# Mars, Fungus, Spores, and Reproductive Behavior

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**Abstract**

Fungal reproductive behavior, the growth of hyphae and mycelium, and the production of spores, on Earth and (possibly) Mars, are reviewed. Spherical specimens that nearly 70 experts have identified as fungal "puffballs" ("basidiomycota") have been photographed in the equatorial regions of Mars, within Meridiani Planum in particular. Over two dozen "puffballs" have been photographed emerging from beneath the ground and increasing in size. Networks of what appear to be fungal hyphae and mycelium, structural morphological changes associated with sporing, substances resembling clumps and carpets of white spores adjacent to these spherical "puffballs" and what may be embryonic fungi within these clumps of spores, have been observed. Although the authors have not proven that fungi have colonized the Red Planet, the evidence coupled with comparative morphology supports the hypothesis that fungi are growing, generating spores, and reproducing on Mars.

**Key Words:** Mars, Fungi, Spores, Hyphae, Mycelium

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## 1. Fungi on Mars?

Spherical puffballs, gray in color, photographed by the thousands in an equatorial region of Mars (Meridiani Planum) were first tentatively identified in 2014 (Joseph 2014). This led to an elegant computerized online study in which 70 experts in fungi, algae, lichens, geomorphology and mineralogy were able to view these specimens and type in the name and rate on a 1-4 scale, the probability these are living organisms. A significant majority of these experts identified the spherical specimens as "puffballs" or "basidiomycota" and agreed there is a high probability they are living organisms (Joseph 2016). Dass (2017) reviewed the findings and called the evidence "obvious." Armstrong (2021) performed a complex comparative computerize analysis of the spherical specimens photographed in Meridiani Planum, and determined they were morphologically and statistically nearly identical to those of Earth. Sequential photos have documented that the spherical specimens identified as Martian "puffballs" grow out of the soil by the dozens, increase in size, and that fungi even migrate to new locations (Joseph et al. 2021a). Further, as detailed and hypothesized in this report, and as based on comparative photos from Earth and Mars, the Meridiani Planum spherical specimens identified as fungal puffballs (basidiomycota) have been photographed preparing to "spore" and are surrounded by "spores" within which embryonic "fungi" can be discerned. We hereby present evidence of fungal spores and reproductive behavior on Mars.

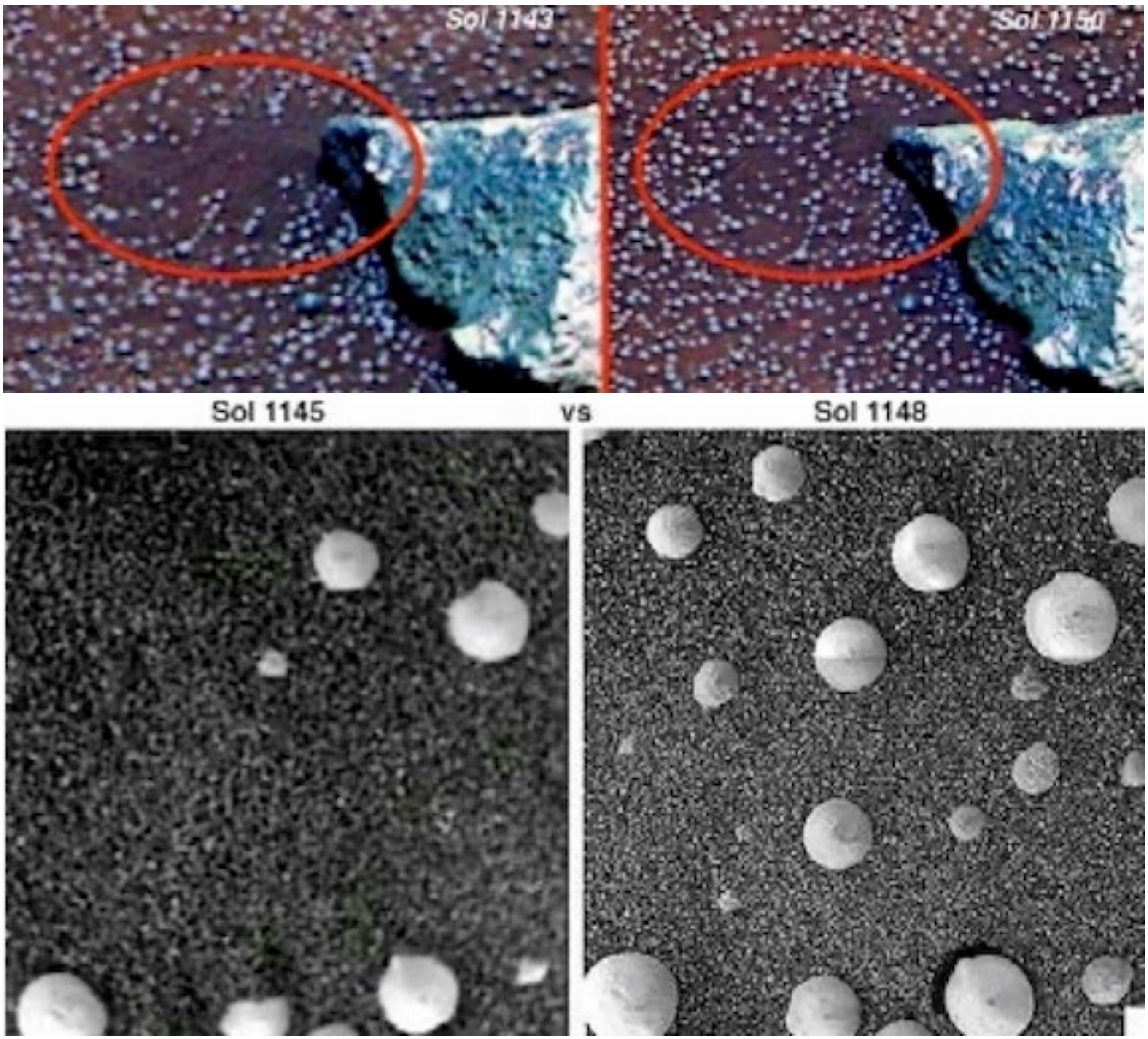



**Figure 1.** Dozens of spherical specimens resembling puffballs growing out of the ground over a seven day period (Sol 1143-1150) and three day period (Sol 1145-1148).

**2. Puffballs, Basidiomycota, Terrestrial Fungal Sporing & Reproductive Behavior**

The Kingdom Fungi are classified as eukaryotic organisms that include yeasts, molds, mushrooms and puffballs (Levetin 2021; Money 2011). Fungi are closely related to Animalia but are also constitute a distinct lineage that diverged from Animalia, Plantea, and bacteria at some unknown date in the past. The majority of fungi are believed to be absorptive heterotrophs that relay on organic compounds as sources of nutrition and that may form symbiotic or pathogenic relationships with other species (Levetin 2021; Money 2011). However, fungi have been found growing on the walls and surroundings of the damaged Chernobyl nuclear reactor (Dighton et al. 2008; Zhdanova et al. 2004) and are attracted to, will seek out and appear to derive nourishment from high levels of radiation (Dighton et al. 2008; Wember & Zhdanova 2001; Zhdanova et al. 2004; Tugay et al. 2006). Protection from radiation at ground level is made possible via the production of melanin that coats the outer surface of fungi (Dadachova et al. 2007); and likewise, airborne and upper atmospheric fungi and spores are protected from desiccation and UV-radiation, by thick layers of pigment that coat the outer walls (Levetin 2021).

Fungi generally form a a thread- chain- or tube-like body composed of hyphae which form interconnected networks referred to as mycelium. These networks of hyphae/mycelium also serve complex reproductive functions (Money 2011; Spoerke 2021). Some spores are formed via "sexual" (mating) or asexual processes. These latter spores are associated with undifferentiated hyphae that may fragment or sprout branches referred to as conidiophores. Sexual spores are often enclosed within a sporangium and are referred to as sporangio-spores. Up to 10,000 sporangio spores may be enclosed within a single sporangium. However, when these latter spores mature, the sporangium deteriorates and the spores are dispersed by wind (Levetin 2021; Money 2011). Sexual reproduction occurs when opposite mating types of hyphae come in contact. The fungal phyla known as Ascomycota (ascomycetes) and Basidiomycota (basidiomycetes) reproduce sexually and constitute up to 95% of all terrestrial fungi whereas up to 50,000 different species of fungi belong to the phylum Basidiomycota (Money 2011).

Terrestrial puffballs are classified as "basidiomycota" and belong to a fungal group that produce spores and enclosed globose fruiting bodies (Larsson & Jeppson, 2008). These fruiting bodies undergo a process of autolysis as they mature, and appear as a powdery spore-bearing mass (Læssøe & Spooner, 1994). The fruiting body produces its spores on the outside of club-shaped structures referred to as "basidia," and fungi that generate "basidia" are referred to as "Basidiomycetes" (Spoerke 2021). Basidia are formed via sexual reproduction, such that two semi-independent basidium fuse and produce a zygote. The zygote immediately undergoes meiosis which in turn develop basidiospores which are produced externally by each basidium in the form of large fruiting bodies (basidiomycetes) along the gills on the upper surface. The basidia and basidiospores of puffballs form within an enclosing wall of the fruiting body. However, some basidiomycetes also reproduce asexually by forming conidia (Levetin 2021; Money 2011).

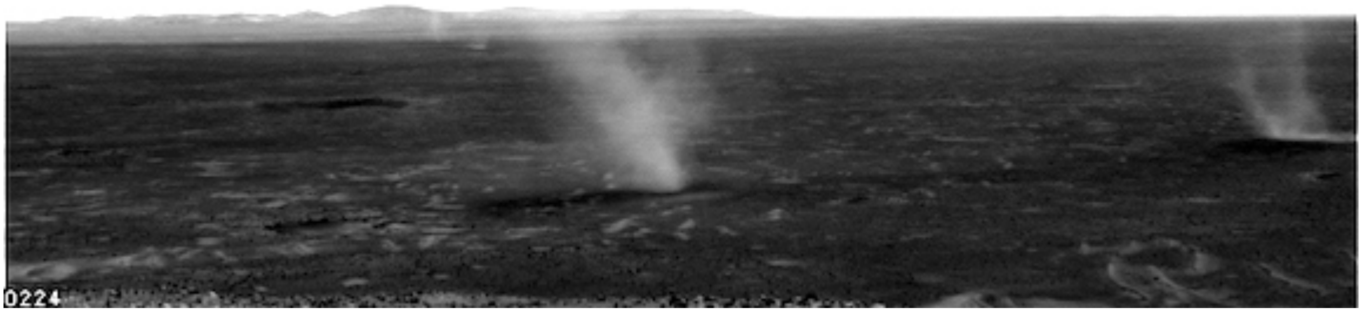


Figure 2. Sol 568. Dust devils in Gusev Crater, Mars.

