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Growth of Cyanobacteria in Gale Crater, Mars, Based on Sequential Images

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ABSTRACT

Multiple specimens that closely resemble calcium-encrusted cyanobacteria (blue-green algae) were photographed by NASA's rover Curiosity in Gale Crater, Mars, several having a blue-green coloration. Comparisons of sequential photos, taken three to five days apart, indicate that putative cyanobacteria are growing, changing shape, multiplying, and secreting spreading pools of what may be calcium carbonate. Specimens that resemble algae/cyanobacteria were first observed during NASA's Viking Mission and have since been reported in other areas of Mars. Structures resembling microbialites and stromatolites--presumably fashioned by cyanobacteria--have been previously observed in Gale Crater. Cyanobacteria are also primary oxygen producers and the Martian atmosphere is continually replenished with oxygen. Some of the specimens reported here may have been infiltrated by fungi. It has been previously reported, based on sequential photos by the rovers Opportunity and Curiosity, that fungi grow, change shape, increase in size, and multiply. The observations and photos presented in this and other reports strongly support the theory that biologically active cyanobacteria have colonized Mars.

Keywords: Green Algae, Blue Green Algae, Life on Mars; Cyanobacteria, Fungi

INTRODUCTION

Algae and the growth of "cyanobacteria" in gale crater?

Green specimens similar to algae have been observed upon rock-like sediment in Utopia Planitia and Chryse Planitia [1,2] and those with features similar to green algae and cyanobacteria have been photographed in Gusav Crater and Gale Crater [3-11]. In addition, formations closely resembling microbialites and concentric stromatolites presumably constructed by cyanobacteria and green algae-have been observed in several locations on Mars, Gale Crater in particular [3, 7, 9, 12-22]. As reported here, specimens resembling encrusted calcified cyanobacteria, many with a blue-green color, have now been observed in Gale Crater growing, including those that change shape and orientation and multiply over three to five days as based on comparisons of official NASA sequential photos.

LITERATURE REVIEW

Analysis of photographs by NASA's Curiosity's Micro-Imager Camera indicates the specimens presented here resemble calcium carbonate-encrusted cyanobacteria similar to *Nostoc flagelliforme, N. parmelioides, N. verrucosum, N. pruniforme,* and *Subtifloria* in particular [9]. The semi-symmetrical patterns assumed by some specimens are similar to the cyanobacteria *Snowella litoralis* (Synechococcales), and Cyanophyta (Figures 3,4). However, without extraction and genetic and microscopic examination, it is impossible to precisely determine the identity of these forms other than to note many specimens are blue-green, adjacent to water pathways, and that all are encrusted with what may be calcium carbonate. Many are also covered with bulging spherical thrombi and/or nostoc balls (Figure 1): substances produced via cyanobacteria secretions and that form calcified sheaths within which cyanobacteria are typically embedded [23]. Several of the specimens reported here (Figures 5-11) resemble *Candidatus Gloeomargarita lithophora*, as well as *Cyanophyta* and *Snowella litoralis* all of which produce intracellular Ca-carbonates that coat the cellular surface, and that typically form several radiating chains that correspondingly increase in length and size and change orientation as the cyanobacteria grow [24-25]. Because of the depth of field and angle and distance of these specimens from the camera the inclusion of "scale bars" would be deceptive and misleading. The graphic scale of the specimens in these images cannot be obtained from information NASA makes available. We estimate that the average size of the majority of these specimens is approximately 40 micrometers (40µm) with lengths and diameters approaching up to 100µm. However, their actual length, width, and diameter are unknown.

