesis is not supported by the evidence and is incompatible with the nature of these spheres (Burt, et al. 2005; Dass 2017; Joseph 2014; Knauth et al. 2005; Rabb 2018; Small 2015). Although spheroidal hematite concretions (Moqui Marbles) in the Navajo Sandstone of Utah, USA, have been offered as a possible terrestrial analogue (Chan et al. 2004), the fact is, the Navajo concretions have a wide variety of shapes and sizes and are distributed randomly (Knauth et al. 2005) and none of them are topped with mushroom shapes attached by stems to rocks and/or orient skyward (Joseph et al. 2019).

Moreover, there is no evidence that these mushroom-shaped Martian spheres consist of hematite. Nor is there any evidence of large bodies of water, ancient hot springs or volcanic activity at any time in the past history of Eagle Crater and thus there was no means of producing hematite which requires a boiling liquid or volcanic source at temperatures of at least 900°C in order to form (Anthony et al. 2003; Morel 2013).

In an attempt to circumvent and explain away the fact that the environment of Eagle Crater has never been conducive to the creation of hematite, it has been claimed that under "dry laboratory conditions" "goethite" can be "converted to hematite" at 300°C (Christensen and Ruff, 2004). However, Eagle Crater is not a laboratory and equatorial temperatures, as reported by NASA, seldom exceed of 20°C. The last time surface temperatures in Eagle Crater reached or exceeded 300°C may have been hundreds of millions if not billions of years ago when struck by the meteor which cratered the surface (Knauth et al. 2005).

Although Knauth and colleagues (2005; Burt et al. 2005) did not address the mushroom-shaped formation of Eagle Crater, they proposed that the "blue berries" upon the Martian surface may have been created upon meteor impact. However, obviously, these top-heavy mushroom-shaped specimens attached to rocks by thin stems, could not have been formed millions or even thousands of years ago by any catastrophic or geological-weathering process, as the stems would have long ago crumbled, broken, and, along with their bulbous caps, toppled over due to weathering, wind, and frequent Mars-quakes as the planet is seismically quite active Banerdt et al. 2020). In fact, unlike hematite or formations of minerals or salts, the stems/stalks are hollow (Figure 3) a feature common to stalked/stemmed plants and lichens (see: https://lichens.twinferntech.net/pnw/images/large/Cladonia/squamosa/27758PodetiaInterior.JPG) and which serves to transport water and nutrients from rock and soil.

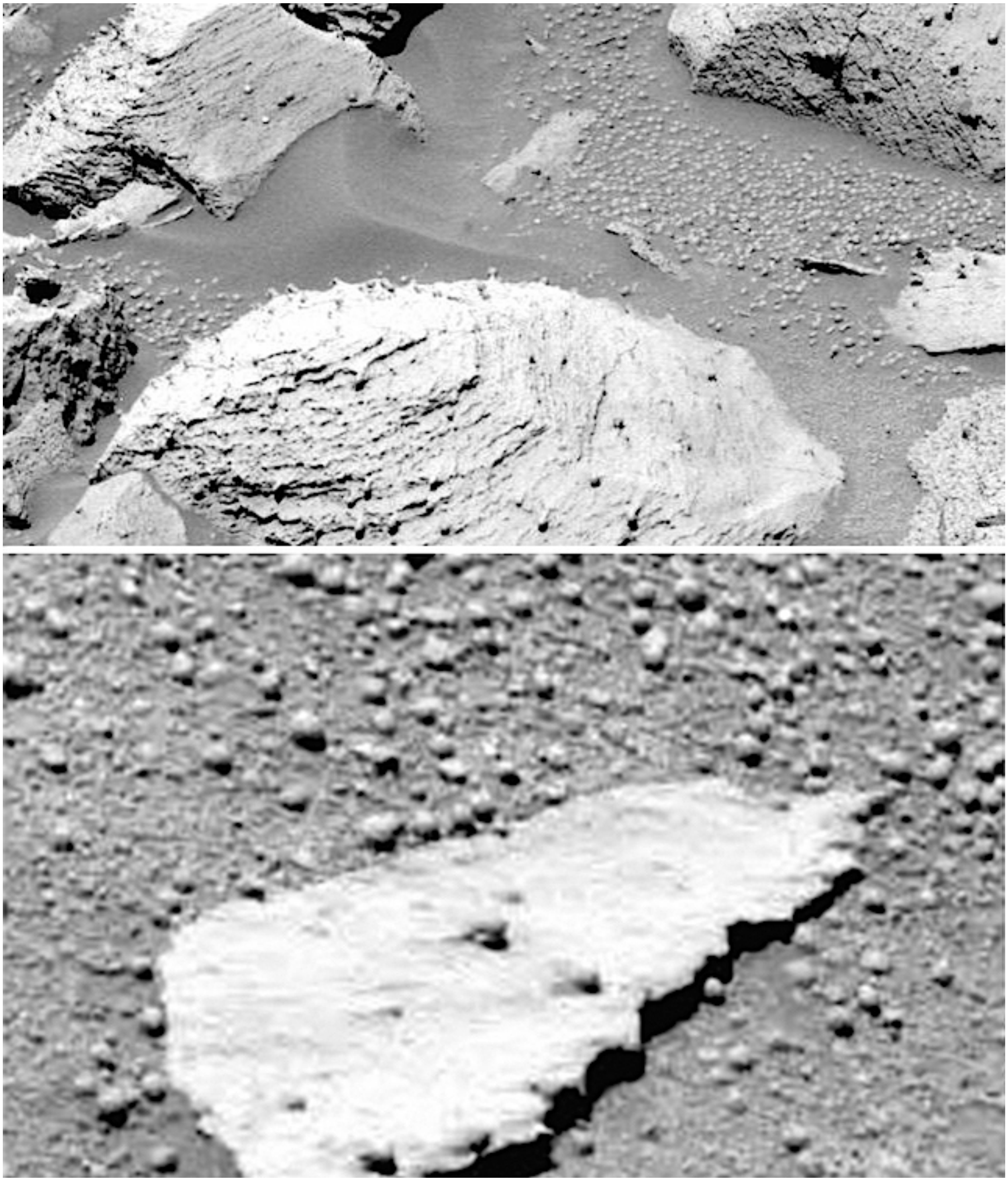

Figure 4. Opportunity - Sol 85. Top photo: 20-cm-wide rock (center, top) with specimens on sides of rocks oriented downward and those on tops of rocks oriented skyward; differential orientations possibly due to access to gravity, and direct sunlight and exposure to vs protection from wind. Bottom photo: sphere-shaped and mushroom-shaped specimens upon the Martian surface and on center-slab of rock, all directed oriented right-ward and perhaps top-heavy with fruiting bodies.