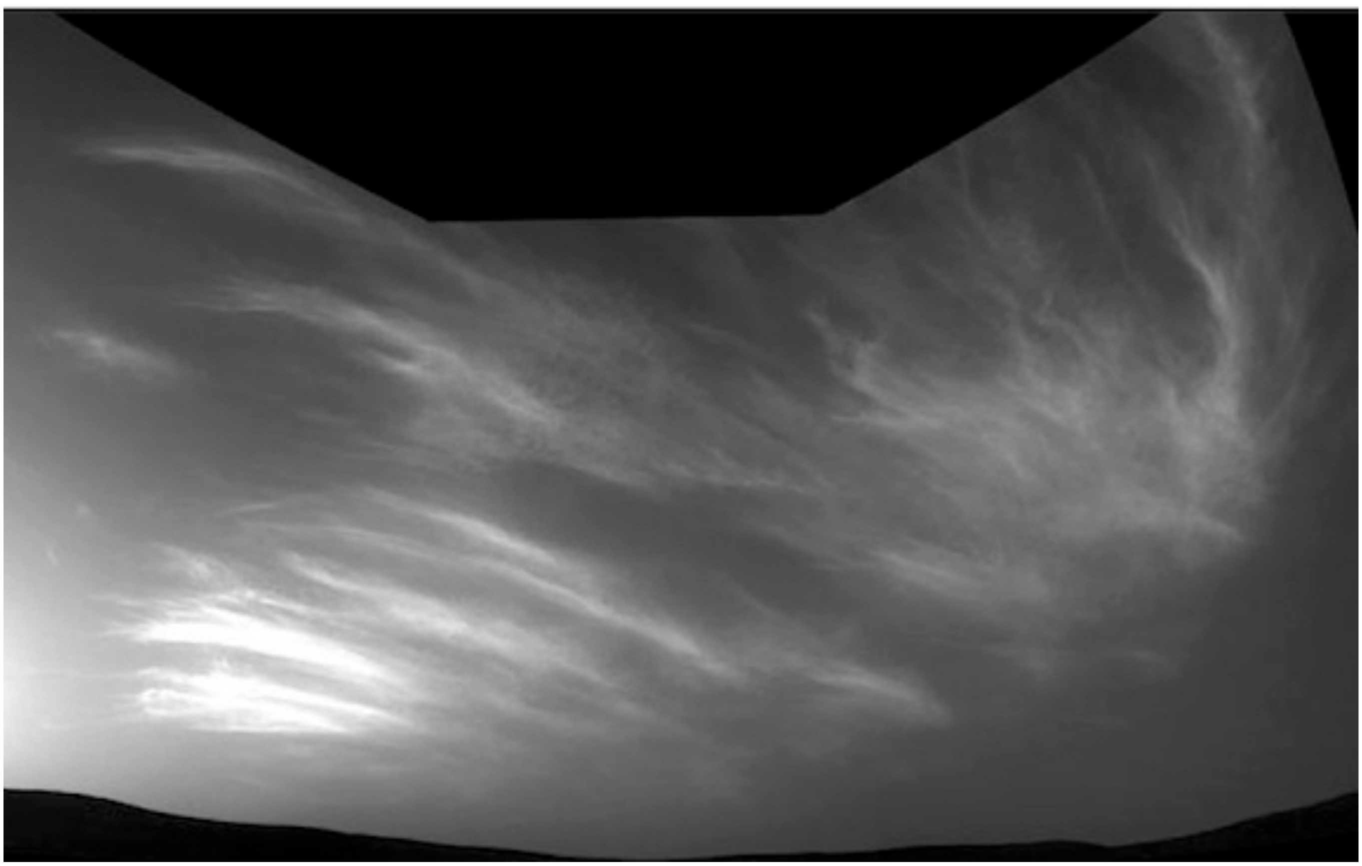


Figure 3. Sol 2400. Equatorial clouds over Gale Crater, Mars.

Figure 4. Sol 950. Equatorial clouds clouds over Meridiani Planum, Victoria crater, Mars.

Spores may be released passively via wind or rain (Aylor, 1990; Lacey, 1996). Even minimal levels of wind, with speeds between 0.2 and 2.0 m/sec, can propel spores into the atmosphere (Lacey, 1996; Hau & de Vallavielle-Pope, 1998). Spores are also discharged above ground (epigeous) via a ballistosporic spray down to the surrounding surface (Basidiomycota) or are propelled into the air (Ascomycota). Ascomycota and Basidiomycota spores are also transported varying distances via wind (Lacey, 1996; Hau & de Vallavielle-Pope, 1998). These mechanisms of distribution insure that at least some of these spores will make contact with host roots and enable the mating of germinants (Horton 2017; Money 2011).

Terrestrial fungal spores are dispersed by the tons into the atmosphere yearly (Elbert et al. 2007) and have been recovered in the stratosphere, growing on the outside surface of the International Space

Station (Grebennikova et al. 2018) and on the outside and inside windows (Novikova 2009) and within the interior of the International Space Station (Novikova et al. 2016; Vesper et al. 2008) where they have proved impossible to eradicate as they are invigorated by radiation. It has been proposed that fungal (and other spores) discovered on the outside surface of the (ISS) International Space Station (Grebennikova et al. 2018) and in Earth's upper atmosphere may have originated on other planets including Mars; and were lofted into the upper atmosphere of their home planets, some of which were then propelled through space by solar and galactic winds (Joseph & Duvall, 2021; Joseph et al. 2019, 2020a);. It is well documented that fungi (as well as algae, lichens, seeds, fish eggs, and a host of bacteria) can survive long term exposure to space (Novikova et al. 2016; Orlov et al. 2017). Terrestrial fungus spores are discharged and catapulted from gill surfaces, achieving a velocity of up to 1.8 m $s^{-1}$ (Stolze-Rybczynski et al. 2009; Pringle et al. 2005). A single fungus can release up to 30,000 basidiospores every second; billions on a daily basis (Money 2011). Among ascospores it is believed their release may be triggered by the condensation of vapours on the cell surface (Webster et al. 1989). Moisture is absorbed causing the "ascus" to swell then burst thereby explosively releasing tens of thousands and eventually billions of spores into the air. However, this moisture evaporates once the spore is airborne (Hassett et al. 2015). In the atmosphere of Earth basidiospores are believed to act as nuclei which attracts moisture that in turn triggers water condensation and the formation of clouds (Hasset et al. 2015); clouds (Figures 3, 4) and evidence of thermal vents and subsurface aquifers (Joseph 2020a, 2021b; Suamanarathna et al. 2021; Clark 2005) and water pathways (Figures 15-18) have been observed in the same areas where fungus, hyphae/mycelium and fruiting bodies have been observed (Joseph et al. 2021a). Basidiospores are also released under dry conditions (Levetin 2021).

Spores may be colorless or pigmented; unicellular (non-septate), multi-cellular (septate); spherical, oval, curved, coiled, elliptical, cylindrical, fusiform, club-shaped; 2 to 3 µm in diameter or exceed 100 µm in length, such that on average, they may be said to range from 5 to 15 µm in size (Levetin 2021). The sexual spores (Basidiospores) consist of single cells and range in size, shape, and color and from 5-12 µm in size. The overall shape of basidiospores can be globose, elliptical, fusiform, nodulose, angular, or irregular. In addition, the basidiospores of many mushrooms and bracket fungi are asymmetrical due to the presence of a hilar appendage, which attaches the spore to the basidium. This attachment structure can be distinct or indistinct. Spore walls may be smooth or ornamented with spines, warts, or ridges. When dehydrated they may collapse (Levetin 2021; Money 2011).

As noted, it has been proposed that upper atmospheric fungi and fungus found on the outside of the

ISS, may have originated in space (Grebennikova et al. 2018); i.e. from other planets, including Mars (Joseph et al. 2019, 2020a; Joseph & Duvall 2021). Fossilized fungi have been observed in meteorites and in rock samples dated to 3.7 bya (Pflug 1978, 1984). This may explain why it has been, as of this writing, impossible to determine when terrestrial eukaryotic fungi supposedly diverged from bacteria. When this fossil evidence is excluded and based on calibrations assuming that mammals and birds diverged 300,000,000 mya, it has been estimated that the Ascomycota/Basidiomycota split was 1,808,000,000 mya (Taylor & Berbee 2006) and that the lineage that leads to the fungi may have been preceeded by nucleariid amoebae (Steenkamp et al. 2006); and that after the main fungal lineage was established the next divergence led to Blastocladiomycota (James et al. 2006). When puffballs (Basidiomycota) were first established on Earth is unknown; though it has been established that they can rapidly adapt to changing and extreme environments (Clark et al. 2004). As noted, fungi even survive long term exposure to the vacuum and extreme temperature fluctuations encountered in space (Novikova 2009, Novikova et al. 2016; Onofri et al. 2018; Pacelli et al. 2016). Further, they can survive in Mars-simulated environments (Sanchez et al. 2012; Selbman et al. 2015) .

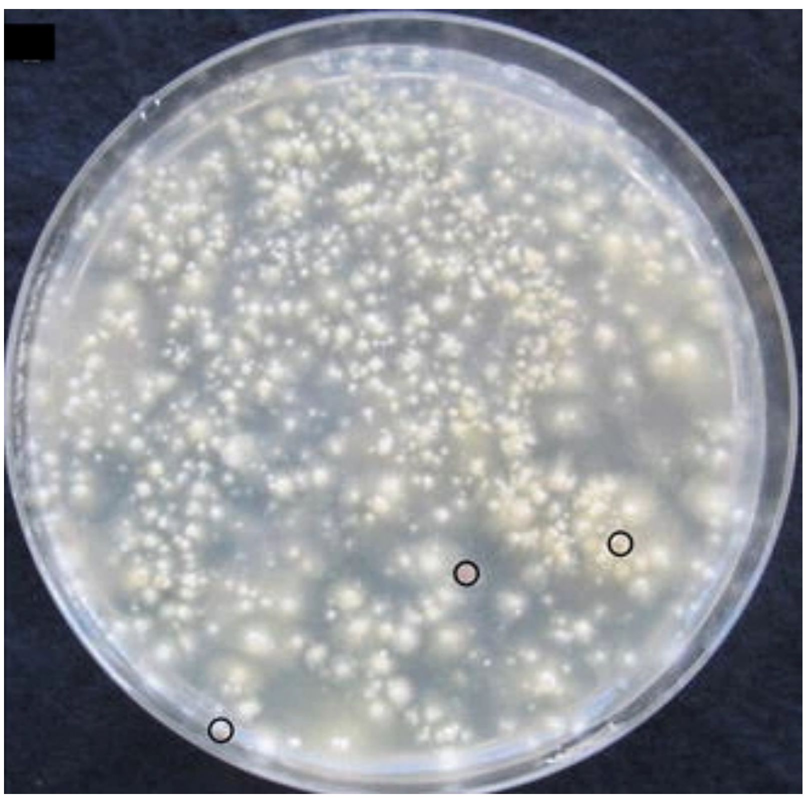


Figure 5. Colonies of germinating basidiospores similar to those observed on Mars adjacent to "puffballs" (Figures 13, 25-28) collected in the plastic lid of a Petri-dish. Encircled are three red yeast colonies. Reproduced from Lakkireddy & Kües, 2017.