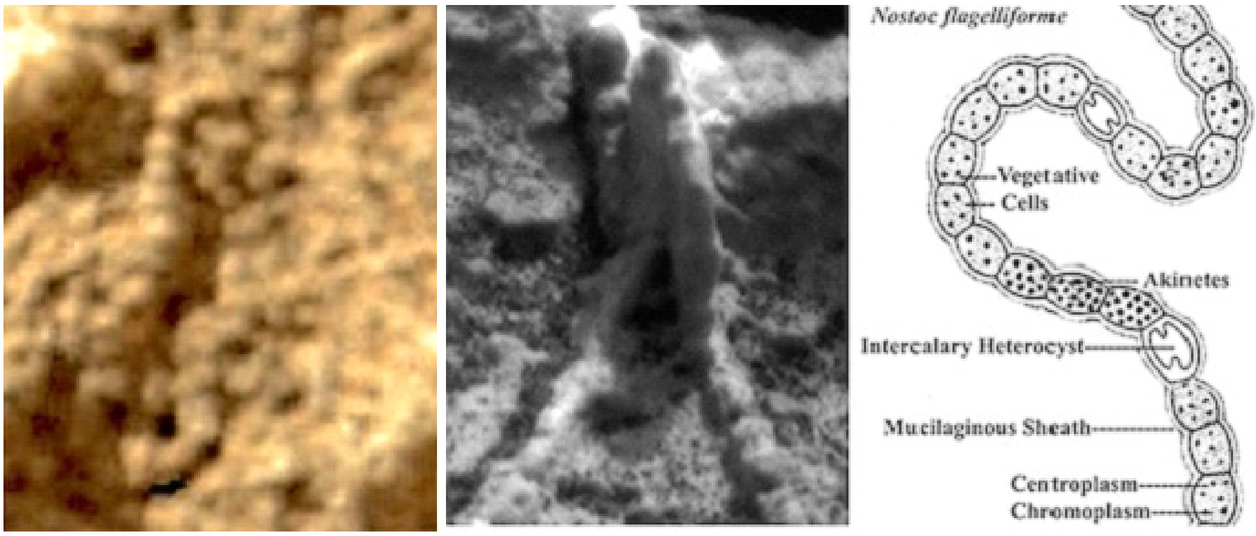

Figure 1. Left/Middle: Gale Crater. Calcium carbonate encrusted cyanobacteria, perhaps similar to *Nostoc flagelliforme*. Note "Nostoc balls," and vesiculous thalli and thrombolites (large and small micritic clots), similar to *Subtifloria* (a fossil member of the Girvanella group). These segmented spherical are formed via calcification of extracellular polymeric substances making up multiple biofilms and within which calcified sheaths of cyanobacteria are typically embedded. These sheaths most likely consist of intracellular calcium-carbonates biomineralization forming several chains within its cells.

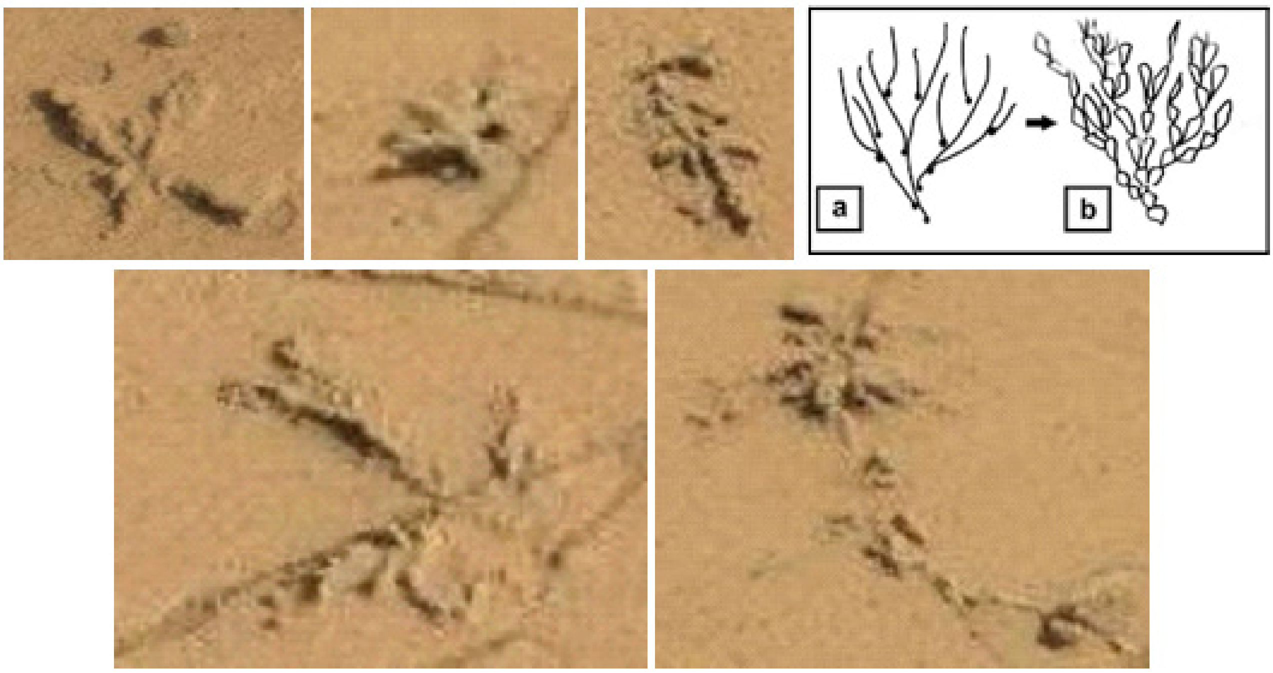

Figure 2. Branching cyanobacteria filaments incrusted as carbonate encrusted tubular shrubs with smaller tuft of branching filaments growing toward the outer periphery. Left: Gale Crater specimen photographed on 0753MR0032370200403743E01_DXXX. Middle: Gale Crater specimens photographed on 0753ML0032370090400010E01_DXXX. Right: Diagram of (a) Growth of branched cyanobacterial filaments and (b) followed by increasing calcification as it grows (Modified after Koban) [26].

Figure 3. Note Water Pathways. 0767MR0033070000403866E01_DXXX.