Figure 5. Opportunity - Sol 85. Colonies of lichen-mushroom-like specimens approximately 2 to 6 mm in length, photographed in Eagle Crater.

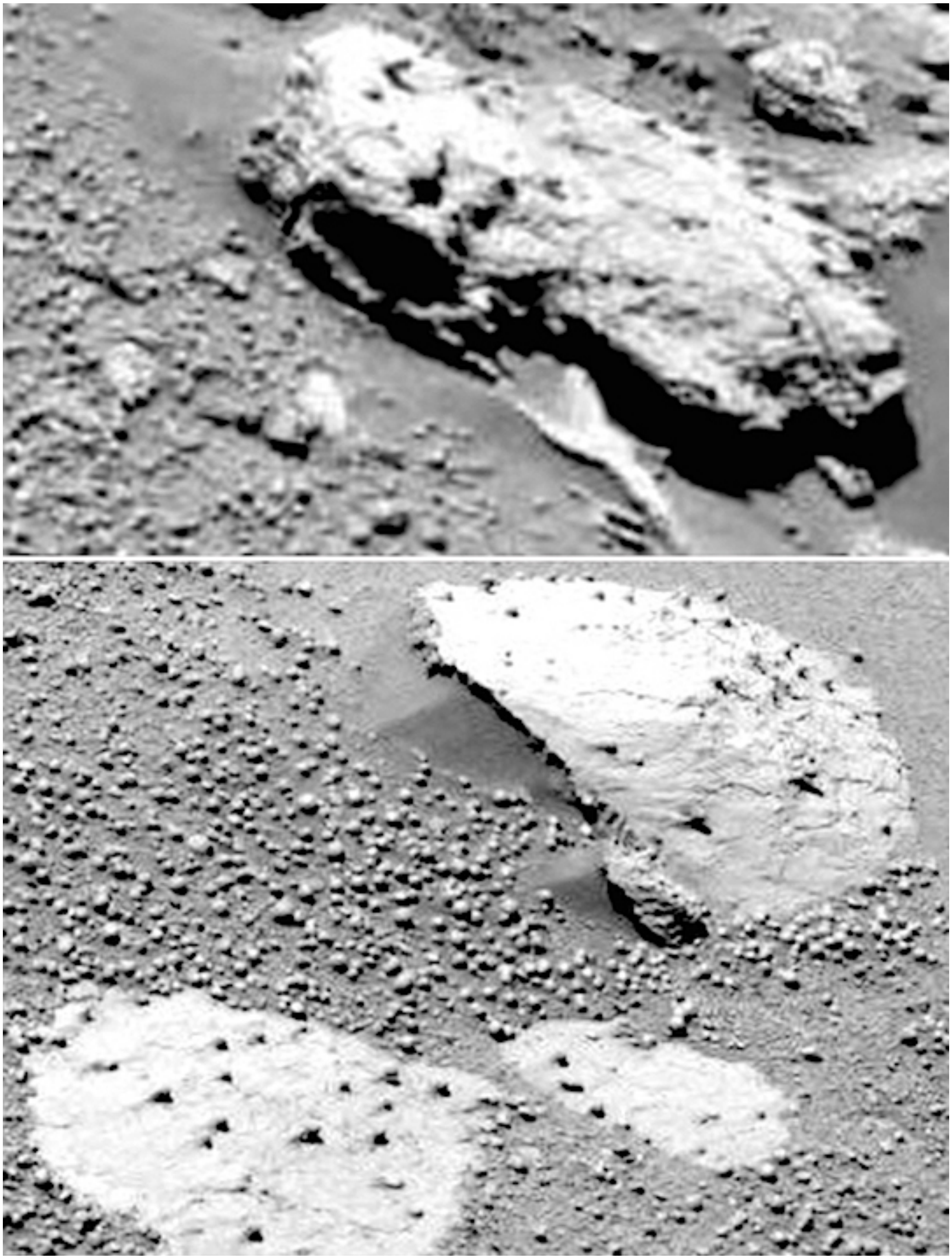

Figure 6. Opportunity - Sol: 85. Lichen-like specimens approximately 2 to 8 mm in length. Orientation of specimens on tops of rocks appears to be affected by gravity, or erosion of the rock surface, and may differ depending on if they are or are not sheltered from the wind; i.e. those on opposite sides of rocks vs tops of rocks may face different directions.

Figure 7. Opportunity - Sol: 85. Lichen-like specimens approximately 2 to 8 mm in length. Note similar orientation of specimens on tops of rocks and which may be affected by gravity due to the top-heavy bulbous caps.

Figure 8. Opportunity - Sol: 85. Lichen-like specimens approximately 2 to 8 mm in length. Note similar orientation of specimens on tops of rocks and which may be affected by gravity due to the top-heavy bulbous caps.