## 3. Martian Mushrooms

Colonies of mushroom-like structures, attached to rock-like substrates via stems topped with bulbous caps were first tentatively identified in Eagle Crater, Mars, in 2006 and referred to as "Martian mushrooms" (Joseph 2006). Lichens are composite fungal-algae organisms; and lichens, fungi, and algae can survive long term exposure to simulated Mars-like environments (Sanchez et al. 2012; Selbman et al. 2015; De la Torre Noetzel et al. 2017; De Vera 201; De Vera et al. 2014) and lichens and algae have been observed on Mars (Armstrong 2021; Bianciardi et al. 2021; Kaźmierczak 2016, 2020; Latif et al. 2021; Joseph 2014; Joseph et al, 2019, 2020a,b). In 2006, hundreds of spherical specimens were also observed at ground level surrounding the surface around these rock-dwelling lichen-like specimens; later identified as fungal puffballs and "basidiomycota" (Joseph 2014, 2016; Dass 2017; Joseph et al. 2020b, 2021a).

It is well documented, via sequential photographs, that specimens identified fungi, on Mars, grow out of the ground, increase in size, dwell in crevices and between rocks, and will multiply and engage in movement (Joseph et al. 2021a). Evidence of what appears to be spores, sporangium, hyphae and interconnected networks of mycelium have also been observed (Joseph 2014, 2021; Joseph et al. 2021a).

In the following section we provide visual-pictorial evidence of (A) puffballs (B) exhibiting physical-morphological features indicative of preparation to spore (C) powdery spores on the surrounding surface (D) embryonic fungi (E) sporangium, hyphae, interconnected networks of mycelium.

## 4. Pictorial Evidence of Martian Puffballs, Spores, Hyphae, Mycelium, Embryonic Fungi

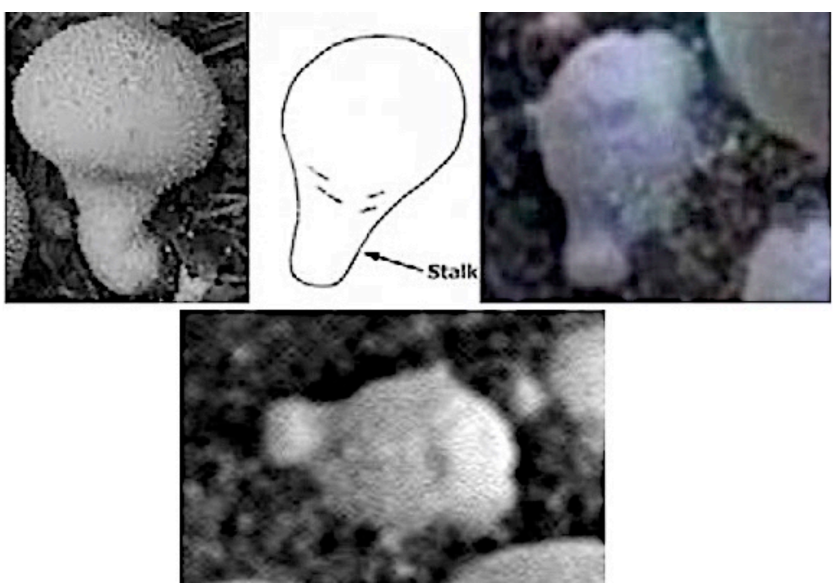



Figure 6. (Left) Terrestrial fungal puffball (Basidiomycota) with stalk. (Top Right & Bottom) Sol 257, Martian fungal Puffballs with stalk.

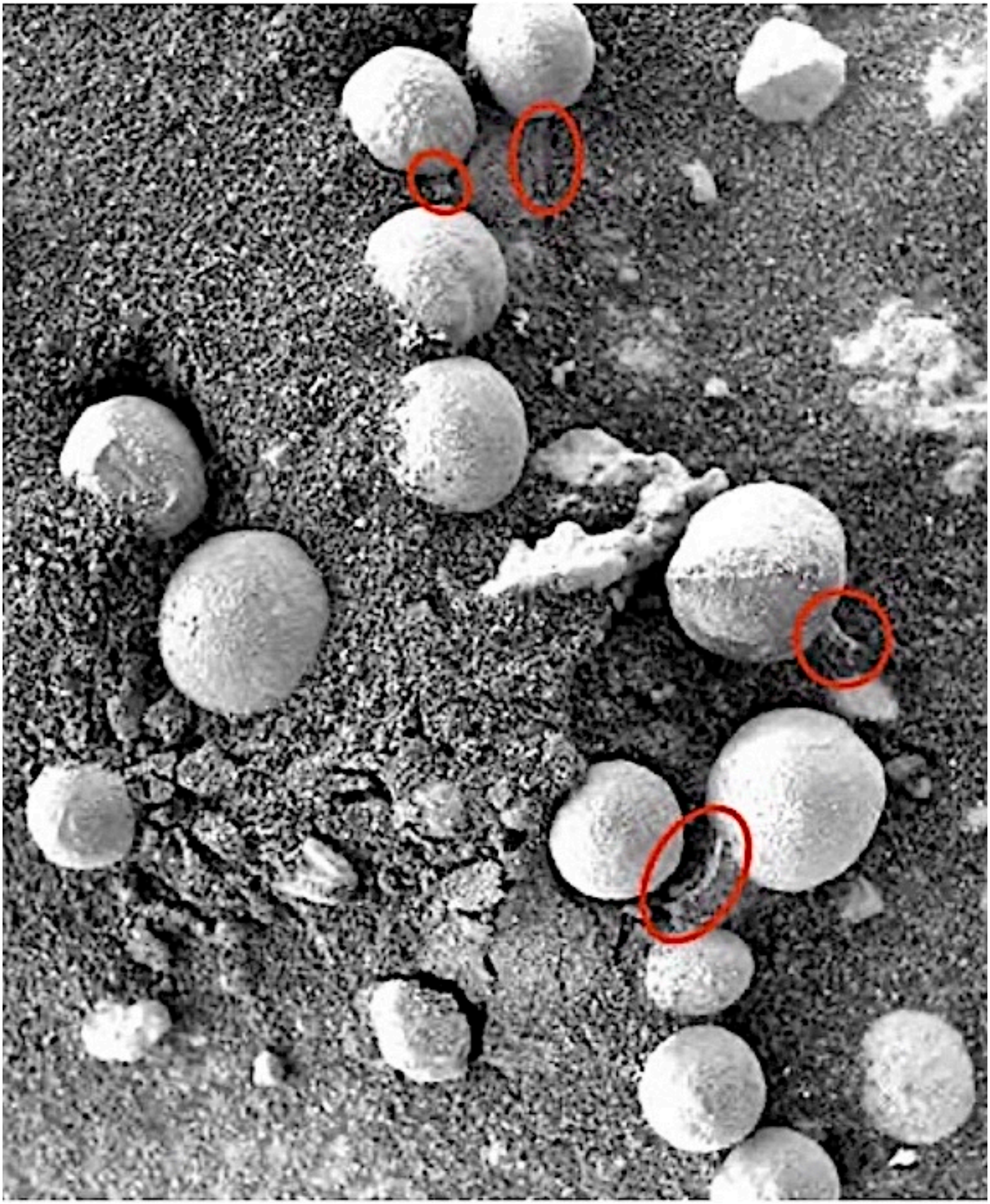


Figure 7. Sol 147. Mars. Martian specimens approximately 3-8 mm in size resembling Puffballs, some with stalks or shedding white spore-like material (leprose).

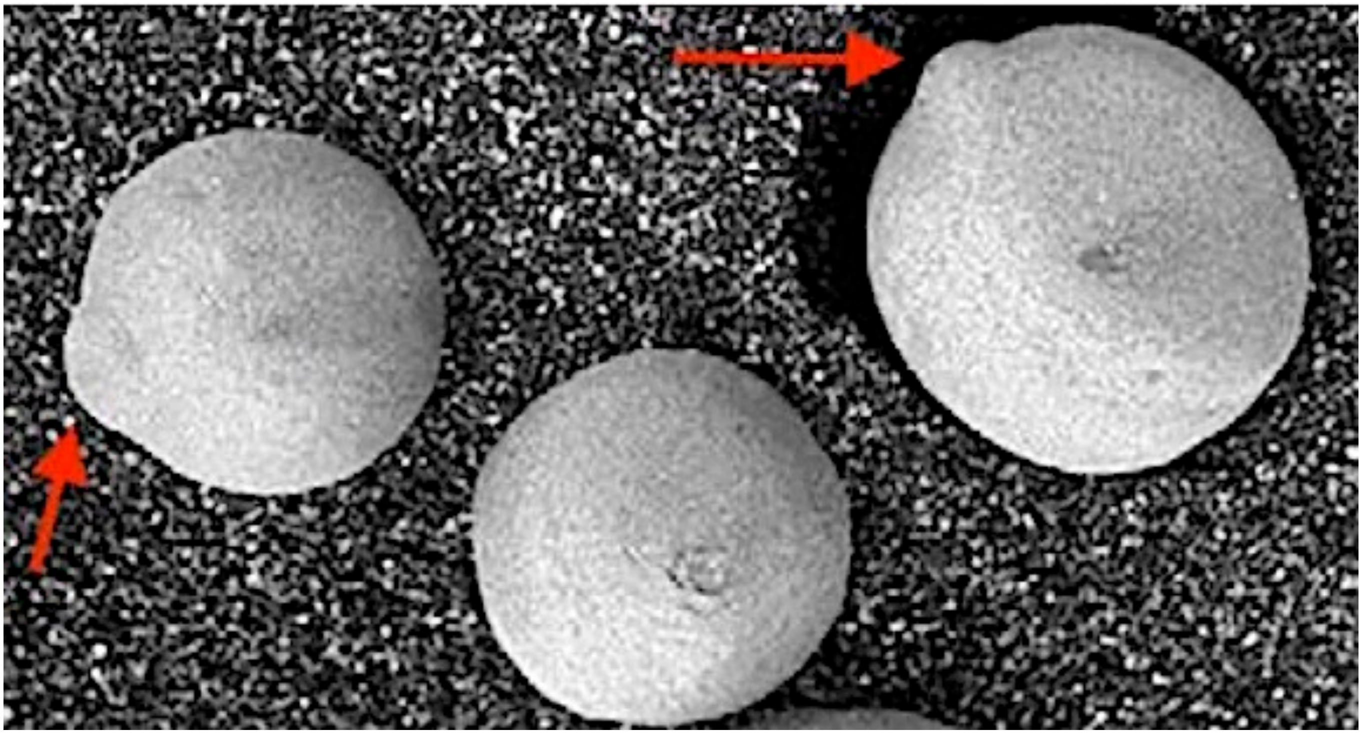


Figure 8. Sol 1148. Mars. Martian fungal “puffball.” Compare bulge/stalk with Figure 9 from Earth.

Figure 9. Earth. Terrestrial fungal “puffball” (Basidiomycota). Note and compare “lemon-shape” stalk bulge with Figures 8, 10-13) from Mars.