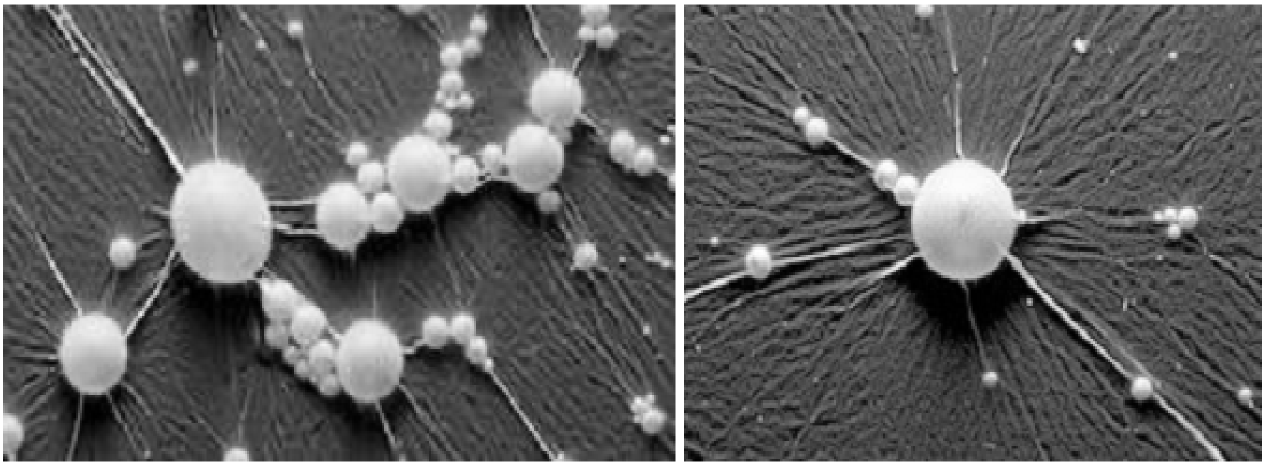

Figure 4. (From Earth) *Cyanobacteria Cyanophyta*.

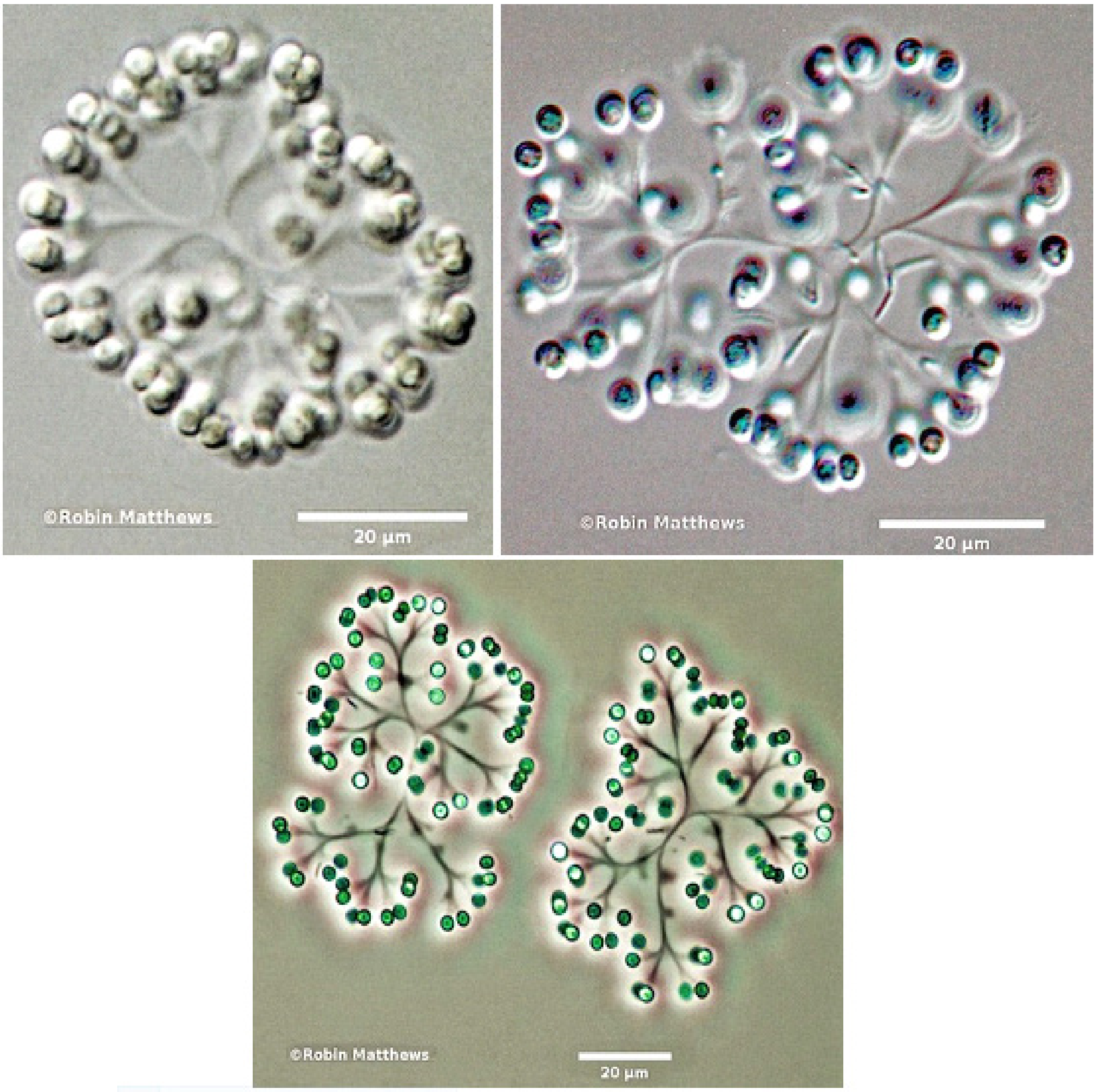

Figure 5. (From Earth) *Snowella litoralis* (*Synechococcales*).