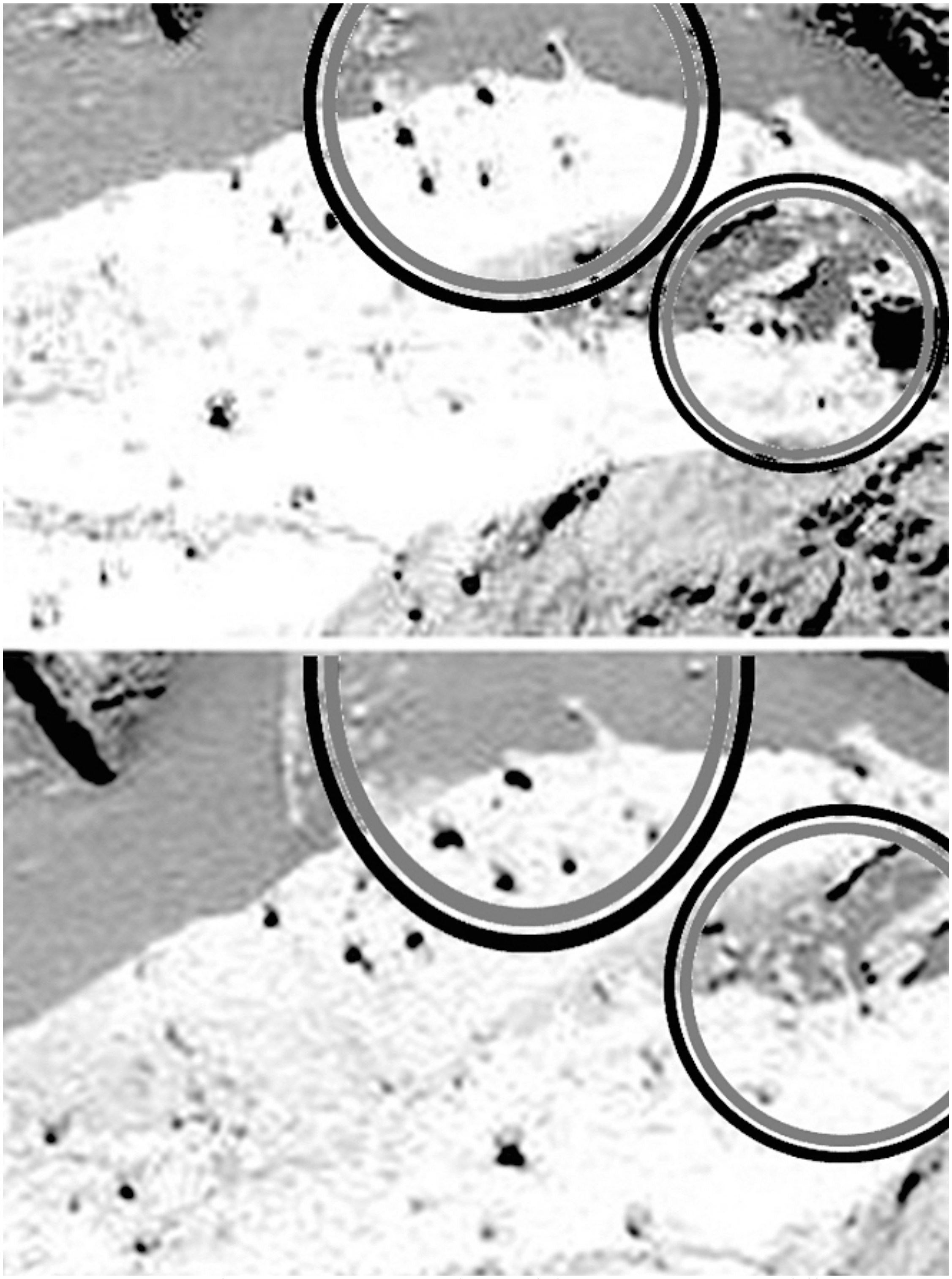

Figure 9. Opportunity - Sol: 85. Two panoramic photos of the same specimens at different times on the same day, i.e. 13:06:15 Mars local solar time (top) vs 13:14:15 Mars local solar time (bottom). Note that seven of the "mushrooms" within the red circles have bent down in a leftward or upward rightward direction (bottom vs top photo). Although the change in angle is most likely due to change in camera angle, this cannot explain the changes in the downward and upward direction. This supports the hypothesis that the stems, top heavy with mushroom (fruiting body) caps, are flexible and that sun, wind, or turbulence associated with the rover may have been contributing factors.

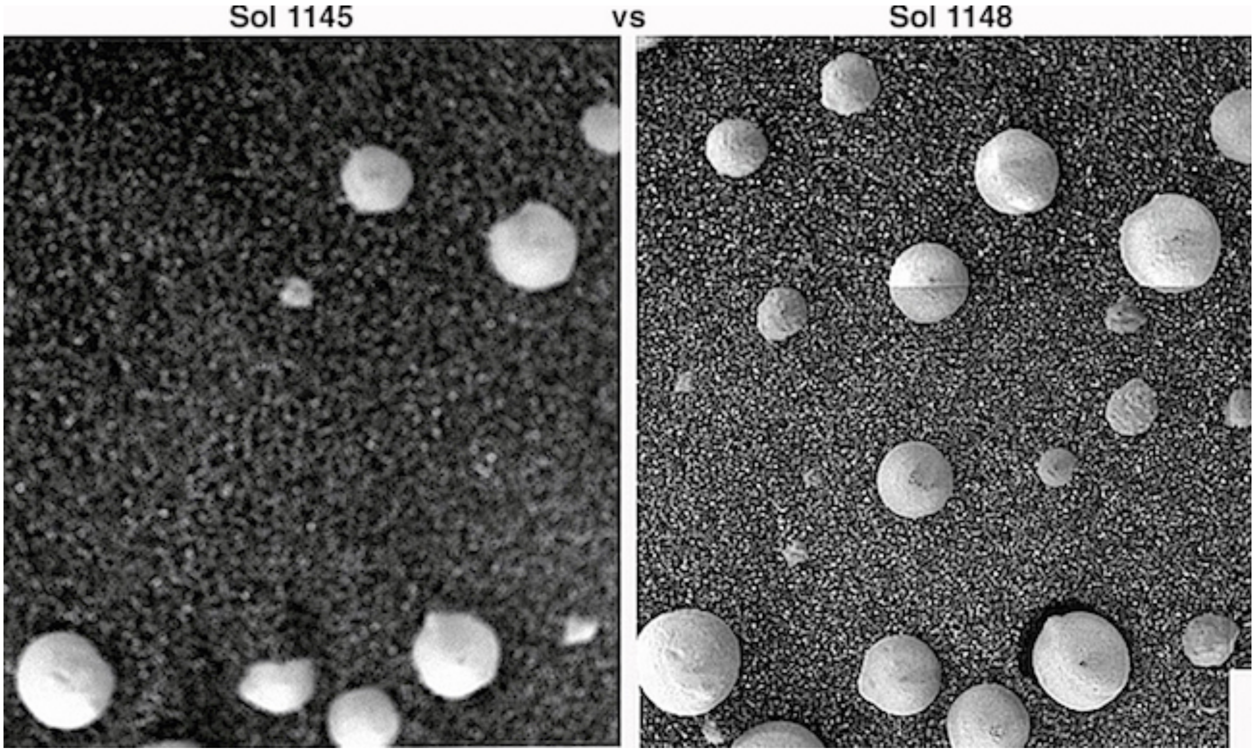

Figure 10. Opportunity - Sol 1145-left v Sol 1148-right). Comparing Sol 1145-left vs Sol 1148-right. Growth of twenty-three Martian specimens over three days, twelve of which emerged from beneath the soil and all of which increased in size. Ground level wind speeds between 40 to 70 m/h are required to move coarse grained soil on Mars, and no strong winds, dust clouds, dust devils, or other indications of strong winds were observed, photographed, or reported during those three days in this vicinity of Mars. Nor does the Sol 1148 photograph show any evidence that the surface has been disturbed by wind, as there are no parallel lineaments, ripples, waves, crests, or build-up of soil on one side of the specimens as would be expected of a directional wind (Kidron et al. 2017). Photographed by the Rover Opportunity, NASA/JPL. Differences in photo quality are secondary to changes in camera-closeup-focus by NASA.