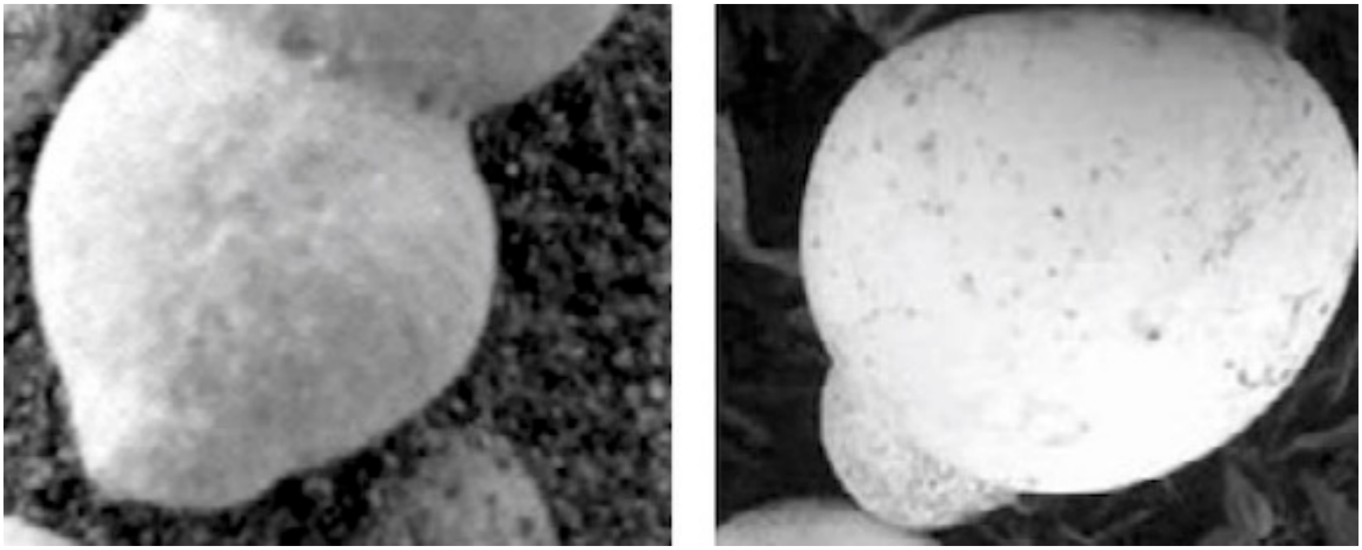


Figure 10. (Left) Sol 182 Martian fungal puffball. (Right) Earth. Terrestrial fungal “puffball” (Basidiomycota). Note “lemon-shape” stalk/bulge.

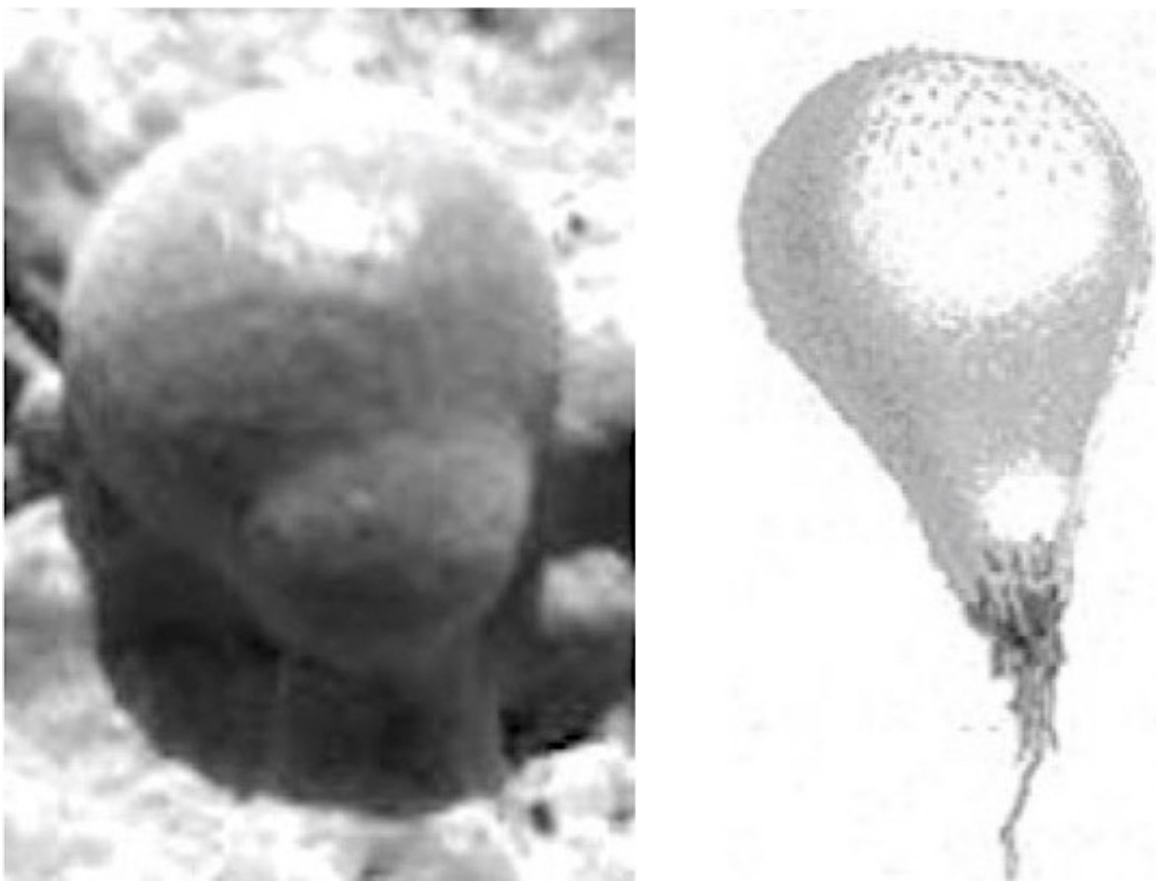
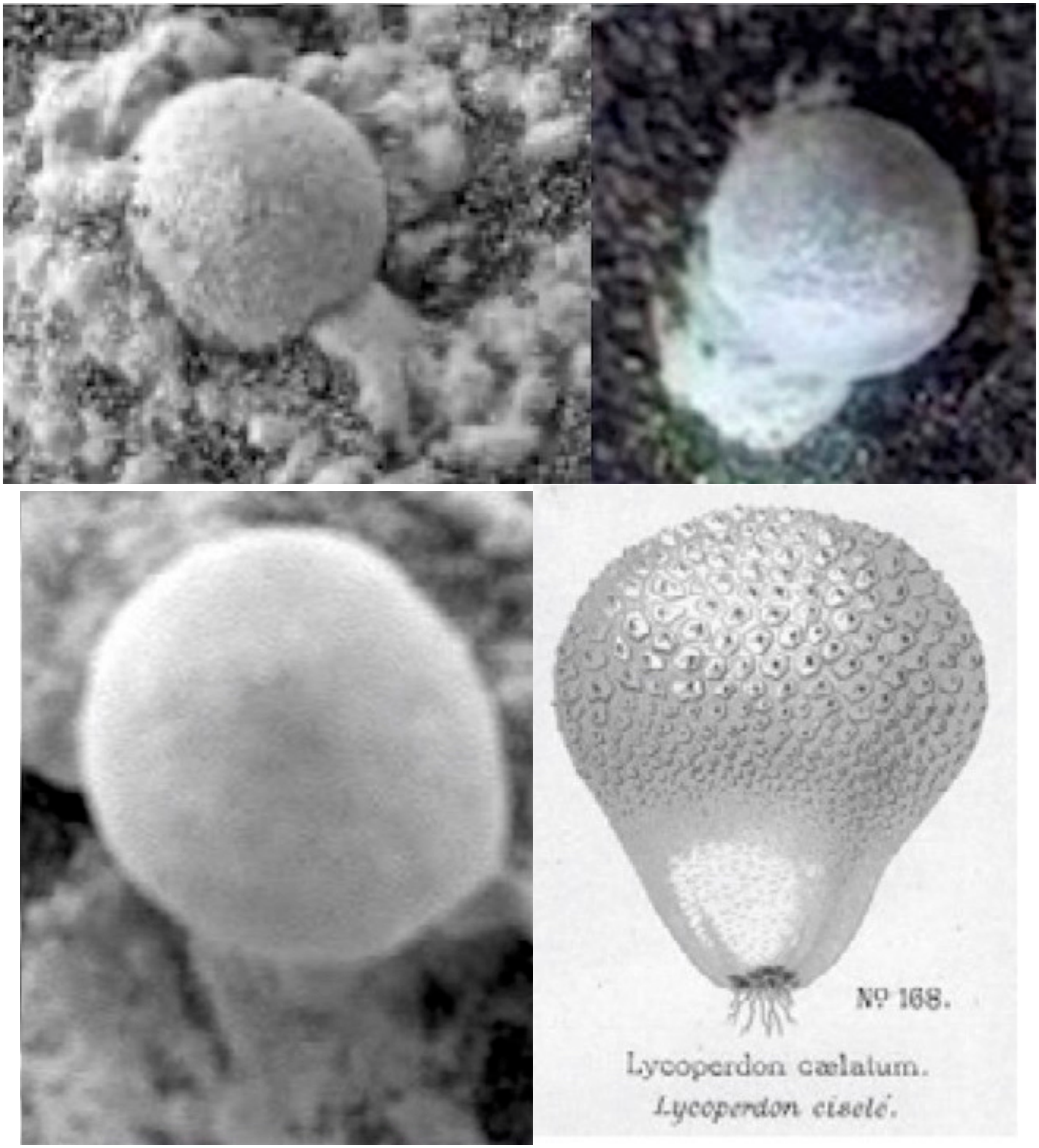


Figure 11. (Left) Sol 119 Martian fungal puffball. (Right) Earth. Terrestrial fungal “puffball” (Basidiomycota). Note “lemon-shape” stalk/bulge and roots (hyphae).




Figures 12, 13. (Top row and bottom right) Martian fungal puffball and hyphae/mycelium. (Bottom right) Earth. Terrestrial fungal "puffball." Note "lemon-shape" stalk/bulge and roots (hyphae).

Figure14. Sol 177. Martian fungal puffball with hyphae and surrounded by spore-like substances.

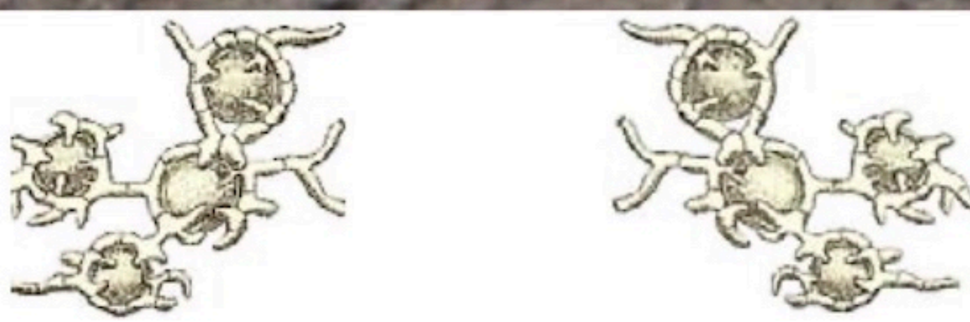


Figure 15. (Top) Mars, Gale Crater. Sol 270. Donut shaped specimens--approximately 1-2 mm in size--resemble networks of hyphae, mycellium, fruiting bodies and bulbous fruiting sporangia. Interconnected white networks may have become rigid, encrusted and seemingly calcified with calcium oxalate crystals (whewellite/weddelite) which is secreted by fungi and lichens. Note water pathway. (Bottom) Fungal hyphae 'harvest' nutrients produced by the photobiont; accomplished via fungal hyphae and mycelium branching and encircling and penetration of globose photobiont cells in order to harvest the photosynthetic products. From Schneider 1987.