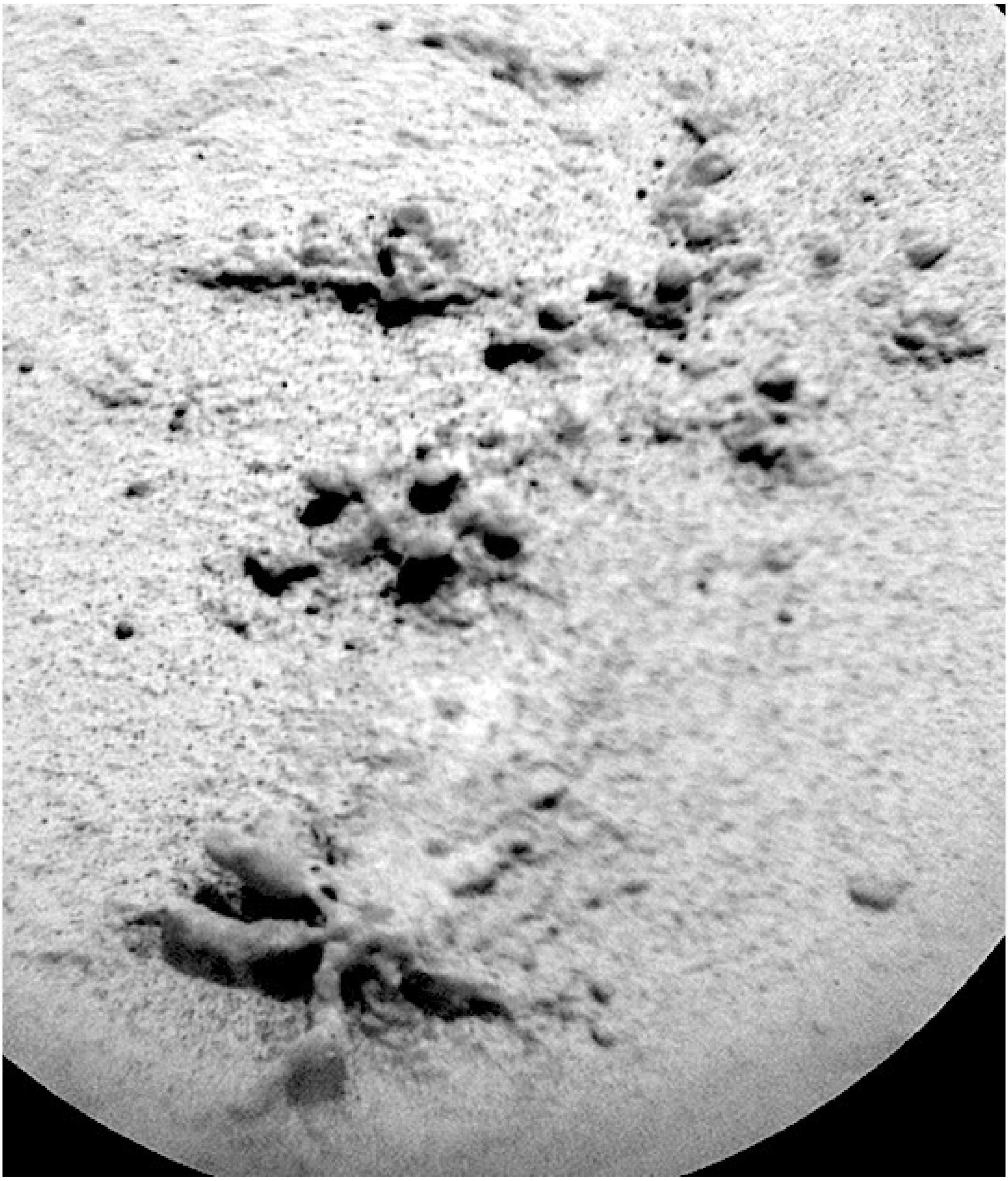

Figure 6. CR0_464779288PRC_F0421020CCAM02758L1. Photographed by Curiosity's Micro-Imager Camera in Gale Crater, Mars. These specimens resemble calcium oxalate, calcium incrustations and calcium carbonate encrusted cyanobacteria--perhaps similar to *Nostoc flagelliforme, N. parmelioides, N. verrucosum, N. pruniforme* Note spherical "Nostoc balls," and vesiculous thalli. "Nostoc balls" are a calcium encrusted byproduct directly related to the photosynthetic activity of cyanobacteria, formed by the calcification of extracellular polymeric substances making up multiple biofilms and reflect fundamental features of cyanobacteria growth and calcification. The average size of these specimens is approximately 40µm with diameters approaching up to 100 µm.

Figure 7. Fossilized cyanobacteria (Girvanella, Orpikania freucheni) from the Ekspedition Brae Formation, southern Freuchen Land, Greenland National Park (from Peel [27]).