Figure 11. Comparing terrestrial fungi / "puffball" (left) with Martian specimens (right) Sol 221 photographed by the Rover Opportunity at Meridian Planum, Mars.

Figure 12. Sol 182 photographed by NASA Rover Opportunity. A majority of experts identified these specimens as "fungi" and "puffballs" (Joseph 2016). Note what appears to be spores littering the surface. NASA favors a hematite hypothesis.

Figure 13. Sol 257 photographed by NASA's Mars Rover Opportunity. Martian specimens resembling Puffballs (Basidiomycota), some with stalks and shedding what appears to be spores and the outer cap, lower cup, and universal veil that covers embryonic fungi. To speculate further, the thick coats of white material being shed from the sides of some specimens may consist of crustose, and the white powder-spore-like material may consist of leprose. It is impossible, however, to determine with a high level of confidence if these are in fact living organisms.

8. Data Does Not Support the Hematite Hypothesis. Spheres Were Never Selectively Analyzed

The problems with the hematite hypothesis are legion (Burt et al. 2005; Knauth et al. 2005; Joseph et al. 2019). For example: The Opportunity's instruments were not calibrated to selectively detect hematite and the cameras were not capable of taking true color photos. Therefore, the actual and true color of the landscape, rocks, outcrops, sand, dust, dirt, is unknown. Instead, composite false color images were generated by the Opportunity's panoramic camera's 750-, 530- and 480-nanometer filters (Soderblom et al. 2004). Based on these "color composites" blues and greens were detected throughout the lower landscape. With the exception of the dull gray stones embedded inside cement-like outcrop matrix (Bell et al. 2004; Squires et al. 2004) the spherules of

Eagle Crater were judged to be yellow, orange, and purple (Soderblom et al. 2004) whereas the stemmed Martian specimens with mushroom features appear to be purple in color (Figures 1-3).

As is well known, a variety of terrestrial organisms including lichens and fungi may appear green, purple, orange or yellow. The Eagle Crater spheres upon the ground ("blue berries") and those jutting skyward attached to rocks ("Martian mushrooms") were judged to be purple, orange and yellow (Soderblom et al. 2004). By contrast, terrestrial hematite is variably colored black, silver-gray, brown, reddish-brown, or red (Anthony et al. 2003; Morel 2013). Thus, based on these composite colors from the Eagle Crater, the "blue berries" and purple Martian mushrooms could not be hematite.

Although investigators observed, via photographs, specimens with lichen-like mushroom features jutting up from rocks within Eagle Crater (Bell et al. 2004; Squires et al. 2004), there was no selective, focused attempt to determine if they were biological or consisted of hematite or other minerals. Further, despite recognizing that the spheres (blue berries) upon the surface were a different color than hematite (Soderblom et al. 2004) and much smaller than terrestrial hematite, ranging in size from 0.6 to 6 mm in diameter (Herkenhoff et al., 2004) it was assumed they must be hematite based on *inference* and the *interpretation* of results generalized from panoramic images that included sand, soil, dust, and outcrops, and as based on generalized all-inclusive spectra recorded by the Opportunity's Mössbauer Spectrometer, Alpha Particle x-ray Spectrometer and Miniature Thermal Emission Spectrometer (Bell et al. 2004; Christensen et al. 2004; Klingelhöfer et al. 2004; Rieder et al. 2004; Squires et al. 2004). These instruments were not even mineral specific. The response functioning of these instrument also continually changed "over the course of the mission" and did not correspond to pre-mission "instrument calibration" thereby requiring ad hoc calibration adjustments (Glotch and Bandford, 2006).

Hematite was never directly or positively detected in any of the spheres by the spectrometers. Instead, its possible presence was inferred based, for example, on the averaging of what were assumed to be high and low temperatures derived from outcrops and plains (Klingelhöfer et al. 2004), and the elimination of spectral signals until arriving at spectral signatures that could be *interpreted* as similar to hematite in a controlled laboratory setting (Christensen et al. 2004).

As is well established, different colors have different spectra and differentially absorb and reflect light and heat. Likewise, biological organisms generate heat and their pigments reflect and absorb different spectra. Moreover, Martian sand, dust, dirt, rocks, outcrops, all appeared to and would be expected to have different albedos, colors (Bell et al. 2004; Klingelhöfer et al. 2004; Soderblom et al. 2004) and heat signatures. However, the temperature and true color of the Eagle Crater landscape are unknown.

Nevertheless, the spectra from false colors created by the camera filters were analyzed and compared to "test spectrum" obtained from a "magnetite-derived hematite" laboratory sample; and as admitted by Glotch and Bandfied (2006), the data was nevertheless a "poor fit" and did not match laboratory samples.

Moreover, all obtained spectral signatures were confounded and contaminated by numerous uncontrolled and unknown variables, the properties of which could not be accurately and precisely determined. Hence, due to depth of field, reflected light from the Opportunity and the differential angles of the surrounding objects, and layers of obscuring dust and sand, and as the temperature sensors had failed, it was impossible for the Opportunity's suite of spectral sampling instruments to obtain accurate and selective spectral signatures. All data collected included dust, dirt, sand, outcrops, large flat oblong rocks, surrounding matrix and soil, were affected by reflected light and atmospheric temperatures and solar radiance; and then the data was combined, adjusted, averaged, and then attributed to the spheres which were falsely claimed to contain hematite (Christensen et al. 2004; Klingelhöfer et al. 2004; Rieder et al. 2004). As admitted by Grotzinger et al. (2005): the spectra from rocks lying on the surface were "indistinguishable from that of the average spectral character of dust." And as acknowledged by Klingelhöfer and colleagues (2004): "images obtained by the Microscopic Imager sampled only outcrop matrix." And yet, the Opportunity's team of investigators, claimed that the spheres consisted of hematite despite having no accurate data to support this interpretation.

Despite "the failure of temperature sensors on the on-board calibration targets" (Glotch and Bandfield 2006) Klingelhöfer and colleagues (2004) claimed to have averaged high and low temperatures from multiple sources, and inferred the existence of hematite within the spheres based on these generalized averages. Klingelhöfer et al. (2004), admitted that spectra were believed to "imply" hematite and were therefore "assigned to hematite" (Klingelhöfer et al. 2004).