Figure 16. Mars. Sol 192. Donut shaped specimens--approximately 1-2 mm in size--resemble-fruiting bodies and bulbous fruiting sporangia. Interconnected white networks of hyphae and mycelium that may have become rigid, encrusted and seemingly calcified with calcium oxalate crystals (whewellite/ weddelite) which is secreted by fungi and lichens. Note water pathways.

Figure 17. Mars. Sol 270. Hyphae that snake across and sometimes rise above the surface. The white networks consist of calcified fungal mycelium punctuated with fossilized bulbous fruiting bodies. Note water pathway.

Figure 18. Mars. Sol 270. The white networks likely consist of calcified fungal hyphae and mycelium or encrusted plasmodium and protoplasmic tendrils punctuated with fossilized bulbous fruiting bodies.

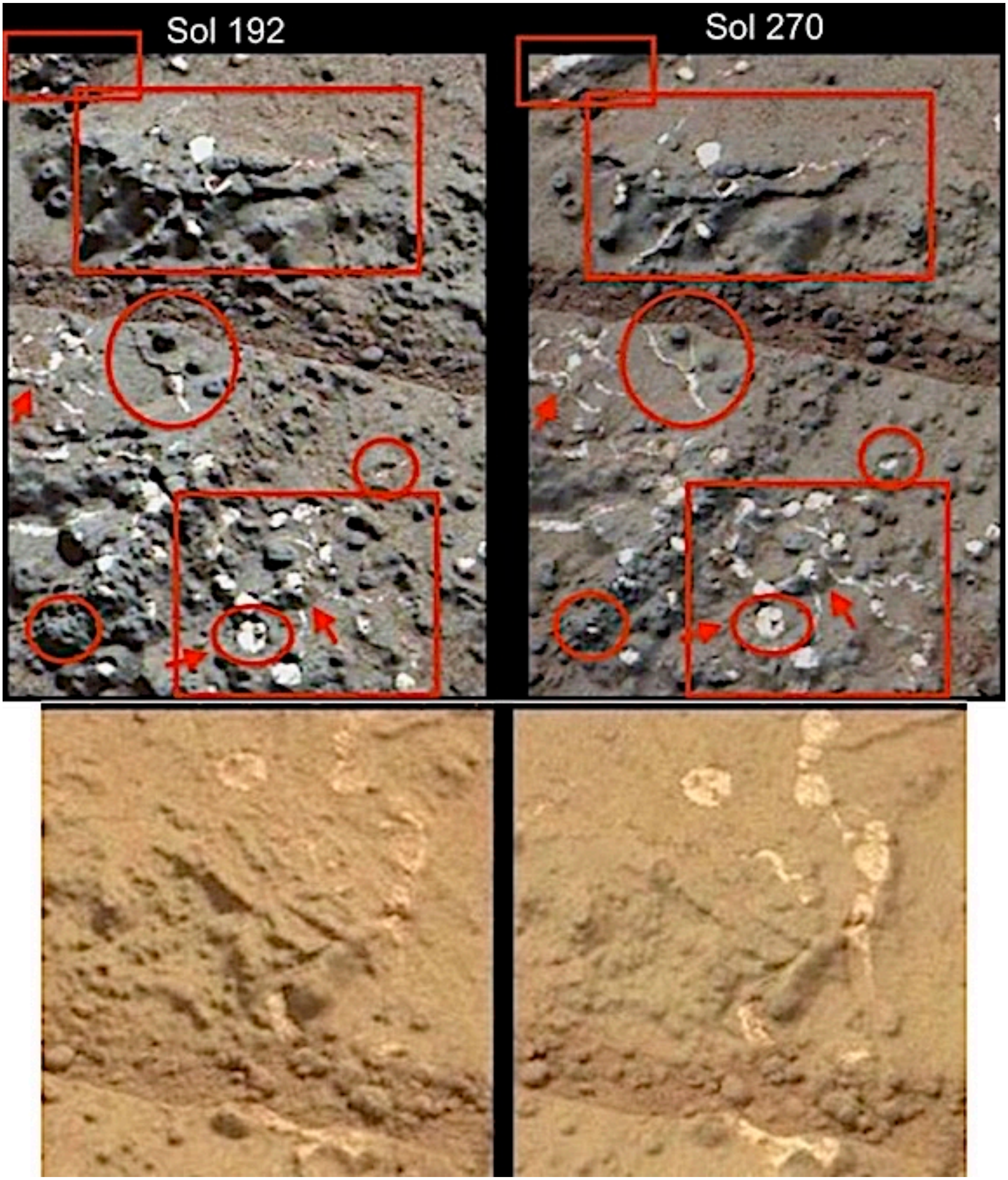



Figure 19. Evidence of growth. Sol 192 (left column) vs Sol 260 (right column). White specimens resemble plasmodium, the bulbous fruiting sporangia and interconnected networks of mycelium, hyphae and fruiting bodies possibly secreting calcium oxalate crystals (weddelite) as they grow from beneath the soil above the ground.

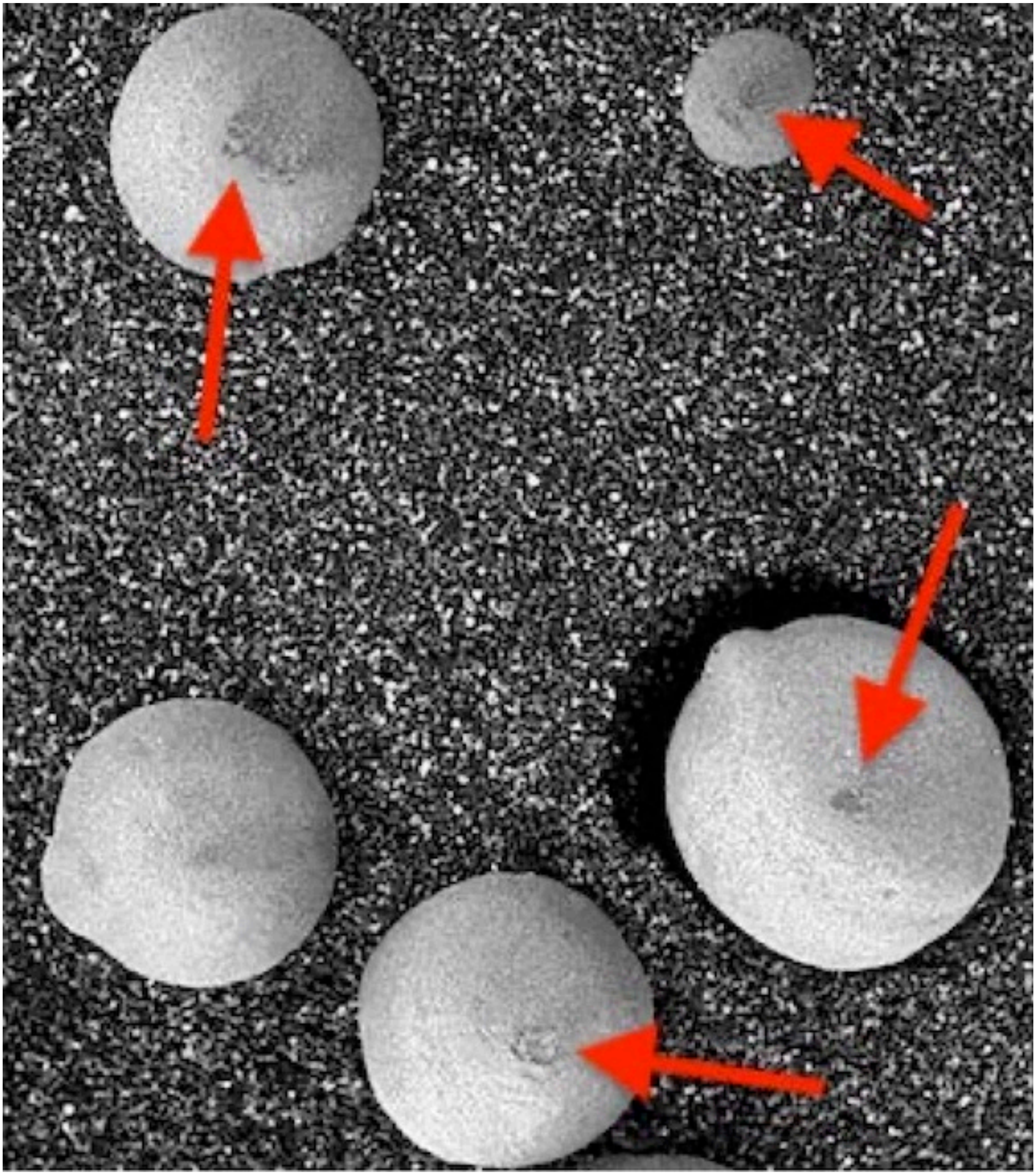


Figure 20. Sol 182. Mars. Martian puffballs preparing to spore through their top cap. Note holes/ apertures.