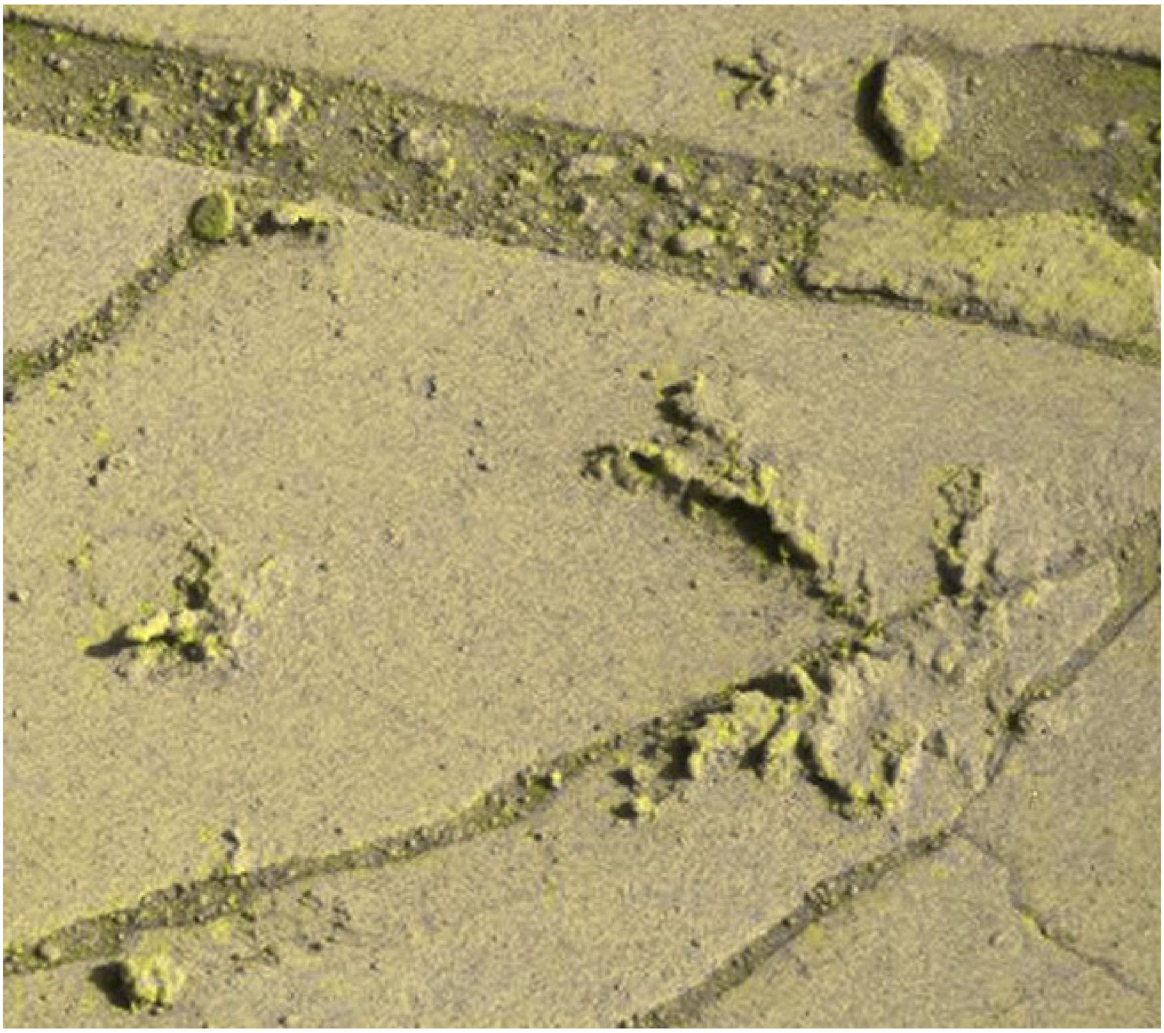

Figure 8. The greenish color is embedded in the spectrum of the original NASA photograph taken by Curiosity's Micro-Imager Camera, in Gale Crater on Sol 0753ML0032370090400010E01_DXXX. This photo was color-saturated but not colorized and no colors were added. The greenish color is typical of blue-green cyanobacteria. Note multiple cyanobacteria and branching tufts and tubular filaments. It is possible, but not obvious, that fungal hyphae may have infiltrated some of these specimens. When compared with photos taken three days later (Sol 753 vs 758) it is apparent that the central specimen is most likely alive as portions have changed shape and orientation (see Figure 8). The average diameter and/or length of these specimens may range from approximately 20 µm to 100µm.

Figure 9. Top/Bottom Left) 0753ML0032370090400010E01_DXXX. (Bottom Right) three days later: 0758MR0032550000403772E01_DXXX. A comparison of these photos taken three days apart indicate the specimens have changed shape and orientation of tufts and an ovoid smear has spread outward on both sides. Not water pathways (top photo).