Furthermore, the data that was claimed to have been obtained from single spheres were obtained from panoramic views of the landscape (Christensen et al. 2004; Klingelhöfer et al. 2004) and from flat oblong rocks which were then inexplicably mischaracterized as spheres (see Figure 6 in Bell et al. 2004). Not only did Bell et al (2004) utilize multiple images and spectra from a single large oblong rock, but their data was also based on panoramic photographs depicting multiple features, and was contaminated by solar radiance, atmospheric irradiance, surface temperature and albedo which could only be guessed at and estimated, thus confounding the data. Furthermore, Bell et al (2004) admitted the data is "not consistent" with solid hematite but jarosite and ferric iron and "exhibit crystalline ferric iron spectral signatures." And yet, Bell (2004) and the others claimed that the spheres contained hematite (Christensen et al. 2004; Klingelhöfer et al. 2004; Squires et al. 2004) when this confounded data was actually derived from a single oblong rock and there was no data based on or selectively derived from these spheres to substantiate this assumption which was based on inference and speculation.

Christensen and colleagues (2004), also claimed to have directly examined these spheres but instead relied on panoramic images to determine "the mineral abundances and compositions of outcrops, rocks, and soils" via the "Miniature Thermal Emission Spectrometer (Mini-TES)." According to Christensen et al. (2004) the Mini-TES "collects infrared spectra and were combined with panoramic images and as based on thermophysical properties, atmospheric temperature profiles and atmospheric dust and ice opacities." Thus, the Mini-Tes acquired its data not by examining a single sphere, but from composites obtained from "ice opacities" when no ice was observed, atmospheric temperatures when the temperature sensors had failed and the atmospheric temperature was (and is) unknown, and from large panoramas via "long-integration single-point stares at 14 locations along the outcrops... and vertical scans of the plains." Christensen et al. (2004) also acknowledged that their data was affected by "reduced spectral contrast" and was "likely contaminated" by sand, dust, and other materials, and which led them to "overestimate the hematite."

Christensen et al. (2004) also admit that they removed spectra "by first deconvolving each spectrum with an end member library of 47 laboratory minerals and four scene spectra...and then subtracting" spectra until this "derived spectrum" could be interpreted to resemble "a laboratory hematite sample." Thus, the inferred presence of hematite was based on the selective elimination of spectral signals until arriving at a spectrum that was interpreted to be similar to the spectral signature of a sample of hematite examined in a laboratory setting; the lighting and controlled conditions of which, of course, would be completely different from Eagle Crater or a natural terrestrial environment.

Although soils and outcrop matrixes of Eagle Crater likely contain considerable iron and jarosite (Bell et al. 2004; Christensen et al. (2004; Herkenhoff et al., 2004; Klingelhöfer et al. 2004; Rieder et al. 2004; Squyres et al. 2004), the fact is: no direct evidence of hematite was found, the presence of iron was inferred to indicate hematite, and not one of the thousands of mushroom-shaped lichen-like specimens (Martian mushrooms) photographed in Eagle crater were individually or selectively examined by Opportunity's suite of spectral sampling instruments for any evidence of hematite. Likewise, the spheres (blue berries) upon the soil were never directly, selectively, individually, and specifically examined for the presence of hematite or spectra that might imply hematite. Oblong rocks are not spheres. The spectrometers employed were not even mineral specific, there were problems with calibration, temperature sensors had failed, and the data obtained was generalized from multiple sources then combined, manipulated, averaged, or selectively deleted, until what remained was still a "poor fit" for spectra obtained from laboratory samples. Thus, there is no convincing or significant evidence to support the claims that these *spheres,* especially those with stalks and caps, consist of hematite.

9. Meteors, Spherules, Solar Winds, and the Interplanetary Transfer of Life

Knauth et al. (2005) have hypothesized that the spheres of Eagle Crater were fashioned following a "large iron meteorite impact" which interacted with regolith "containing salts, ice, and brine" and that an "enormous wet surge created by this impact" produced "fine basaltic particles, salts, ice, brine, accretionary lapilli and... a large population of iron condensation spherules." In support of this argument, they point out that: "Large impacts are known to produce condensation spherules" (see Lowe et al. 2003) and that spherules (aka tektites) have been found in the Ries Crater in Germany (Graup, 1981). However, impact-induced spherules are typically black (or dark red), and those in Ries Crater, and other craters are most likely secondary to volcanic activity (Bohor and Glass, 1995; Gaup, 1981; German, 2020).

There is no history or evidence of volcanic activity in Eagle Crater. Moreover, terrestrial spherules, created by impact or vulcanism have absolutely no resemblance to the Martian mushrooms-lichens presented in this report. Tektites, volcanic, and impact spherules do not have long thin stems, attached to rocks, topped by mushroom-shaped caps, and which form vast colonies which orient skyward.

However, it is possible species ancestral to those detected in Eagle and Gale Crater, may have been deposited on Mars via meteor, asteroid, comet or solar winds; and that Mars, Earth, and Venus, may have repeatedly exchanged life beginning billions of years ago via microbial-laden atmospheric dust and bolides ejected into space (Arrhenius, 1908; Beech et al. 2018; Joseph, 1997, 2009; Joseph and Schild 2010; Melosh 2003). Microbes, fungi, spores and lichens have been recovered from Earth's upper atmosphere. Powerful solar winds have repeatedly blown material from the upper atmosphere into space (Reviewed by Joseph 2019). Studies have shown that these same microbes can survive over a year exposed to direct space outside the ISS. If fungi, lichens, and spores are ejected into space from the upper atmosphere, they could reach Mars in less than 12 weeks. Certainly, survivors would be expected to go forth and multiply.

Over 635,000 impact craters at least 1 km (0.6 miles) wide, have been located on Mars (Robbins and Hynek, 2012) whereas there are 200 known major terrestrial impact craters (Earth Impact Database, 2019). In addition, over the course of the last 550 million years on Earth there have been 97 major impacts, leaving craters at least 5 kilometers across (Earth Impact Database, 2019). Hence, both Mars and Earth have been struck thousands of times resulting in the ejection of millions of rocks, boulders and tons of debris into space (Beech et al. 2018; Melosh, 1989, 2003; Van Den Bergh, 1989) along with any adhering microbes, spores, and fungi.