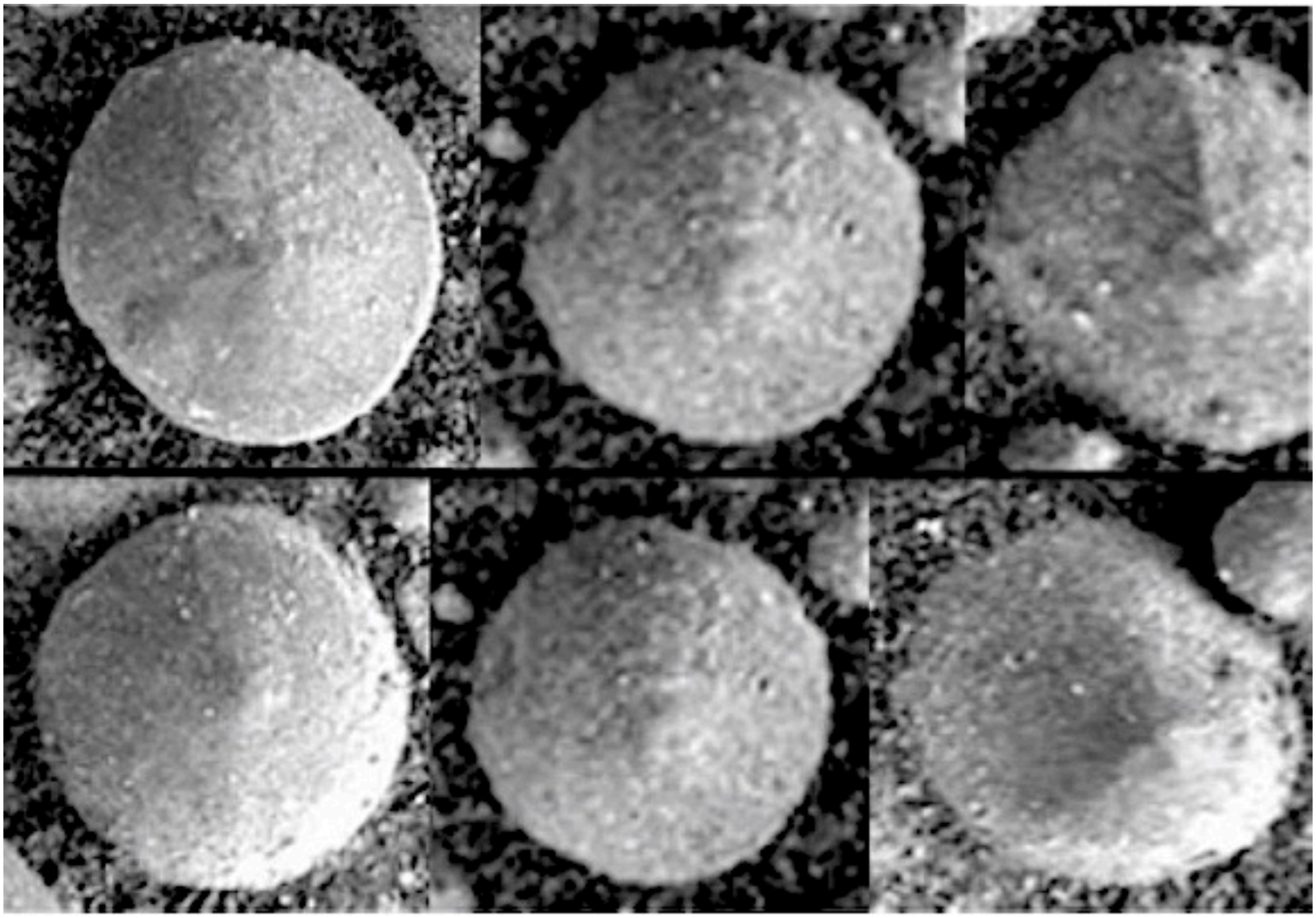


Figure 21. Mars. Martian puffballs preparing to spore through their top cap. Note holes/apertures.

Figure 22. Earth. Fungal puffballs preparing to spore through the bulge and the top of the cap.

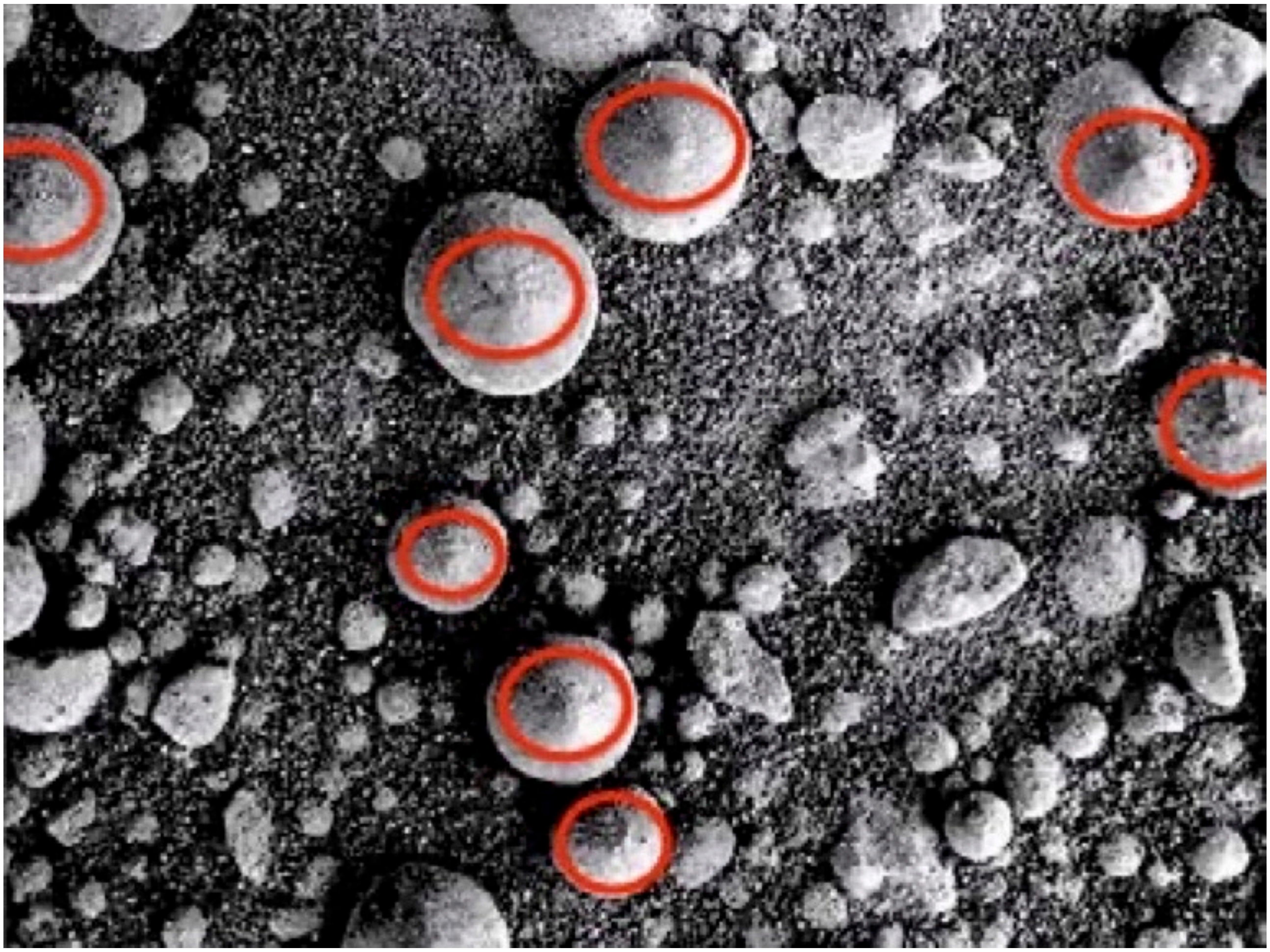


Figure 23. Mars. Martian mushrooms (puffballs) preparing to spore through their top cap. Note holes/ apertures.

Figure 24. Earth. Terrestrial fungal puffballs) preparing to spore and sporing through their top cap.

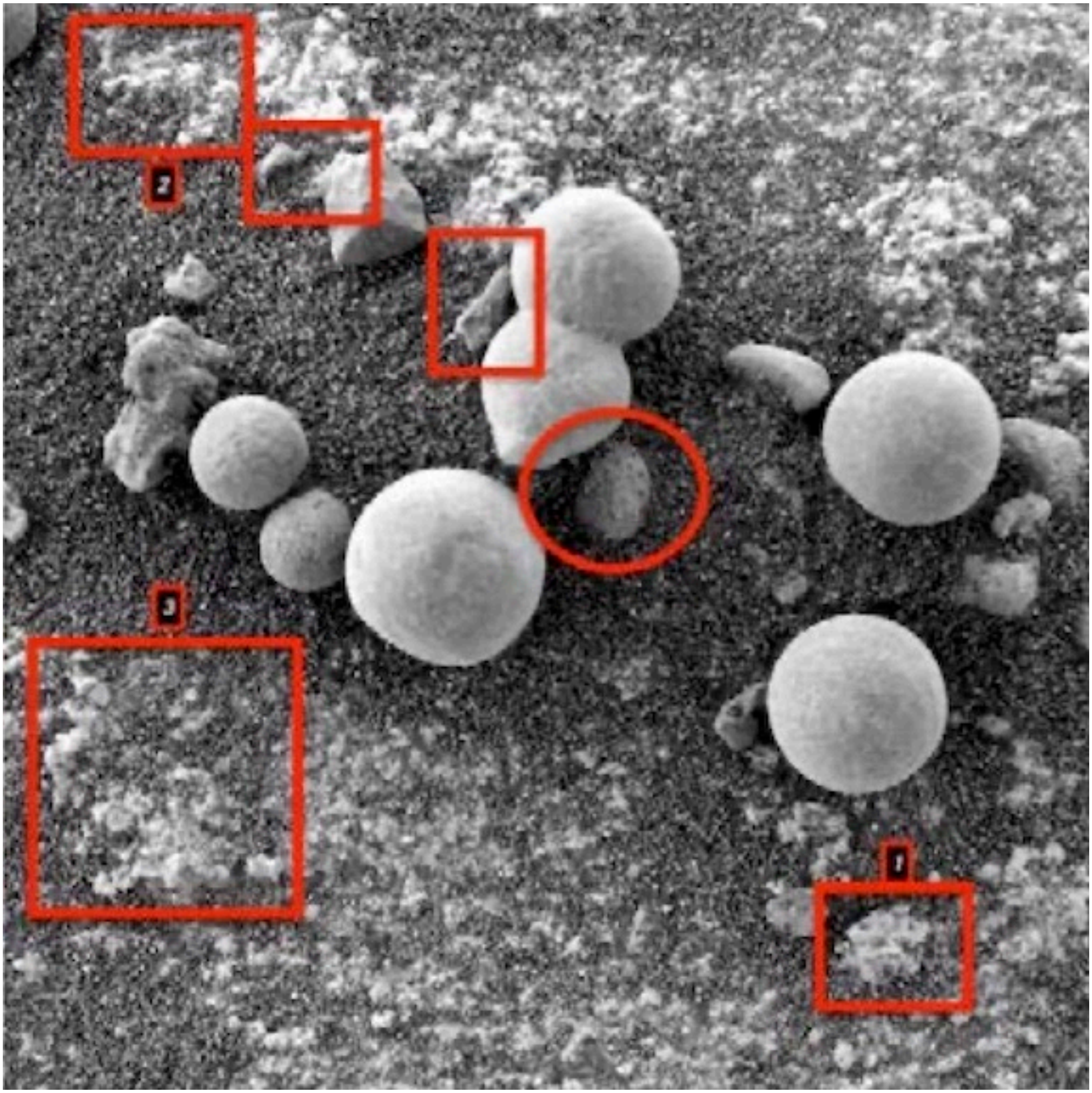



Figure 25. Mars. Sol 182.  puffballs surrounded by fluffy white spores within which embryonic fungi are growing (see Figure 26).