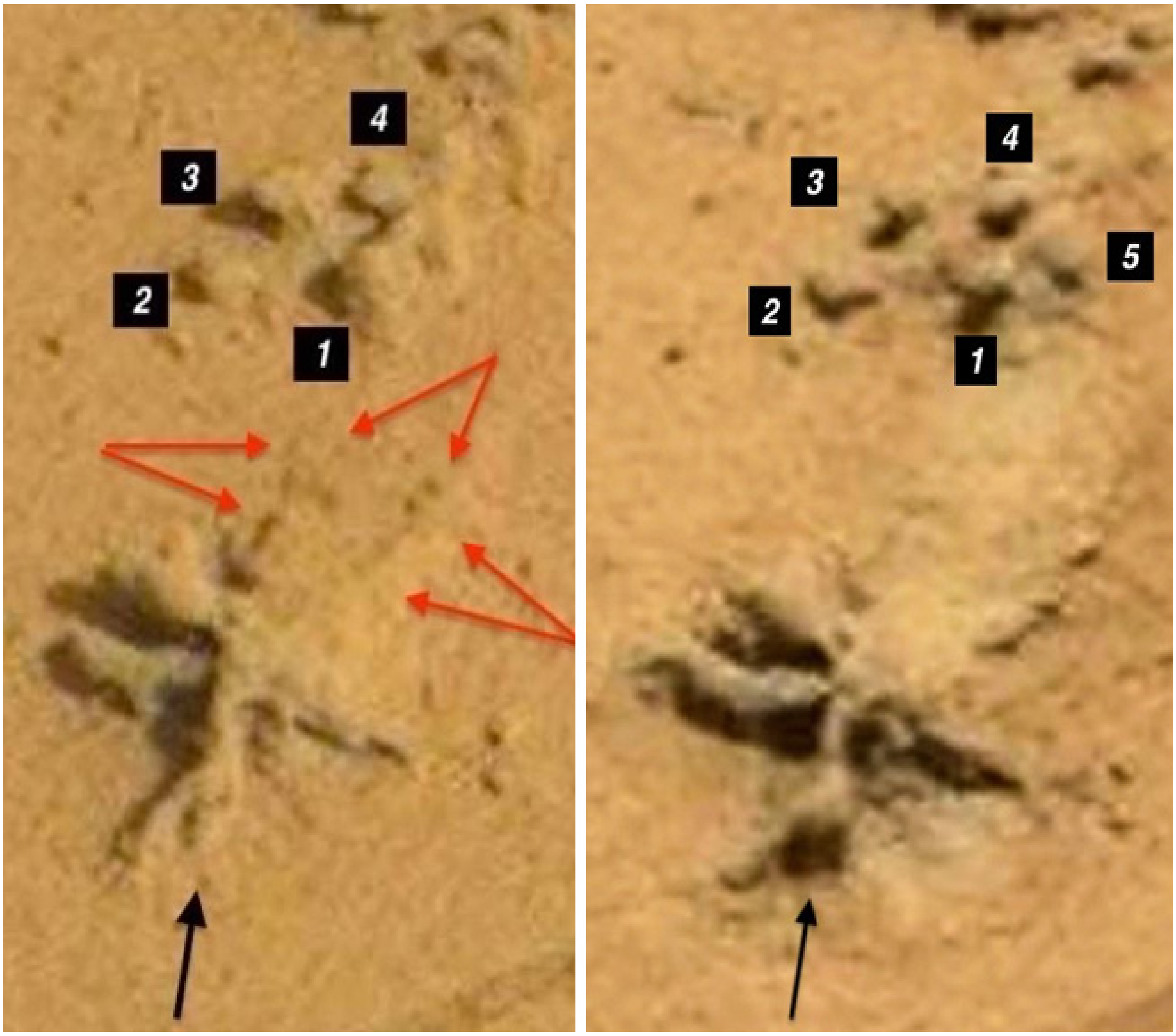

Figure 10. (Left--Sol 0753): Four "numbered" bulbous protrusions, and red arrows: two elongated protrusions can be discerned (0753MR0032370070403730E01_DXXX). Five Days later (Right-Sol 0758) a fifth bulbous protrusion appeared, and there are now five protruding from the soil with stalks (approximately 3 mm in size) which may indicate infiltration by fungi. In addition, what had been two elevated elongations (marked by red arrows) radiating outward toward the mushroom-shaped structures (Left) have become a lumpy smear upon the soil which has also spread outward from the posterior portion of the specimen (Right 0758MR0032560000403773E01_DXXX). As indicated by the black arrows at the bottom, a bulb-like protrusion has appeared at the end of the elongated structure. A second tubular extension to the upper left of the specimens has grown longer and wider, these organisms appear to be coated with and secreting calcium carbonate forming a spreading pool. Because of the depth of field and angle and distance of these specimens from the camera the inclusion of "scale bars" would be deceptive and misleading. The graphic scale of these images cannot be obtained from information NASA makes available. We estimate that the average size of the majority of these specimens is approximately 40 micrometers (40 µm) with lengths and diameters approaching up to 100µm. However, their actual length, width, and diameter are unknown.

Figure 11. Left Top: 0753MR0032370090403732E01_DXXX). (Right Top & Bottom 0758MR0032550000403772E01_DXXX) Note changing shape and the spreading "smears" to each side of the organism. Note water pathways.

Figure 12. (Sol 767): A possible conglomeration of calcium and calcium oxalate concretions and/or extracellular polymeric substances secreted and created by cyanobacteria and thus inducing adherence with sand and soil (0767MH0003630010300137C00_DXXX).

Figure 13. CR0_473216607PRC_F0442414CCAM02853L1. Photographed by Curiosity's Micro-Imager Camera. These specimens resemble calcium incrustations and calcium carbonate-encrusted cyanobacteria--perhaps similar to *Nostoc flagelliforme, N. parmelioides, N. verrucosum, N. pruniforme* as well as spherical "Nostoc balls," and vesiculous thalli. Each of these interconnected "balls" is estimated to be 0.1 mm in diameter whereas the entire specimen may be 1 mm in total length, based on the microscopic camera specifications. Unfortunately, Because of the depth of field and angle and distance of this specimen from the camera its actual length, width, and diameter are unknown.