Given that microbes can survive the shock of a violent impact and hyper velocity launch ejecting them into space, as well as direct exposure to space and the descent to the surface of a planet (reviewed by Joseph 2019), the interplanetary transfer of viable microorganisms, via bolides, within our Solar System, is overwhelmingly likely (Beech et al. 2018); beginning, possibly, soon after life appeared on Earth over 3.8 bya. It's been estimated, given a 25 km/s impactor velocity, that up to 5.5×10^{12} kg of debris and approximately "10^{13} kg of potentially life-bearing matter has been ejected from Earth's surface into the inner solar system" (Beech et al. 2018) along with unknown volumes of water, and perhaps millions of trillions of organisms buried within ejecta (Joseph 2009, 2019).

If life first began on Earth, Mars, Venus, or on planets from other solar systems and galaxies, is unknown. However, it appears that early in the history of this solar system, 3.8 bya, life was already present on Mars (Noffke 2015; Thomas-Keprta et al. (2002, 2009) and Earth (Pflug 1978 Mojzsis et al. 1996; Rosing and Frei 2004), which supports the hypothesis that living organisms were deposited on both planets during a period known as the heavy bombardment (Joseph 2009; Joseph et al. 2019). Therefore, although it is improbable that an impacting meteor fashioned the Martian mushrooms described in this report, the ancestors to these putative Martian organisms may have been deposited on Mars (and Earth), from space.

10. Three Types of Spheres: Martian Mushrooms, Cement Concretions, Blue Berry Puffballs

Martian Mushrooms: The "Martian mushrooms" presented here are up to 8 mm in length, have thin stems up to 5 mm in length and less than 1 mm in diameter and topped with bulbous caps up to 6 mm in diameter. These specimens have a different morphology, color, and are smaller than hematite; there is no evidence to support the belief these are hematite; their caps and stalks appear uniform in shape which is a biological and not an abiogenic trait as well as being characteristic of living lichens and mushrooms. As to those on the top-sides of rocks, their collective, flexible upward angled orientation is exactly what would be expected of photosynthesizing organisms. By contrast, those on the sides of rocks, and being top-heavy with bulbous caps, are pulled downward as if by gravity. Furthermore, those on the tops and sides of rocks have an obvious and completely different structural organization and composition from the outcrops and rocks from which they jut out skyward or downward, and distinctly different visible and infrared properties as compared to these outcrops (Bell et al., 2004) indicating they were not sculpted from rock. In addition, several specimens on the top-sides of rocks appeared to change their angle of orientation during a single day, such that arched downward, thus suggesting that their stems (top-heavy with bulbous caps) are flexible (Figure 9). In all respects these Martian mushrooms appear biological and distinct from surface substrates.

There are, however, two other types of "spheres" that have been observed and photographed in Eagle Crater and which differ significantly from the thin stemmed "Martian mushrooms" and each other, in morphology, location, color and attached substrate: A) "yellow, orange and purple" spheres upon the soil (Soderblom et al. 2004) which have been referred to as "blue berries" and resemble fungal "puffballs" (Dass 2017, Joseph 2016; Joseph et al. 2019; Rabb 2018); and B) gray spheroidal cement-like concretions (Bell et al. 2004; Squyres et al. 2004; Herkenhoff et al. 2004).

Cement-like Concretions and Fossilization: In contrast to Martian mushrooms and "blue berries" the gray spheroidal-cement-like concretions are embedded in a cement-like matrix (Bell et al. 2004; Squyres et al. 2004; Herkenhoff et al. 2004) and have been described as "harder than surrounding rock" (Squyres et al. 2004) though what they consist of was never determined. It is believed that these gray spheroids had undergone "cementation" thereby "cementing" this matrix and the concretions embedded in this cement (Herkenhoff et al. 2004). If these represent a form of fossilization unique to the Martian environment, if they consist of calcium, or were formed secondary to iron metabolism, or if they are completely abiogenic, is unknown.

However, based on terrestrial analogs, the lichen-like specimens growing atop rocks may contain iron which is a lichen characteristic (Bajpai et al. 2009; Hauck et al. 2007). Many species feed on iron. If these specimens, due to the unique Martian and iron-rich environment, have a greater uptake of iron as compared to terrestrial species, is unknown. Moreover, cyanobacteria produce calcium via their secretions. To speculate, could high levels of iron uptake or calcium secretions make these specimens "harder than rock" if fossilized such as following a sudden change in the biosphere due to a catastrophic event-- thus accounting for the embedded gray cement-like concretions observed by Squyres and colleagues (2004; Bell et al. 2004; Herkenhoff et al. 2004)? Fossilization, cannot be ruled out.

Blue Berry Puffballs and Growth vs Wind: Specimens similar to "puffballs" ("blue berries") have been observed on the Martian surface of Meridiani Planum (Dass 2017; Joseph 2014; Rabb, 2015, 2018; Small, 2015). Some of these ground-level specimens have "lemon shapes," others have a short or long thin stalk, but the majority appear to have no discernible stalk. Furthermore, with the exception of those attached to an unknown (fungi-like) substrate and which, via that substrate, are elevated above the ground (Figures 1, 4) most ground level spheres, including those with long and thin stalks lay upon the surface as if they fell over. Even those observed to emerge from beneath the soil do not rise up on their stems as is typical of mushrooms and lichens; and which may be due to the inability of the soil to support them. The answer to this is unknown. However, it is possible that those upon the soil (vs those on rocks) consist of many different species, assuming they are biological.

The biological interpretation is supported by the previously reported observation of fifteen spherical specimens which increased in size and emerged from beneath the coarse grained surface (Joseph et al. 2019). Here we present pictorial evidence of twenty-three puffball-shaped specimens, photographed on Sol 1148 which increased in size over a three-day period, twelve of which were not visible three days earlier on Sol 1145 (Figure 10). We have determined that wind was not a factor in the emergence and size increase of these specimens.

It's been estimated that the movement of coarse-grained Meridiani Planum soil requires wind velocities of 70 m/s at least one m above the surface, but that velocities of 40 m/s may "occasionally" displace coarse-grained sand and soil (Jerolmack et al. 2006). Although on Earth, ground level 20 km/h winds can displace fine grained sand (Kidron and Zohar, 2014) all surrounding soil in Sol 1145 and 1148 is rocky and coarse (vs fine) grained.

Soil crusts, including and especially those infiltrated by micro-organisms, are relatively resilient to wind erosion. In a two year study of soil and wind in the Negev Desert--considered to be a Mar-like analog environment (Kidron 2019)--it was reported that only exceptionally strong and prolonged winds were capable of crust rupture, disintegration or flaking and the removal or erosion of buried crust (Kidron et al. 2017). No strong winds or dust storms in Meridiani Planum were reported by NASA on Sols 1145, 1146, 1146, or 1148. Likewise, there is no evidence or comparative evidence of wind, dust storms, or dust devils or the accumulation of dirt, sand, ripples, lines, or dust as based on a visual examination of all photos between Sol 1145 and 1148. Nor is there any evidence of soil or sand displacement, soil or sand buildup or "filling in" or that soil is higher or lower on one side of any of these specimens as might be expected if subject to powerful directional winds (Kidron et al. 2017). It is reasonable to deduce that these puffball-shaped spheres grew up out of the ground and expanded in size over a three-day period.