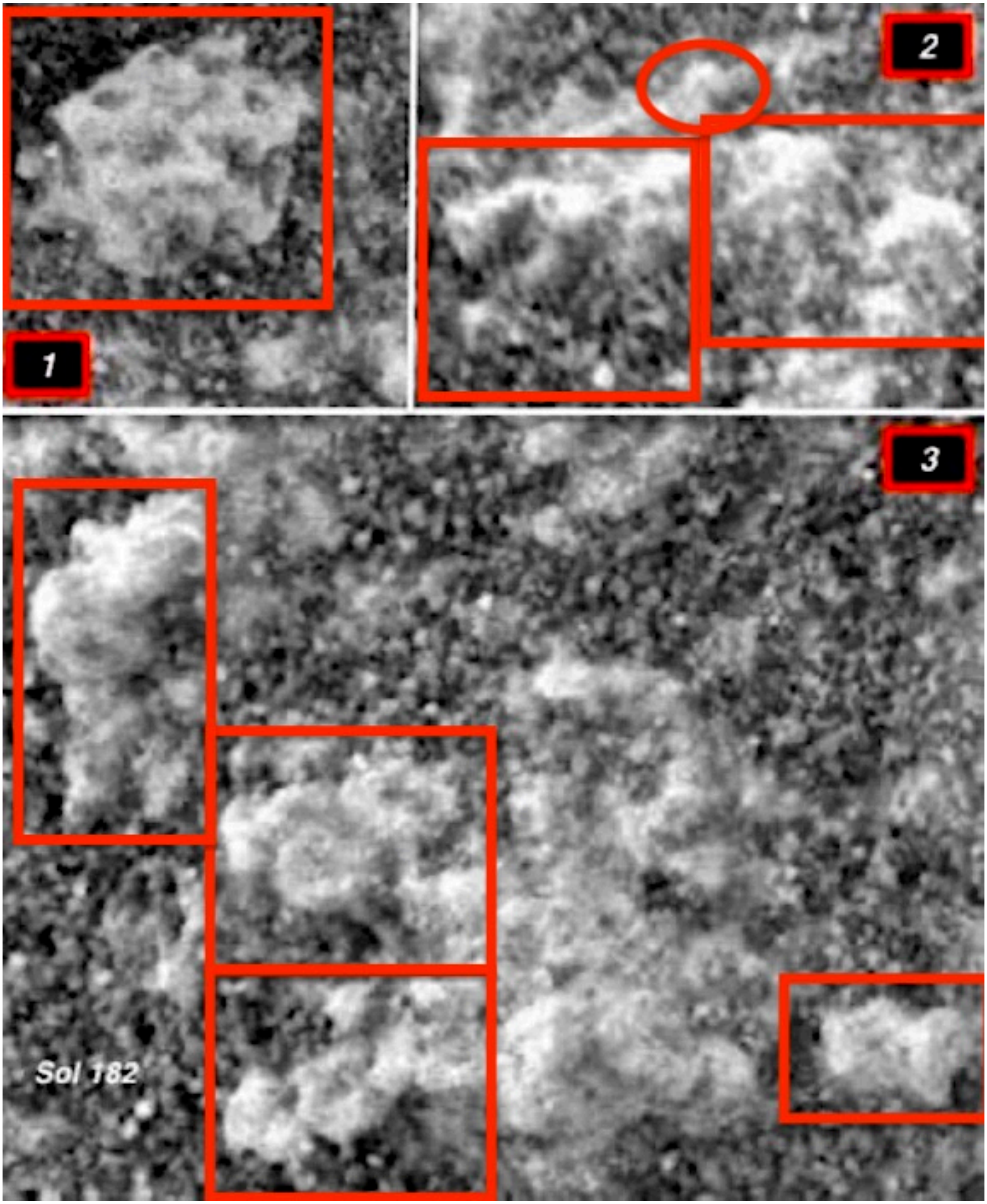



Figure 26. Mars. Sol 182. Embryonic fungi growing with spores (see Figure 25).

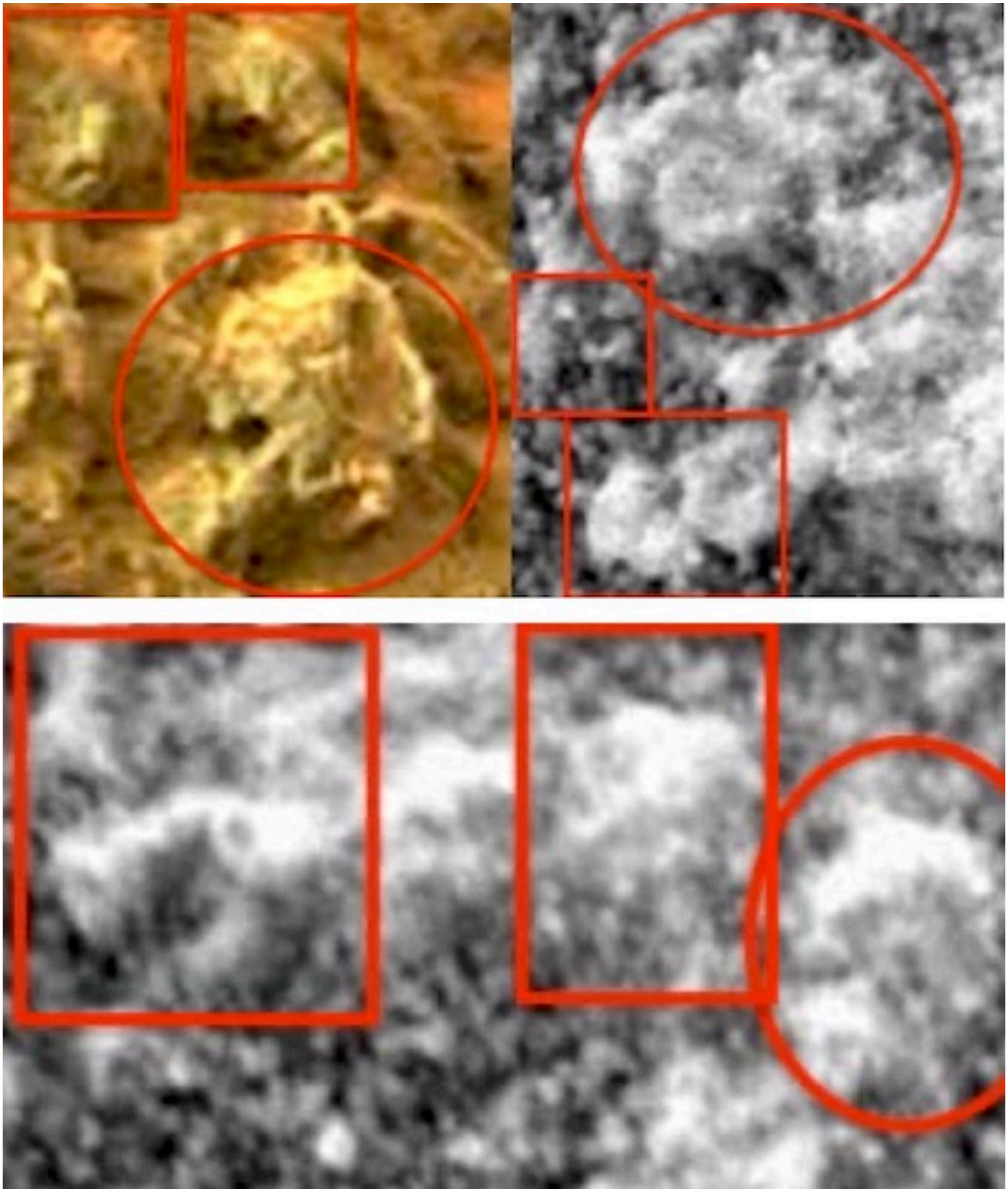


Figure 27. (Top left) Mars, Gale Crater. (Top right and bottom) Martian Embryonic tubular and mushroom-shaped fungi.

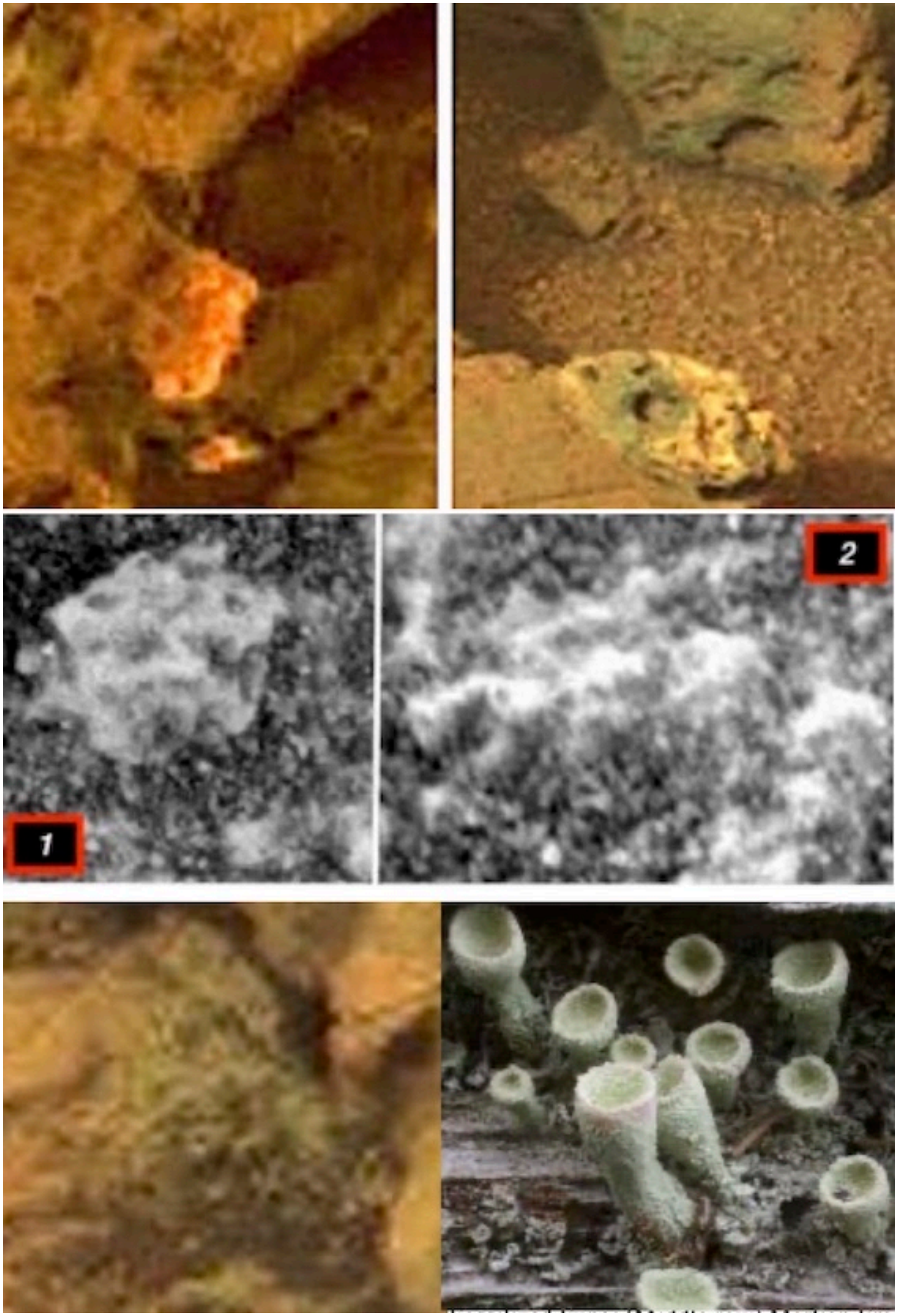



Figure 28. (Top row) Mars, Gale Crater. (Mid-row and bottom left bottom) Martian Embryonic tubular and mushroom-shaped fungi. (Bottom right) Earth: Terrestrial lichenized fungi.