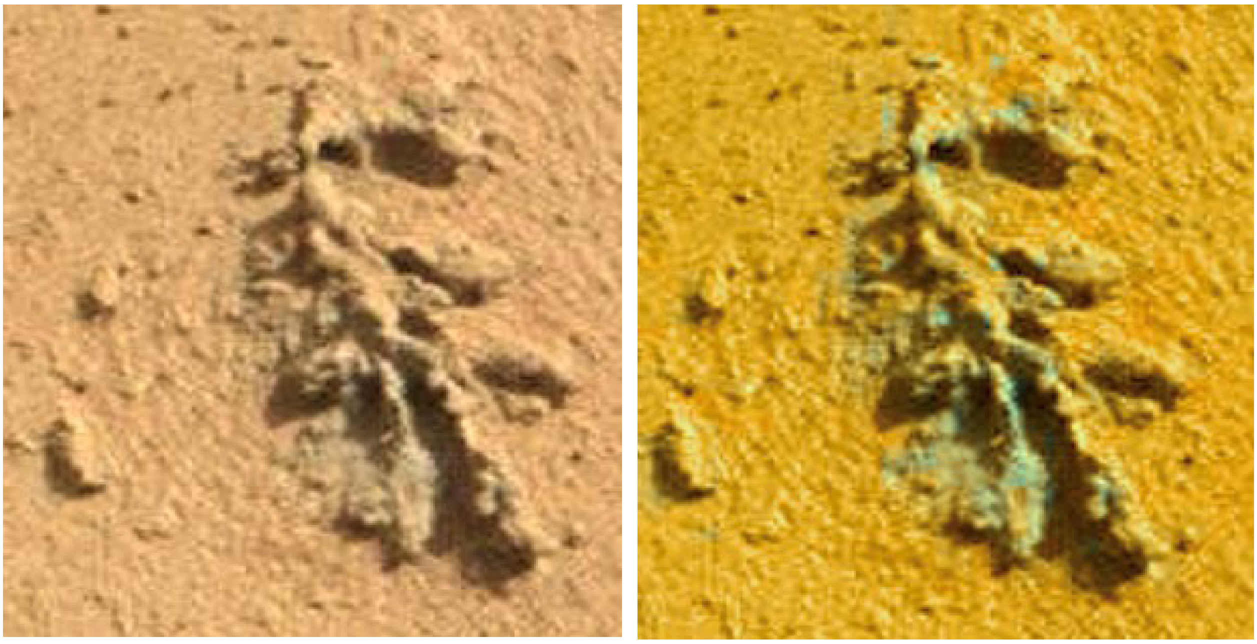

Figure 14. Color embedded in original NASA photos. 0767MR0033040000403863E01_DXXX Blue-green color (left), extracted and saturated (right).

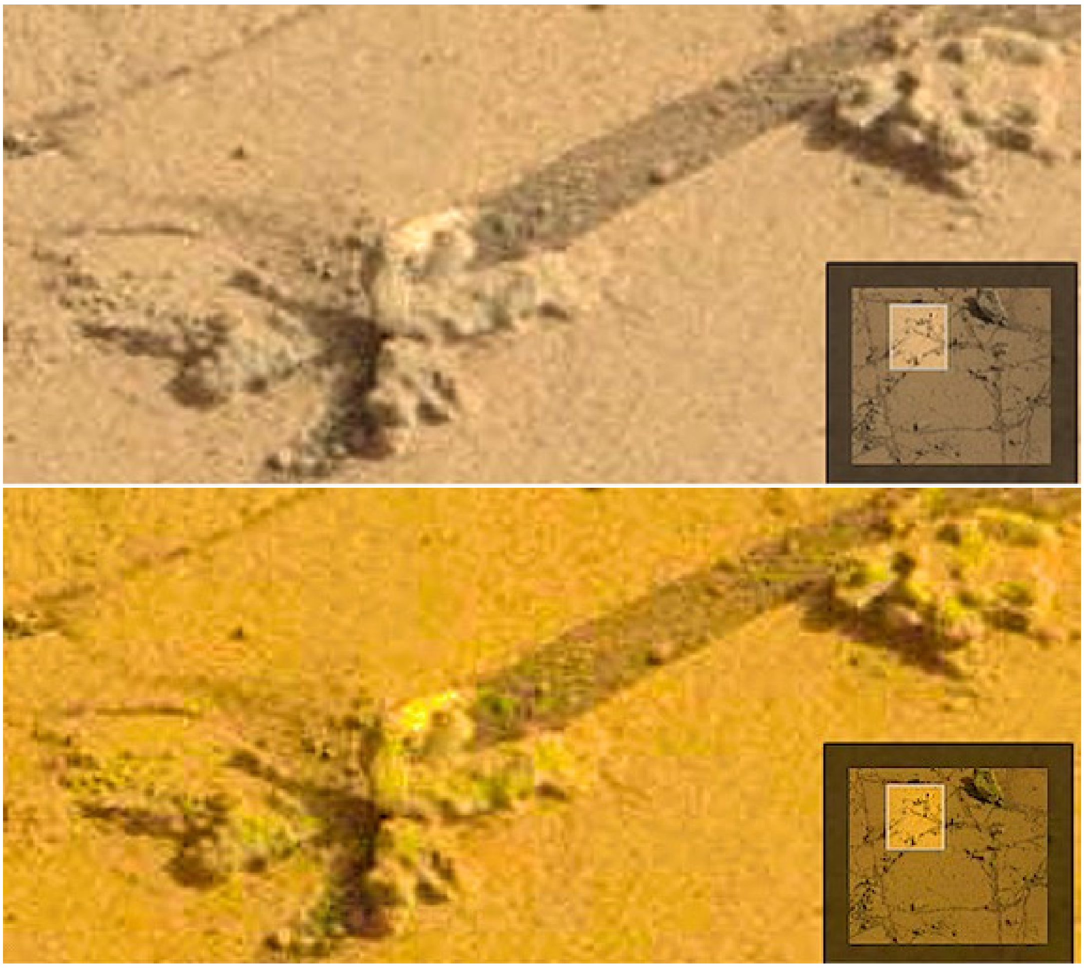

Figure 15. Color embedded in original NASA photos. 0767MR0033030000403862E01_DXXX Blue-green color ((Top), extracted and saturated (Bottom). Note water pathways.