11. Fungi and Lichens Survive Extreme and Simulated Martian Environments

The mushroom-shaped specimens in this report are different in all respects from hematite and the cement-like concretions embedded in the cement-like matrix and which do not have a thin stalk capped by a mushroom-like appendage. These "Martian mushrooms" can also be distinguished from the surface-dwelling spheres (blue berries / puffballs) which do not have a mushroom shape. The "puffballs" are most likely fungi. By contrast, morphologically the "Martian Mushrooms" resemble lichenised fungi/alga and non-lichenised fungi.

It has been repeatedly documented that fungi, algae, and lichens are adapted for life on Mars (reviewed by Joseph et al. 2019) and survive in Mars analog environments (reviewed by de Vera et al. 2019). In experiments lasting a year or more, it's been demonstrated that fungi, algae and lichens survive in space outside the International Space Station, and exposure to UV radiation, cosmic radiation, and vacuum conditions and simulated Martian temperatures, atmosphere, and humidity (Baque et al. 2017; de Vera 2012; De la Torre Noetzel, et al. 2017; Onofri et al. 2018 Sanchez et al. 2012; Zakharova et al. 2014). Simulation studies performed by numerous teams of independent investigators have demonstrated that prokaryotes and eukaryotes, including cyanobacteria, methanogens, fungi and lichens, could survive and even flourish on Mars, especially if dwelling within rock shelters or beneath the soil and provided water--for which there is evidence as reviewed in this report and elsewhere (Joseph et al. 2020a; Malin & Edgett 1999, 2000; Perron et al. 2007; Renno et al. 2009; Villanueva et al. 2015).

For example, microcolonial fungi, *Cryomyces antarcticus*, and *Knufia perforans* exhibited no evidence of stress after long term exposure to thermo-physical Mars-like conditions (Zakharova et al. 2014) whereas dried colonies of the Antarctic cryptoendolithic black fungus *Cryomyces antarcticus*, suffered no or minimal damage to DNA and ultrastructure despite sixteen months exposure to Mars-like environments (Onofri et al. 2018).

A wide variety of fungi are chemoautotrophs and can obtain nourishment via inorganic sources such as ferrous iron which is abundant on Mars and Eagle Crater (Bell et al. 2004; Klingelhöfer et al. 2004, Squires et al. 2004). These Martian specimens may be able to feed on radiation, minerals, and sunlight as reflected by their upward directed orientation.

Martian ground level radiation has been estimated to equal "0.67 millisieverts per day" (Hassler et al. 2013) which is profoundly below the radiation tolerance levels of eukaryotic fungi which can withstand radiation doses up to 1.7×104 Gy (Saleh et al. 1988). Even if radiation levels rise above their tolerance levels, and their DNA damaged, these genes are rapidly replaced or repaired due to a redundancy of genes with repair functions (White et al. 1999).

Tugay and colleagues (2006; Zhdanova et al. 1991, 2004) exposed fungi to pure radiation, gamma irradiation, and mixed beta and gamma radiation (an electron dose of 300-500 Gy). These investigators found that 60% of fungal strains were invigorated by radiation and exhibited positive radiotropism, significant growth, and enhanced spoor production. Fungi, as well as lichens, thrive and are attracted to highly radioactive environments (Becket et al. 2008; Dadachova et al. 2007; Tugay et al. 2006; Wember & Zhdanova 2001). Fungi flourish along the walls of the highly radioactive Chernobyl nuclear reactor (Dighton et al. 2008; Zhdanova et al. 2004) and seek (Wember & Zhdanova 2001; Zhdanova et al. 2004) and grow towards radiation which serve as a metabolic energy source (Dighton et al. 2008; Tugay et al. 2006). Furthermore, fungi have infiltrated and can't be eradicated from the International Space Station (Novikova 2009, Novikova et al. 2016; Vesper 2008) and specimens resembling fungi (Ksanfomality 2013) and the classic mushroom-shaped fungus, have been identified on Venus (Joseph 2019). These findings "support the possibility that fungi, in general, may be hyper-extremophiles, capable of colonizing Mars, Venus, and the harshest of alien environments" (Joseph 2019).

Lichens also survive environmental extremes, lack of water, desiccation, temperatures as low as -196°C (Armstrong 2017; Becket et al. 2009), as well as high levels of UV radiation and direct exposure to the radiation intense environment of space and Mars simulated environments (Sancho, et al. 2007; Raggio et al. 2011; De la Torre Noetzel et al. 2017). Despite 18 months exposure, lichens remained viable and demonstrated normal metabolic activity.

12. Martian Mushrooms in Eagle Crater. Lichenised vs Non-Lichenized Fungi

If the mushroom-like specimens presented in this report are fungi or composite algae-fungal organisms, can only be determined via extraction and microscopic examination. Most of these specimens resemble the lichen, *Dibaeis baeomyces* in morphology, shape, growth patterns, and size including possessing stalk/thallus and bulbous apothecia (Joseph et al. 2019). *Dibaeis baeomyces* are similar in a number of respects to these Martian specimens which appear to depict the gradual development of ascomata from small globulars which become stalked structures capped with a fruiting body (Figures 2,3). Like their terrestrial counterparts, there appear to be thallus granules and nodules on the Martian substrate surface.

Dibaeis baeomyces are well adapted for life on Mars, and have colonized the most extreme environments and been found growing in desert sand, dry clay, on rocks, and in the arctic (Brodo et al. 2001; Jonsson et al. 2008; Platt & Spatafora 2000; Ryan et al. 2002; U.S. Department of the Interior 2010). Because of their stress-tolerance, slow growth rates, low demands for water and nutrients, longevity, and adaptations to stressful conditions, lichens might easily colonize Mars.

The amount and availability of water within Eagle Crater is unknown. Lichens can tolerate long periods of drought and dehydration, a function, in part, of their slow growth rate and metabolism (Armstrong and Bradwell 2010). Some species spend considerable time in a dehydrated state in which there is little physiological activity and no demand for nutrients (Armstrong 2017, 2019) and survive long periods without water and in nutrient-poor habitats.