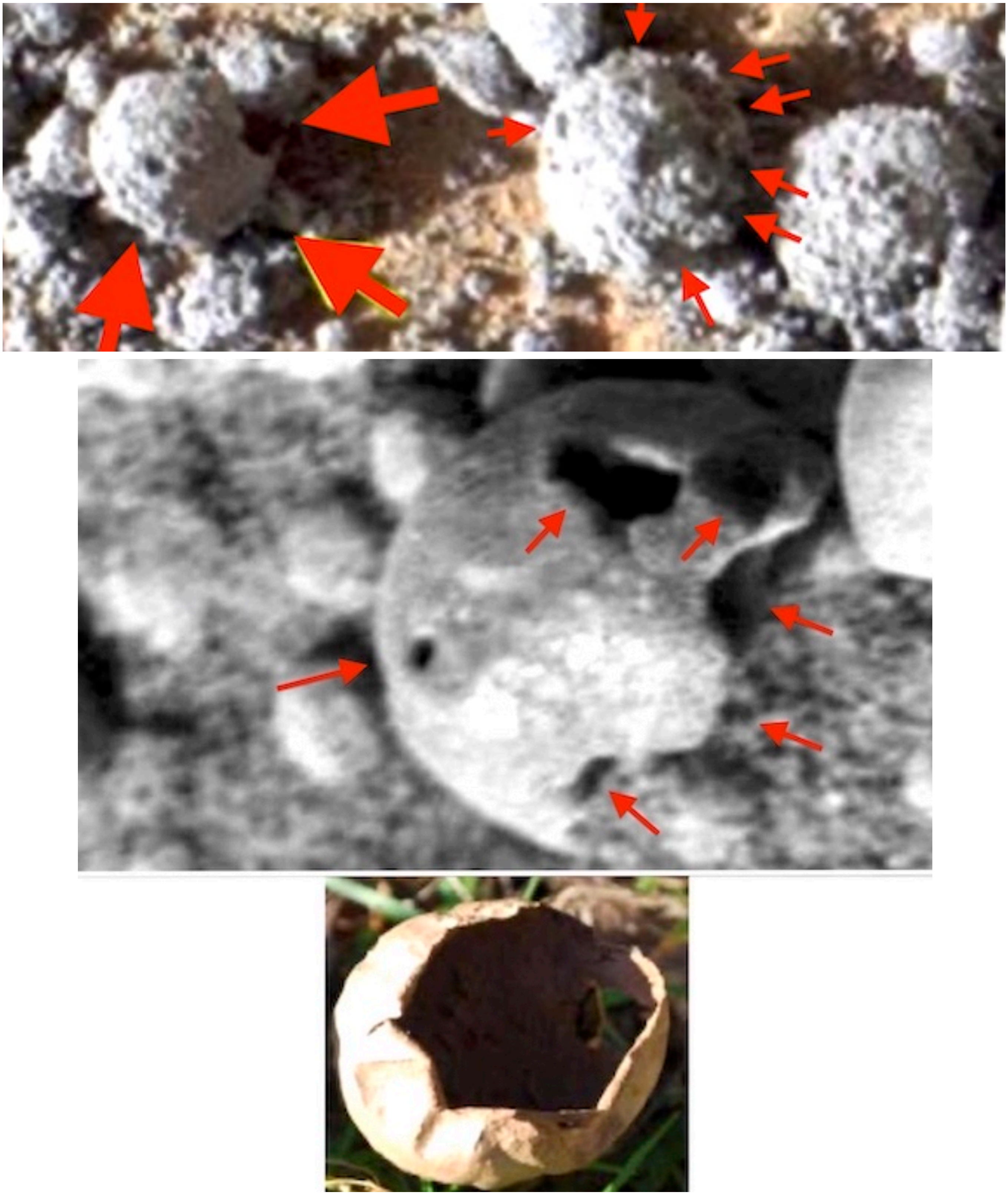


Figure 29. (Top and middle row): Mars. Meridiani Planum. Sperical specimens photographed adjacent to Martian puffballs and fluffy spores upon the surface. (Bottom): Earth. Dead shells of fungal puffballs after they have spored. Curtesy of WildFoodUK.com

## 5. Fungi and Martian Mud

Mud requires the presence of water and biomass (fungi, microbes) that enable soil to clump (Ceasar-Tonthat, 2002; Forster 1989; Voroney et al. 2008; Tiessen and Stewart 1988). In this report, and others, we have provided evidence of mud and that fungi have colonized Mars.

That there has been, and there is water on Mars, has also been established beyond doubt, though it is believed that much of this water is frozen in the polar ice-caps and just beneath the surface and that it periodically melts and floods or percolates to the surface (Andrews-Hanna et al. 2007; Arnold et al. 2019; Bibring et al. 2006; Joseph et al. 2020b,c; Sori et al. 2019) and forming liquid brines (Renno et al. 2006) and mud (Joseph et al. 2020d).

Mud, clumps of mud, and cloudy-ice have been photographed attached to NASA's Mars rover wheels, and evidence of moist soil in the tire tracks has been photographed on numerous occasions (Joseph et al. 2020d). As documented in Figures 30-31, there are clumps of mud on the outer surface of the rover wheel wells, muddy-water marks within the wheels adjacent to clumps of cloudy-feathered ice.

Figure 30. Sol 560. Clumps of moist mud on the outside wheels of the Mars Rover Curiosity. The fluffy-feathered-horned appearance of this ice mirrors the raised chevrons on the outside of the wheel. The compacted mud is darker than surrounding soil surfaces, and is clearly moist and wet, as also indicated by its adhesion to the outside of the wheel.

Figure 31. Sols 528, 529. Mud and moist soil adhering to the rover Curiosity wheels. The compacted mud varies in shades of darkness, which is an indication of varying degrees of moisture and drying. That this adhering soil moist and wet is also indicated by its adhesion to the outside of the wheel. The soil is the rover tire tracks also varies in coloration, the darker color indicting the presence of moisture, which may have been released by compression due to the pressure of the rover wheels against the surface.

Mud and the attachment of mud to metal surfaces is made possible in the presence of moisture (Fountaine 1954; Li et al. 2019, Sun et al. 2016; Tong et al. 1994) coupled with the adhering properties of biomass (Kidron et al. 2017, 2020). It is soil biomass (diverse bacteria, actinomycetes, and fungi), and their excretions, coupled with water, which act to aggregate, clump together, bind and adhere clumps of soil to smooth surfaces (Ceasar-Tonthat, 2002; Forster 1989; Voroney et al. 2008; Tiessen and Stewart 1988), including the affinity of clods of soil to attach to metal surfaces (Bazaka et al. 2011; Ceasar-Tonthat, 2002; Chen et al. 2014).

Biological contributions to soil binding include the mucilage produced by basidiomycete fungus (Ceasar-Tonthat, 2002). Fungal mucilage serves as a biological glue which binds soil particles together. Specifically, basidiomycete fungi and other microorganisms, including cyanobacteria, when exposed to hydrated soil, secrete various substances including polysaccharides which stabilize and bind surrounding soil (Bazaka et al. 2011; Ceasar-Tonthat, 2002; Chen et al. 2014; Chenu 1995; Kidron et al. 2020) thereby causing soil to adhere to metal and other surfaces (Loosdrecht et al. 1987) particularly when the soil or those surfaces are wet (Absolom et al. 1983; Rosenberg and Kjelleberg, 1986; Stotzky 1985). If polysaccharidics and/or bacteria and fungi are experimentally eliminated from soil samples there results a dramatic loss of soil aggregate and adhesive stability (Tang et al. 2011). The evidence of mud and clumps of soil adhering to the rover wheels indicates that fungi, bacteria, and the biological secretion of polysaccharidics have infiltrated the soil. However, in addition to soil bonding properties, polysaccharides provide resistance to desiccation (Bazaka et al. 2011) thereby enabling these microbes and fungi to survive long periods without water.

Mud on Mars provides additional evidence supporting the hypothesis that fungi have colonized the Red Planet and have infiltrated the soil.

## 6. Discussion, Speculation & Conclusions

Without extraction and direct physical examination it is impossible to know with absolute certainty if the spherical specimens of Mars are "puffballs," or if they belong to the fungal family known as "basidiomycota" or if they are a lichenized fungus. However, these spherical specimens closely resemble puffballs (Dass, 2017; Joseph 2016, 2021; Armstrong, 2021), are almost uniform in shape and size, collect together in "colonies" of what may be tens of thousands of organisms; have been photographed in numerous locations within Meridiani Planum often adjacent to dried water pathways; have been crushed by the rover wheels only to re-appear in old rover tire tracks; and sequential photos have documented that they grow out of the ground by the dozens over a three to seven day period (Joseph et al. 2021a). Furthermore, although they appear "gray" in color, they have also been described as heavily pigmented with yellows, greens, purples and blues predominating (Soderblom et al. 2004), which are also the colors of pigmented organisms that engage in photosynthesis (reviewed by Joseph et al. 2021b). They have also been photographed adjacent to networks of what appear to be hyphae and mycelium and what appear to be white spores within which can be discerned what the author's believed to be embryonic fungi.

Clouds have been photographed in the Equatorial regions of Mars including where these fungus-like spheres have been observed, liquid brines and mud have been reported (Renno et al. 2009; Joseph et al. 2020d) and there is evidence of nearby hydrothermal vents (Joseph 2021b; Suamanarathna et al. 2021) and in other areas of Mars large volumes of ice and melt water beneath the surface that are being heated by unknown thermal anomalies (Arnold et al. 2019; Sori et al. 2019); and evidence of repeated and recent inundations of large volumes of water in different surface areas (including Meridiani Planum) due presumably to the periodic melting and upwelling of subsurface glacial-lakes and rivers of glacial water (Andrews-Hanna et al. 2007; Bibring et al. 2006). There is also evidence of underground aquifers, beginning at a depth of 1 meter beneath the surface (Clark et al. 2005) in the same area (Meridiani Planum) where vast numbers of spherical "puffballs" have also been photographed. Moisture and mists would sustain these organisms and promote sporing. Indeed, fungal spores may be contributing to the formation of clouds and fungi may make possible the formation of mud that adheres to the rover wheels.

In addition, although fungi seek out, grow towards and thrive in response to high levels of radiation, and survive exposure to the UV and gamma rays of space; strong crustal magnetic fields have been detected on Mars, via the Global Surveyor, particularly within craters including those in the equatorial regions (Acuña et al., 1999, 2001; Connerney et al., 2001) where fungi have been observed as reported here and in other studies. These crustal ground level magnetic fields are as strong as those of Earth and might deflect radiation and provide some protection for any organisms dwelling on the surface.

It is recognized that the authors have not proven, in this report, that fungi have colonized Mars and/or that fungi are generating spores and reproducing. Proof requires extraction, examination, and experimentation. Nevertheless, the authors believe that the evidence, reviewed and presented here, supports the hypothesis that these are living organisms engaged in sporing and reproductive behavior.

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