DISCUSSION

The observations of the growth of martian organisms

In this report, we have provided official NASA sequential photographs of numerous specimens resembling calcium-encrusted cyanobacteria (blue-green algae) including those that are growing, multiplying, and changing shape and orientation. Many are located adjacent to water pathways and several putative cyanobacteria also appear to be secreting a semi-liquid substance that forms spreading pools as these organisms grow.

It is possible that fungi have infiltrated and formed symbiotic relationships with these putative cyanobacteria. It has been previously reported that Martian specimens resembling fungi grow, increase in number, changes shape and even move to new locations as based on NASA sequential photos [28]. These latter fungi-like specimens have been photographed in crevices, beneath rock shelters, on the fully exposed surface, and atop the rovers Curiosity and Opportunity. Fungi-like specimens have also been photographed engaged in sporing [29]. Likewise, as viewed from orbit, in the far northern and southern hemispheres, what may be colonies of fungi, algae, lichens, and mould increase in size up to hundreds of kilometers in length and diameter during the Martian Spring when temperatures increase (thereby presumably flooding the surface with meltwater), only to decrease in size and almost completely disappear during the Fall and Winter; and this pattern of waxing and waning repeats every year [30]. In addition, based on sequential photos, an anomalous ovoid life-like specimen with what appear to be forward-facing eyes was photographed within a small hole in Gale Crater sediment and the following day it appeared several centimeters outside the hole [31,32]. The cyanobacteria-like specimens reported here, therefore, are not unusual, as there is an increasing body of evidence that biologically active living organisms have colonized Mars.

Observations of cyanobacteria / algae on mars

Specimens resembling green algae and blue-green algae (cyanobacteria) have been repeatedly observed in Gale Crater [3, 5, 7, 9, 15, 21]. In one study, ten established experts in algae or algae-fungi symbiotes and related organisms identified Martian specimens as most likely algae; which were photographed at ground level, atop and alongside rocks, mudstone, and sand [9]. All were green or blue-green in color. These algae-like specimens, depending on the substrate, appear as green clumps, spherules, cake-like layers, thin sheet-like layers, and thick-layered leafy vegetative masses of material that partially cover Martian rocks, sand, and fungi-like surface features. Many specimens appeared to be moist or covered by a thin layer of ice and may include blue-green algae (cyanobacteria), green algae, diatoms, and mosses [5, 9]. These algae-like formations were often associated with or adjacent to specimens similar to ooids, microbial mats, and stromatolites all of which, on Earth, are "glued" together via the secretion of calcium and extracellular polymeric substances that encase growing tubular filaments that radiate outward or tangle together [9].

Cyanobacteria and calcium carbonate

Calcium carbonate is a biological byproduct of algae/cyanobacterial photosynthetic activity and their mucous secretions of polysaccharides which act as binding sites for Ca^{2+} thereby producing carbonate minerals and concentrations of calcium. Evidence of calcite and calcium carbonate has been detected on Mars [33-36]. Although calcite may be formed via geological weathering coupled with fluid evaporation (thereby promoting biological activity) calcium carbonate is almost exclusively a biological byproduct. However, the detection of large amounts of calcium carbonate has been elusive, in large part because calcium is subject to destruction by weathering and UV and other forms of ionizing radiation. Yet, despite destructive UV rays, several published reports, directly and indirectly, indicate the presence of calcium and calcium carbonate on Mars; the most likely source of which is the biological activity of cyanobacteria as reported here [33-39].

Oxygen production on mars: Evidence of photosynthesis

Green algae and cyanobacteria are primary producers of 70% of Earth's oxygen and the remainder a product of water and soil-dwelling plants and organisms including lichens [21, 40]. It has been known since the 1950s that oxygen is a component of the Martian atmosphere [41-43] .whereas in the 1970s it was documented that oxygen levels varied over time [44], and doubled over a year; ranging from 0.5% to 1% of the total upper atmosphere [45]. Hence, oxygen is continually replenished. In 2004, based on a reanalysis of the Viking data, a distinct seasonal variation of oxygen was documented [46]. In 2019, Trainer and colleagues reported that the amount of oxygen in the Martian atmosphere increases by approximately 30% in the Spring and Summer based on atmospheric composition measurements acquired in Gale Crater at ground level by the rover Curiosity's Science Laboratory [47]. Joseph and col-leagues in turn determined that these waxing and waning seasonal variations parallel the seasonal fluctuations in the biological produc-tion of oxygen on Earth [21,40]. The production and continual replenishment of oxygen in the Martian atmosphere support the theory that the specimens presented here may be calcium-secreting oxygen-producing photosynthesizing cyanobacteria.

CONCLUSION

Presented in this report are multiple specimens that closely resemble calcium-encrusted cyanobacteria. As based on official NASA sequential photographs many of these specimens are blue-green in color, and others are growing, changing shape, multiplying, and secreting pools of what may be calcium carbonate that spread across the surface and coats these putative organisms. These findings and impressions are supported by and consistent with previously published observations of specimens that resemble green algae, cyanobacteria, microbialites and concentric stromatolites; the growth of what may be algae, fungi, lichens, and mold, based on sequential photos; and the production, replenishment and seasonal increases of atmospheric oxygen that parallels the seasonal production of oxygen on Earth due to the biological photosynthesizing activity of cyanobacteria and related organisms.

In conclusion, the observations and photos presented in this report strongly support the theory that biologically active cyanobacteria have colonized Mars.

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