Extremes in cold temperature would not be a limiting factor. Lichens flourish on the Antarctic continent and its adjacent islands (Llano 1965; Ahmadjian 1970; Longton 1979; Lindsay 1978; Smith 1984) and despite subzero temperatures for prolonged periods. Dark and nPS respiration is maintained even at subzero temperatures (Schroeter and Scheidegger 1995).

Hundreds of these Martian mushrooms form colonies which are selectively oriented skyward. The orientation of the presumed fruiting-bodies with respect to light appears to be behavioral and indicative of phototropism during fruiting body development.

Many of the specimens presented here

lack an obvious crustose thallus which is a *Dibaeis baeomyces*' characteristic (Armstrong, 2019; Armstrong and Bradwell 2010). If these specimens were produced by a lichen-forming fungus, then it might be expected that the symbiotic lichen thallus would be endolithic and inside the substrate, and for which there is evidence as depicted in Figures 2-3. These endolithic attachments could be individual as well as collective fungal hyphae. However, terrestrial hyphae are usually 2-5 microns in diameter (Armstrong 2017).

If these are lichens, then they may have adapted and evolved in response to the Martian environment and its high levels of ground radiation. Hence, the absence of an obvious crustose thallus may be an evolved adaptation. For example, in response to heightened radiation exposure--well beyond the "0.67 millisieverts per day" on Mars (Hassler et al. 2013)—terrestrial lichens as well as fungi have developed adaptive features (reviewed by Joseph et al. 2019)--a property described as "radiostimulation," "radiation hormesis," and "adiotropism" (Levin 2003; Tugay et al. 2006; Zhdanova et al 2004). These radiation-induced adaptations include tissue and cellular regeneration and new growth (Basset 1993; Becker 1984; Occhipinti et al. 2014; Levin 2003; Maffei 2014; Moment, 1949). The varying levels of radiation on Mars may have contributed to the evolution of unique features making Martian species distinct from, albeit remaining similar to terrestrial organisms.

The specimens presented here could also be non-lichenised fungi similar to *Leotia lubrica*, *Cordyceps capitata*, *Tulostoma brumale*. Given their size and morphology, they could also represent stalked reproductive fungal components, such as *ascomata* or *basidiomata* (complex fruiting-bodies producing sexual spores) or *stilbelloid synnemata* (complex conidiophores producing asexual spores). If these Martian mushrooms are fungi then it can be assumed they produce these fruiting bodies to facilitate spore dispersal. However, as there is no evidence of spore dispersal in Figure 1-9) and given the flexibility and hollow nature of their stems, then it is more likely they are lichens and engaged in photosynthesis and contributing to the oxygenation of the Martian atmosphere and soil.

IV. Conclusions

Edgar, Grotzinger, Hayes, and colleagues (2012) have argued that "the stratigraphic architecture of sedimentary rocks on Mars is similar (though not identical) to that of Earth, indicating that the processes that govern facies deposition and alteration on Mars can be reasonably inferred through reference to analogous terrestrial depositional systems." The same reasoning should apply to biology and oxygen and argue against the possibility these Martian mushrooms are abiogenic.

We have provided evidence of over 200 specimens with thin stalks and spherical-caps which appear to be purple in color, and have a mushroom-shape and resemble lichens in size and morphology and jut upward toward the sky. Thousands of these specimens have been observed in Eagle Crater (see Methods) and those similar to these in Gale Crater (Joseph et al. 2020a). There are no terrestrial abiogenic processes that can sculpt high density colonies of mushroom-shapes, attached by thin stalks to rocks and which form colonies that selectively orient their bulbous caps skyward in the same general direction exactly as what might be expected of photosynthesizing organisms. This interpretation is supported by the seasonal fluctuations and dramatic (30%) increases in Martian atmospheric oxygen during the Spring and Summer and which parallel seasonal fluctuations in the biological production of oxygen on Earth. It is reasonable to deduce that photosynthesizing organisms on Mars are responsible for the production and replenishment of oxygen which is an obvious biomarker.

In addition, twenty-three sphere-puff-ball-shaped specimens were photographed by the rover Opportunity either increasing in size or emerging from beneath the soil, over three days in the absence of any contributing wind or other abiogenic process. These behavioral indices (i.e. growth, skyward orientation, flexibility of the stems), coupled with morphology and oxygen production, are indicative, but not definitive proof, of biology, the first evidence of which was detected by the Viking experiments (Levin & Straat 1976, Levin et al. 1978).

These "Martian mushrooms" are uniform in appearance and do not resemble and are smaller and a different color than hematite; and they were never directly or selectively examined by any means for evidence of hematite--despite misleading claims to the otherwise. The Eagle Crater environment was not and is not conducive to producing hematite; there were significant problems with calibration and target sensors such that the instrumentation and methodology employed to detect spectral signatures that could be interpreted as hematite were dubious at best; and the claim that any of the spheres observed in Eagle Crater contain hematite has been described as "inappropriate" (Burt et al. 2005; Knauth et al. 2005) and a "poor fit" when compared to laboratory samples (Glotch and Bandfield 2006). The spherical hematite hypothesis is based on speculation and inference and lacking in any definitive scientific or factual foundation.

It is not probable that these specimens consist of salt, sand, or other abiogenic substances. Consider: these mushroom-shaped specimens look identical to mushrooms and lichens, and are attached to rocks by thin stalks, and top heavy with spherical caps that weigh some of these specimens so they arch upward then downward. If abiotic, these thin stems, top-heavy with skyward orientated bulbous caps, would have long ago broken apart and shattered in response to powerful winds, Marsquakes, meteor strikes, or, more recently, by turbulence created by the rover Opportunity. They did not.

It is important to stress that there is as yet no definitive proof these are, or were, living organisms. However, there are no "analogous terrestrial" processes which can explain the unique and uniform morphology, size, color, thin hollow stems, and collective skyward orientation of these mushroom-shaped specimens, or the seasonal fluctuations and increases and replenishment of Martian oxygen, other than biology. That these may be living organisms "can be reasonably inferred through reference to analogous terrestrial" organisms; although if they are in fact alive and biological is unknown. To prove these are living organisms would require additional investigation and robotic examination, evaluation, extraction, analyses.

In conclusion, coupled with reports of seasonal variations and increases in oxygen in the Martian atmosphere during the spring and summer, and based on size, color, morphology, flexibility, and what appears to be indications of photosynthesis and growth, the evidence presented in this report does not prove but supports the hypotheses that mushroom-shaped, lichen-like organisms may have colonized Eagle Crater and that there may be life on Mars.

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